WARRIP

WESTERN AUSTRALIAN ROAD RESEARCH AND INNOVATION PROGRAM

Transfer of Appropriate Crumb Rubber Modified Bitumen Technology to WA

Stage 1: Open Graded Asphalt

Stage 1 entails the development of a crumb rubber binder used in open graded asphalt and Draft Specification 516 - Crumb Rubber Open Graded Asphalt

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for Main Roads Western Australia

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SUMMARY

The use of CRM binder in high-performance sprayed seals has been routine practice in Western Australia (WA) for over 30 years. The use of CRM binder for asphalt materials has not been previously investigated in WA. Internationally, the use of CRM binder in open-graded asphalt (OGA) and gap-graded asphalt (GGA) is accepted practice, with utilisation in dense-graded asphalt (DGA) less established.

A review of literature and current practice indicated the following, addressing some Main Roads concerns with the technology:

- National and international literature indicates that the utilisation of crumb rubber is a high-value, sustainable reuse of tyre waste that can benefit the environment and improve the performance of seals and asphalt.
- International literature indicates that the use of CRM binder can be successfully combined with WMA technologies. This was indicated to address one of the main barriers to implementation, namely emissions and worker health.
- Research conducted through the NACoE program, in conjunction with TMR, shows that CRM binder can be successfully used in OGA. The research through NACoE also included the development of a supplementary specification and construction of a trial section.
- Review of selected international practice indicated that the manufacturing, mix design and construction of CRM asphalt generally follows the same principles, although the specification values for each property may vary between each jurisdiction.

A CRM binder with crumb rubber content of 18 and 20 parts, as well as 18% by mass of total binder was developed at ARRB's laboratory.

Using materials supplied by a local Perth supplier, an OGA mix conforming to Main Roads' Specification 504 *Asphalt Wearing Course* (Main Roads 2017) was designed. Laboratory mixes were prepared with the standard binder specified (i.e. A20E polymer modified binder, and the CRM binder. Laboratory results indicated that the A20E polymer modified binder could be replaced with 18% CRM binder at 0.5% higher binder content.

A coarser PSD compared to the conforming mix was also investigated to assess if the air voids could be increased, while using the 18% CRM binder. Based on the laboratory results, the coarser and optimised PSD did result in an increase in air voids of approximately 2%, also at a mix binder content of 5.0%.

The demonstration trial undertaken as part of this project consisted of the following sections:

1. Specification 504 conforming OGA with 4.5% A20E binder content
2. Specification 504 conforming OGA with 5.0% CRM binder content (18% crumb rubber)
3. Coarser OGA with 5.0% CRM binder content (18% crumb rubber).

For the purpose of the demonstration trial, Main Roads developed Draft Specification 516 *Crumb Rubber Open Graded Asphalt*. Fulton Hogan was the industry partner that conducted the design, production and construction of the crumb rubber open grade demonstration trial.

A binder was developed by Fulton Hogan that contained 18% crumb rubber. The developed binder complied to all the draft specification requirements.

The draft specification called for the Marshall design method to be used. Standard PSD OGA and alternative PSD OGA mixes were successfully designed, complying to all the draft specification requirements.

A plant trial at Fulton Hogan's Hazelmere premises built confidence in production, rolling sequence and roller setting. This was followed by the construction of a successful demonstration trial between 17 March 2019 and 25 March 2019 on the Kwinana Freeway between Russel Road Interchange and Anketell Road Interchange.

During the demonstration trial, samples were taken for monitoring of emissions. The results of the monitoring indicated the levels of airborne contaminants at the work site were being adequately controlled with regard to the impact on workers' personal exposure. Almost negligible levels of exposure were recorded for inhalable dust, VOC and PAH emissions.

Use of a WA Carbon Savings Estimation Tool that was developed as part of WARRIP Project 2017-001, indicated an estimated reduction in emissions of between 2% and 4% if warm mix additives were solely used. A further reduction in estimated emissions of between 43% and 47% could be achieved if CRM binder was used. In combination, reduction in estimated emissions of between 45% and 49% can be achieved.

Splash and spray assessment could not be conducted due to the timing of the construction. A subjective splash and spray questionnaire matrix was included for possible future assessment.

ACKNOWLEDGEMENTS

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1.1 Background

Every year millions of tyres in Australia reach their functional end-of-life. These end-of-life tyres contain petroleum derivatives and significant embedded energy and are therefore a potentially valuable resource for recycling. At present, most end up in landfill, inappropriately dumped or exported overseas. Rubber and carbon black make up approximately 70% of the weight of a tyre. One potentially high value alternative destination for these materials is as a crumb rubber modifier (CRM) in bitumen used for road construction. The use of CRM binder in both asphalt and sprayed bituminous seals can provide increased durability and cracking resistance. In addition to improved performance, recycling ground tyre rubber reduces landfill volumes and preserves natural resources.

The use of CRM binders in high-performance sprayed seals have been routine practice in Western Australia (WA) for over 30 years. However, widespread utilisation has been restricted by placement issues such as fume generation. The use of CRM binder for asphalt materials has not been previously investigated in WA. Internationally, the use of CRM binder in open-graded asphalt (OGA) and gap-graded asphalt (GGA) is accepted practice, with utilisation in dense-graded asphalt (DGA) less established.

Main Roads Western Australia (Main Roads) currently permit the use of Austroads class S45R binder, containing crumb rubber for sprayed seal applications. However, increasing the utilisation of CRM binder for inclusion in OGA may have benefits for both the performance of pavements and the environment.

1.2 Purpose

The purpose of this project *Transfer of Appropriate Crumb Rubber Modified Bitumen Technology to WA* is to increase the utilisation of CRM binder in OGA. Through maximising the use of CRM binder in road construction and maintenance (asphalt and sprayed seals), the volume of end-of-life tyres sent to landfill will be reduced. To facilitate the use of CRM in OGA, Main Roads Specification 504, *Asphalt Wearing Course* must be amended.

1.3 Approach

The *Transfer of Appropriate Crumb Rubber Modified Bitumen Technology to WA* is a multi-stage project to increase the utilisation of CRM binder in OGA. A three-stage study has been planned.

1.3.1 Stage 1 – Develop CRM Binder OGA Trial Specifications

The objective to develop CRM binder OGA trial specifications was accomplished through:

- reviewing national and international experience with CRM binder technology, including spray seals, hot-mix asphalt and warm-mix asphalt – Section 2
- undertaking laboratory-based mixture proportioning to evaluate the properties of OGA with CRM binder – Section 3
- supporting Main Roads to develop a draft specification for a trial utilising CRM binder in OGA – Section 4.

1.3.2 Stage 2 – Conduct and Monitor CRM Binder OGA Trial

Stage 2 of the project focused on a demonstration trial utilising CRM binder in OGA and consisted of the following tasks:

- Working with industry and Main Roads to organise the construction of a controlled OGA demonstration trial section, combined with appropriate laboratory testing. The OGA trial sections included A20E and CRM binder. The mix design development and trial construction are reported on in Section 5.
- Performing comparative emissions studies to assess potential occupational health and safety and environmental impact as a result of the emissions, odours, fumes and smoke generated by heating the CRM binder during production and placement. The emission monitoring is described, and results summarised in Section 6.
- Determining the relative sustainability of alternative materials utilised in the trial (Section 7).
- Conducting comparative noise generation studies to quantify the benefit of OGA as compared to DGA and assess performance changes over time. Main Roads will conduct assessment by using the Statistical Pass-by (SPB) method after approximately 6 months of construction of the trial section. This will ensure that any excess binder on the aggregate would have been removed by traffic and that realistic, in-service measurements can be taken. Details of the test and results are not contained in this report.
- Undertaking comparative ‘splash & spray’ studies to quantify the benefits of OGA compared to DGA and assess performance changes over time. Background information on how to undertake such a study is contained in Section 8 of this report.
- Section 9 documents the findings of Stage 1 and Stage 2.

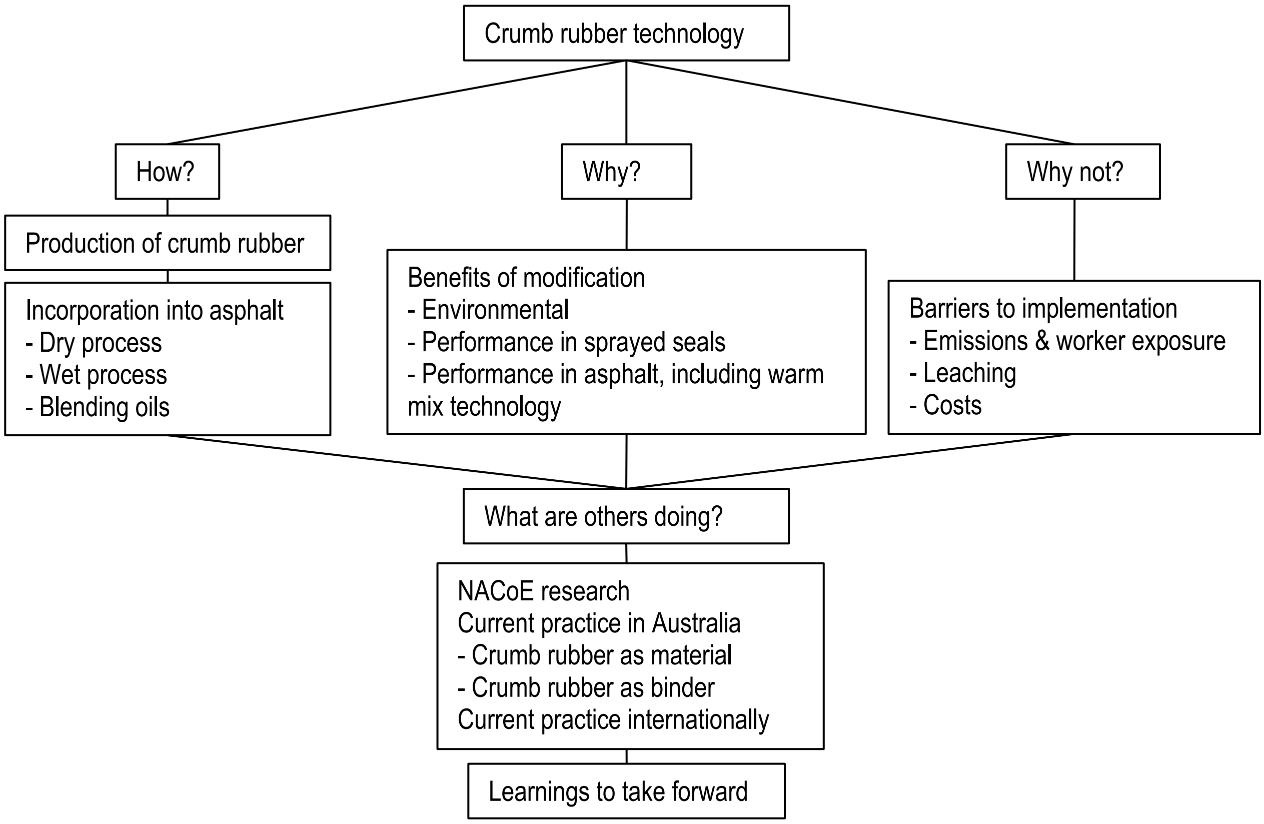
1.3.3 Stage 3 – Future Projects and Specification Update

Stage 3 of the project includes developing the scope for future CRM projects and recommendations for the draft Main Roads Specification 516. This is contained in Section 10 of this report.

2 LITERATURE REVIEW

The topics included in the literature review contained in this section are illustrated in Figure 2.1.

Figure 2.1: Schematic illustration of the topics included in the literature review



2.1 Production of Crumb Rubber Modified (CRM) Binder

Different methods have been developed to produce CRM binder, generally classified into two stages. The first stage consists of producing crumb rubber from scrap tyre rubber, where the second stage involves incorporating the crumb rubber into the asphalt by either bitumen blending (wet process) or directly adding the crumb rubber into the hot mix asphalt (HMA) process (dry process) (Heitzman 1992).

2.1.1 Crumb Rubber Production

The rubber component of CRM binder or asphalt is tyre rubber, comprised of a composite of a number of blends of natural rubber, synthetic rubber and carbon black. Crumb rubber can be produced using recycled rubber from tyres, industrial scrap rubber, and post-consumer scrap rubber products, however, crumb rubber is preferably derived from recycled tyres (Heitzman 1992). Production typically involves shredding, followed by ambient or cryogenic grinding to produce crumbs with a typical size range of 0.5 mm to 5 mm (Lo Presti 2013). Cryogenic grinding, also known as freezer milling, freezer grinding, and cryomilling, is the act of cooling or chilling a material and then reducing it into a small particle size (Messer Group n.d.).

2.1.2 Incorporating Crumb Rubber into Asphalt Applications

Dry process

The dry process defines any method of adding crumb rubber directly into the hot mix asphalt mixing process. The crumb rubber particulates are typically mixed with the hot aggregate prior to the addition of the bitumen. Although the crumb rubber is added to the aggregate, it is still considered part of the bitumen. An extended mixing time is required to ensure adequate blending of the crumb rubber and bitumen (Austroads 2017).

The advantage of the dry process is that it provides an easy way for the manufacturer to produce CRM asphalt. However, only partial blending of the crumb rubber into the binder is achieved during mixing, because it is difficult to quantify and control the amount of blending. This partial or 'uncontrolled' blending may result in limited performance improvement from the crumb rubber, as it is difficult to control the properties of the modified binder. Furthermore, it is necessary to ensure the crumb rubber does not come into direct contact with any heating flames (Wu, Herrington and Neaylon 2015). It is important to note that the dry process is not used for sprayed seal applications.

The conclusion of studies that evaluate the performance of dry blended mixes varies in literature. Ghabchi, Zaman and Arshadi (2016) notes that earlier studies found the performance of CRM asphalt manufactured using the dry process was not as good as asphalt mixes manufactured using the wet process. However, studies between 2004 and 2016 found that the dry process can be successfully used in manufacture with improved performance (Ghabchi, Zaman & Arshadi 2016). Balmaceda and van Wijk (2013) assessed the performance of two projects where CRM asphalt were produced using the dry method in South Africa. The authors suggested (based on their experience) that both the dry process and wet process have advantages and disadvantages that should be considered during design and construction.

Wet Process

The wet process describes any method used that involves blending of the crumb rubber with bitumen. Blending can take place in an asphalt plant or on in the field by adding the crumb rubber directly to the bitumen sprayed (for sprayed seal applications) or with the use of an on-site blending and storage unit (Austroads 2017). CRM binders produced using the wet process have been shown to provide asphalt properties similar to elastomer modified binders, however, relatively high binder contents are required in the asphalt mix.

Crumb rubber can be blended into the bitumen using high shear or low shear mixing methods. Ibrahim et al. (2013) notes that mixing type can affect the properties of the modified binder. Low temperature properties appear to be improved with high shear mixing and medium to high temperature properties appear to be improved with low shear mixing (Ibrahim et al. 2013).

The modified binder is then moved to a storage tank where it is essential to provide continuous circulation to prevent separation of the crumb rubber. However, storage at high temperatures (> 165 °C) gradually degrades the product and the viscosity decreases (Wu, Herrington & Neaylon 2015).

Another wet process, known as the no-agitation method (terminal blends) may improve the workability and stability of the mix, allowing blends to be stored without the need for continuous agitation (Lo Presti 2013). These mixes are produced by blending crumb rubber into bitumen at high temperatures (200–300 °C) using high shear stresses and pressure. The resulting modified binder typically has increased homogenisation compared to modified binder produced using the high viscosity method (Wu, Herrington & Neaylon 2015). However, terminal blends have a lower viscosity, resulting in lower optimum binder contents in hot mixes, which can translate into reduced performance life (Shatnawi 2011).

The advantage of using the wet process is that the binder properties are better controlled than binder produced using the dry process (APRG 1999). Wet processes are more commonly used than the dry process, as the enhanced digestion and chemical interaction between the crumb rubber and binder creates a more homogenous modified binder (Wu, Herrington & Neaylon 2015).

Blending Oils

CRM binders manufactured using the wet process may also include addition of extender oils at approximately 2.5%–6% by mass, prior to the addition of crumb rubber (Wu, Herrington & Neaylon 2015). Extender oils may be used to enhance the interaction of the crumb rubber and the binder by supplying light fractions (aromatics, small molecules) that swell the crumb rubber, facilitating dispersion into the bitumen (i.e. less segregation of the binder and CRM). Furthermore, the use of extender oils may reduce viscosity, facilitate spray applications and promote workability (Caltrans 2003). However, it is important to note that arbitrarily adding extender oils will not necessarily improve the modified binder blend.

The proportion of extender oil included in the modified binder blend should undergo careful consideration as although it is used to enhance the crumb rubber and binder interaction, it also softens the bituminous materials while the crumb rubber stiffens the binder (Caltrans 2003). The addition of extender oils has also been shown to increase the potential for emission of toxic fumes during blending and paving operations (Sabita 2016). Some extender oil property requirements are presented in Table 2.1.

Table 2.1: Extender oil requirements

Property	Requirements
Flash point (min, °C)	180
Saturates by mass (max, %)	25
Aromatic unsaturated hydrocarbon (min, % m/m)	55

Source: Sabita (2016).

2.2 Benefits of Crumb Rubber Modification

2.2.1 Environmental Benefits

The use of crumb rubber as a modifier for bitumen is a high-value, sustainable alternative utilisation for waste tyre rubber. Road construction is one of the few applications that has the potential to reuse large volumes of waste tyres. The environmental benefits of incorporating crumb rubber into asphalt include reducing the waste tyre stockpiles and landfill volumes, CO_2 emissions, the use of natural resources and road noise (Denneman et al. 2015).

Reducing Landfill

In 2015-16 Australia generated more than 56 million equivalent passenger units of end-of-life tyres, roughly two per person. This equates to approximately 450 000 tonnes of waste material of which 10% is recycled domestically, 27% exported as tyre-derived fuel and 63% send to landfill, stockpiled, illegally dumped or exported or buried in mine sites (Parliament of Australia, 2018).

Therefore, by increasing the use of crumb rubber in engineering applications, the quantities of tyre waste can be reduced. The magnitude of these reductions is dependent on developing an efficient recycling and collection chain (Denneman et al. 2015).

Heitzman (1992) estimated that 2 to 6 tyres can be incorporated into a tonne of hot mix asphalt paving material. Annual production of asphalt is approximately 10 million tonnes per annum (Asphalt Magazine 2019). Therefore, the opportunity exists to use approximately 2.5 million tyres per year in asphalt.

The use of crumb rubber in surfacing seals in 2018 by an Australian binder supplier, reportedly amounted to 658 000 equivalent passenger car tyres being used, instead of ending up in landfills (Keys 2019).

Pavement Noise Reduction

International research has identified that the use of CRM asphalt has the potential to reduce the noise generated by traffic on asphalt pavements. A field evaluation of the impact of gap graded asphalt (GGA) mixes containing CRM binder found that compared to the unmodified GGA mix, the noise levels were reduced by up to 2 dBA (Paje et al. 2010). Similarly, Sandberg (2010) found that CRM asphalt pavements may reduce noise by 1–3 dBA compared to similar pavements not using rubber, including SMA and OGA.

However, it is important to note that international studies have shown mixed results regarding the noise reduction observed with CRM asphalt. An eight-year field study in California, USA on the noise performance of typical wearing course mixes found that unmodified OGA levels were in some cases lower than the CRM-OGA mixes, although levels were within 0.5 dBA of each other. Compared to DGA mixes, the use of CRM-OGA reduced noise levels by approximately 4 dBA (Illingworth & Rodkin Inc. 2011).

Reduction in Energy Consumption and Carbon Emissions

The use of crumb rubber as bitumen modifier has been shown to significantly reduce the energy required for tyre disposal, compared to other disposal methods (Sousa, Way & Carlson 2007).

A comparison of the impact of using CRM binder in asphalt with regard to CO_2 emissions is presented in Section 7.

2.2.2 Performance Benefits of CRM Binders in Sprayed Seals

In sealing applications, the benefits of using CRM binder compared to conventional unmodified binders is similar to those achieved by modifying bitumen with polymers such as styrene butadiene- styrene (SBS) and polybutadiene (PBD). The benefits that may be provided using CRM binders, compared to conventional, unmodified binders for spray seals include (Hoffmann & Potgieter 2007; Marais et al. 2017; Wu, Herrington & Neaylon 2015):

- The service life of spray seals may be significantly increased by up to 50%. CRM binders may be applied at higher spray rates, leading to increased binder film thickness and reduced stone loss.
- Anti-ageing, a combination of the increased softening point of the binder and the carbon black component of the crumb rubber, which are antioxidants.
- UV resistance achieved by the antioxidants found in the carbon black of the crumb rubber.
- Reduced likelihood of bleeding and tracking of bitumen at high road temperatures.
- Increased waterproofing of the underlying material due to the high spray rate of CRM binder, which may be up to double the normal binder application rate.
- Improved skid resistance due to less reduced risk of bleeding and embedment of stone.

Cocks et al. (2017) noted that CRM binder in sprayed seals has been used by Main Roads to alleviate reflective cracking and waterproof concrete bridge decks since the 1980s. Furthermore, the use of crumb rubber has been incorporated into double coat geotextile sealing to minimise the risk of bleeding under heavy traffic loadings.

2.2.3 Performance Benefits of CRM Binders in Asphalt

The use of CRM binders in asphalt is well established internationally, particularly in the USA since the 1990s when the Federal Highway Administration (FHWA) mandated the use of CRM binder in asphalt using the wet process (Ghabchi, Zaman & Arshadi 2016). There has since been a considerable number of studies into CRM binder in asphalt, largely originating from the USA.

CRM binders are typically used in two types of asphalt, GGA and OGA with the relatively less common use in stone mastic asphalt (SMA). Terminal blend binders can be suitable for dense graded asphalt (DGA) mixes (Shatnawi 2011). Extensive laboratory studies and field experience have shown that crumb rubber modification enhances the rutting and fatigue cracking resistance of asphalt mixes compared to mixes made with conventional bitumen. Other (less well documented) advantages include improved noise reduction and drainage when used in porous mix designs (Wu, Herrington & Neaylon 2015). Widyatmoko and Elliot (2007) identified that the advantages of CRM asphalt compared to unmodified asphalt mixes include:

- increased durability and resistance to age-hardening
- improved fatigue resistance for surface cracking
- decreased temperature susceptibility
- improved resistance to permanent deformation
- decreased particle loss, attributed to the thicker binder films.

Furthermore, Maupin (1992) compared asphalt with CRM binder to unmodified asphalt mixes using the indirect tensile stripping test, finding that the modified asphalt showed an increased resistance to stripping than unmodified mixes. CRM asphalt mixes are also typically used to reduce the noise emitted due to the tyre/pavement interaction, with Ghabchi, Zaman and Arshadi (2016) noting that CRM binder in OGA mixes can reduce tyre/pavement noise by up to 50% compared to other OGA mixes. However, Shirini and Imaninasab (2016) noted that for OGA the use of crumb rubber reduced the rate of permeability although rutting resistance was found to increase with an increased CRM content.

The performance effects of CRM binder in porous asphalt mixes was investigated by Lyons (2012), compared with unmodified mixes, PMB mixes and different CRM contents. The results of the study indicated that the use of CRM binder reduced abrasion loss, increased rut resistance and effectively minimised the effect of binder drain-down.

Warm-mix Asphalt with CRM Binder

Caltrans recommends that CRM binders are not placed during cold, or rainy weather, over pavements with cracks wider than 12.5 mm and where long haul distances may prevent the paving and compaction of the materials within the recommended temperature ranges (Caltrans 2003). Warm mix asphalt (WMA) technology may be used to mitigate the risks associated with temperature loss over long haul distances.

A comprehensive study of WMA and CRM binder in California found that WMA technologies could successfully be used with CRM asphalt mixes, increasing the workability of the mix and reducing the undesirable emissions associated with CRM binders (Section 2.3.1) (Hicks et al. 2010).

However, Xu et al. (2013) reported conflicting results with WMA technologies (wax and surfactant types). The study found that the WMA-CRM mixes failed to meet the AASHTO low temperature performance specification, indicating that the mixes may be susceptible to early cracking. It was noted that the WMA-CRM mixes were only marginally out of specification.

Behl, Kumar and Sharma (2013) evaluated the effect of using Evotherm WMA technology on the properties and performance of CRM mixes. The study found that CRM mixes could be successfully produced at temperatures as low as 110 °C and compacted at 80–90 °C, whilst retaining the performance benefits of CRM mixes compared to unmodified mixes. Additionally, Esenwa et al. (2010) found that CRM mixes using Evotherm could be paved and compacted at reduced temperatures without any notable issues.

The effect of different WMA additives on the moisture susceptibility, compaction, rutting performance and resilient modulus of CRM asphalt mixes was investigated by Ziari, Naghavi and Imaninasab (2016) using Sasobit, Rheofalt and an anti-stripping additive named Zycotherm. The results indicated that the combination of the WMA additives tested, and CRM improved the rutting performance and resilient modulus compared to unmodified, WMA. Rheofalt was found to be the only additive that increased the ITS of the WMA-CRM compared to the control HMA. The WMA technologies were found to improve the level of compaction of the mixes, although this is decreased with increasing proportions of CRM.

Grobler, Beecroft and Choi (2017) studied the incorporation of CecaBase^R as warm mix additive into OGA with CRM binder trialled in Queensland. The authors reported lower emissions due to the use of the warm mix additive and no other notable issues.

2.3 Barriers to Implementation

Although the incorporation of crumb rubber into road applications has demonstrated both environmental and performance benefits there are ongoing concerns regarding social, environmental and economic factors.

2.3.1 Emissions and Worker Exposure

One of the major concerns that has been consistently raised since the introduction of crumb rubber to asphalt mixes at high temperatures is that it may lead to increased hazardous emissions, which may have an adverse effect on the health of production staff at asphalt plants and road workers. To date, there has been considerable research conducted into the emissions of CRM asphalt and seals, primarily originating from the USA. It is important to note that these studies are focussed on asphalt applications, however, the findings may still have applicability to spray seals.

One study by Stout and Carlson (2003) examined the stack emission generated by the addition of CRM to asphalt compared to non-modified asphalt for mixes tested in California, Michigan and Texas. The investigation found that the emissions of particulate and other hazardous compounds were not significantly different than conventional asphalt and were well within emission guidelines for asphalt. However, it was noted that the increase in mixing temperature and asphalt content can increase the emissions.

The effect of warm-mix asphalt (WMA) technology on the emissions from CRM asphalt is a relatively recent development that aims to address the limitations regarding production and placement. Jones et al. (2012) compared CRM asphalt produced using WMA and HMA processes, finding that the WMA emitted lower emissions, whilst also increasing the workability of the mix. Similarly, another study in California found that the concentration of particulate emissions varied depending on the temperature of the mix at the time of sampling (Farshidi, Jones & Harvey 2013).

The findings from this study also indicated that emissions are higher when the material is loose, compared to immediately after compaction.

Notably, Yang et al. (2018) conducted a study into the environmental and mechanical performance of CRM-WMA using Evotherm technology, compared to CRM-HMA and a conventional asphalt mix collected from the laboratory and the field. The findings indicated that the CRM-WMA could reduce both the fuel consumption of mixing and the emissions of CRM asphalt. Furthermore, testing indicated that the mechanical performance of CRM-WMA had equivalent rutting resistance and low temperature performance, and better fatigue performance and moisture damage resistance compared to the CRM-HMA. Similar conclusions were reached by Grobler, Beecroft and Choi (2017) where CRM-WMA was paved during a demonstration trial in Queensland.

2.3.2 Leaching

The constituents of a typical tyre used to manufacture crumb rubber contain natural rubber, synthetic rubber, carbon black, steel, fabric and fillers (Jansz 2012). However, the composition of a tyre varies between tyre types and manufacturers, making it difficult to accurately assess the compounds present in CRM binder that may adversely affect water quality and environmental toxicity.

Limited research has been conducted on the leaching potential of CRM asphalt to date. However, studies have indicated that compounds leached from CRM asphalt will have a negligible effect on water quality and toxicity (Crockford et al. 1995; Humphrey & Swett 2006).

2.3.3 Costs

International literature indicates that the CRM binder may be more expensive than conventional, unmodified bitumen. However, the increased initial costs may be offset by the improved performance of CRM binders compared to unmodified binders.

Caltrans (2006) states that as the use of CRM binder may reduce the required thickness of asphalt, the cost of CRM binder is less than the equivalent amount of unmodified bitumen required to achieve the same level of performance. Similarly, a South African study indicated that sprayed seals containing CRM binder are approximately 10% more expensive to construct, however, they may deliver an increased service life of up to 50% (Hoffman & Potgieter 2007).

Maximum cost effectiveness is typically found in thin, GGA or OGA surface courses, overlays of 30–60 mm compacted thickness, sprayed seals and interlayer applications. However, it is noted that this may vary for project size and should be evaluated during the life cycle cost analysis as part of the design phase (Caltrans 2003).

2.4 Previous National Asset Centre of Excellence (NACoE) Research

From 2014 to 2017, Queensland Department of Transport and Main Roads (TMR) sponsored a project under the NACoE research program with the aim of increasing the use of CRM in Queensland, with a focus on spray seals and asphalt. The project is ongoing, and resulted in the publication of two documents to date:

- *P31 and P32 Optimising the Use of Crumb Rubber Modified Bitumen in Seals and Asphalt (Year 1 – 2014/15)* (Denneman et al. 2015).
- *P31 Transfer of Crumb Rubber Modified Asphalt and Sealing Technology to Queensland (Phase 2)* (Grobler, Beecroft & Choi 2017).

2.4.1 P31 and P32 Optimising the Use of CRM Bitumen in Seals and Asphalt

The Year 1 report of the NACoE project presents the current state-of-practice in CRM bitumen technology in relation to sprayed seals and asphalt applications in Queensland (Denneman et al. 2015). The report summarises a literature review on crumb rubber modification in relation to production, benefits, national and international practice and perceived implementation barriers. Additionally, the report presents the findings of laboratory characterisation, opportunities for increased use in Queensland and the effect of CRM binder on emissions during a sprayed sealing trial.

In summary, Year 1 investigated a large body of literature, highlighting the following key findings:

- CRM binders may be produced using the high viscosity wet process in Australia or the no agitation wet process, where the no agitation wet process is best suited for DGA mixes.
- The use of CRM binder in asphalt and sprayed seals can lead to improved field performance, reduced road noise compared to conventional binder, reduced CO_2 emissions and a reduced use of non-renewable road construction materials on a whole-of-life basis.
- Australian state and territory road agency specifications have similar requirements for CRM binder whilst the international specifications reviewed typically require fewer tests than TMR.
- Barriers to CRM binder application typically involve the initial construction costs of using CRM binders in place of unmodified bitumen in both sprayed seals and asphalts. However, costs may be comparable to polymer modified binders (PMBs).
- Additional implementation barriers are primarily related to occupational health and safety concerns regarding worker exposure to hazardous emissions although these may be sufficiently mitigated using appropriate engineering controls.
- The dynamic shear rheometer (DSR) is a practical, cost-effective method for characterising CRM binders.
- Significant opportunity exists for end-of-life tyres to be beneficially used on the Queensland road network in asphalt and sprayed seals, however, that in itself will not resolve tyre stockpile issue in Queensland.
- Emissions levels for total suspended particulate and volatile organic compounds were generally higher for CRM binders than PMB for sprayed sealing while polycyclic aromatic hydrocarbon emissions were lower.

Therefore, the findings indicate that the use of CRM binder can lead to improved field performance, but there were a number of limitations that may prevent the increased implementation in Queensland. It was recommended that a demonstration trial be conducted to compare the emissions and performance of asphalts and sprayed seals utilising CRM binder and PMBs.

The next phase of the study, resulting from the outcomes from the Year 1 report, is summarised in the following section.

2.4.2 P31 Transfer of CRM Asphalt and Sealing Technology to Queensland

Following the work by Denneman et al. (2015), this phase of the study aimed to facilitate the increased use of CRM binders in sprayed seals and asphalt. Grobler, Beecroft & Choi (2017) described the tasks of this phase as follows:

- preparing amendments to TMR specifications for sprayed seals and PMBs
- developing a new supplementary specification for CRM OGA

- undertaking comparative binder testing in the laboratory to assess the properties of CRM binders manufactured in Queensland against the new supplementary specification requirements
- constructing and monitoring of a trial that includes a section of CRM OGA, compared to a control section of conventional PMB OGA
- monitoring the emissions during construction of CRM OGA (warm mix and hot mix) and PMB OGA surfacings.

The outcomes of the project included the development of a draft supplementary specification PSTS112 *Crumb Rubber Modified Open Grade Asphalt Surfacing* (TMR 2016) for the purposes of a trial, which may have applicability to Main Roads. The supplementary specification was based upon the crumb rubber requirements in the Arizona and California standard specifications. Appendix B contains a discussion on the derivation of PSTS112.

PSTS112 included two CRM binder classes, CR1 and CR2. Class CR1 typically has a higher level of modification than CR2 and is more suited to the hotter climates in Northern Queensland, whereas CR2 would be suited to use in south-east Queensland. The properties of CR1 and CR2 are summarised in Table 2.2 and Table 2.3 respectively. It is important to note that the binder must contain a minimum of 17% crumb rubber by mass of the total binder.

Notably, PSTS112 differs from the requirements for conventional polymer modified OGA in that CRM OGA does not have to comply with volumetric properties, binder drain-off requirements and asphalt particle loss requirements. The binder content for the mix design must be selected by TMR for mixes prepared at a range of binder contents based on the assessment of the laboratory air void content, binder film index, asphalt particle loss and asphalt binder drain-off.

Furthermore, the main findings resulting from the laboratory testing and field trials indicated that:

- The asphalt industry in Queensland has the capability to manufacture CRM binders in accordance with PSTS112, however, the variability of resilience recovery test results between laboratories may be an issue.
- The CRM OGA trial was completed using typical construction practices for conventional OGA.
- CRM asphalt construction produces emissions comparable to PMB asphalt mixes.
- Producing asphalt at lower temperatures (which may require warm mix additives) may reduce the emissions during asphalt manufacture and placement, however, this may depend on the type of warm mix additive used.
- Benzene concentration measured in the emissions chamber was higher for CRM OGA mixes.

Based on the findings of the study, it was recommended that the correlation between resilience recovery and torsional recovery of CRM binders be further investigated, to allow the torsional recovery test to replace the resilience recovery test. Furthermore, as the study only tested the CRM binder properties in one laboratory, it was recommended that the variability be determined by testing at different laboratories. It was also recommended that additional emissions monitoring studies are undertaken to assess any potential health risk to workers at production level quantities.

Table 2.2: CR1 binder properties

Property	Test method	Reaction time (since incorporation of rubber into the binder)						
		60 mins	90 mins	120 mins	240 mins	360 mins	11 hours	TBN(1)
Penetration @ 4 °C, 200 g, 60 sec, 0.10 mm, min	AS 2341.12	10	–	–	10	–	10	10
Resilience @ 25 °C, minimum (%)	ASTM D5329	25	–	–	25	–	25	25
		25	–	–	–	–	–	–
Torsional recovery at 25 °C, 30 sec (%)	AG:PT/T122	TBR(2)	–	–	TBR(2)	–	TBR(2)	TBR(2)
		TBR(2)	–	–	–	–	–	–
Softening point, minimum (°C)	AG:PT/T131	57	–	–	57	–	57	57
		57	–	–	–	–	–	–
Viscosity @ 175 °C (Pa.s)	ASTM D2196	TBR(2),(3)						
	ASTM D7741/D7741M	1.5–4.0(4)						
Flash point, minimum (°C)	AG:PT/T112	250(5)						
Loss on heating, maximum (%)	AG:PT/T103	0.6(5)						

1 TBN denotes to be nominated by the contractor. Where the contractor desires to store CRM binder in excess of 10 hours (after the 60–minute reaction period) but not more than 4 days (96 hours) prior to usage, testing should be completed to confirm compliance with specification requirements.
2 TBR denotes to be reported.
3 Test results are used to demonstrate the minimum and maximum reaction (and storage) time for the crumb rubber modified binder.
4 Viscosity of the CRM at the time of use.
5 Reaction time does not apply to this property.

Table 2.3: CR2 binder properties

Property	Test method	Reaction time (since incorporation of rubber into the binder)						
		60 mins	90 mins	120 mins	240 mins	360 mins	11 hours	TBN(1)
Penetration @ 4 °C, 200 g, 60 sec, 0.10 mm, min	AS 2341.12	15	–	–	15	–	15	15
Resilience @ 25 °C, minimum (%)	ASTM D5329	20	–	–	20	–	20	20
		20	–	–	–	–	–	–
Torsional recovery at 25 °C, 30 sec (%)	AG:PT/T122	TBR(2)	–	–	TBR(2)	–	TBR(2)	TBR(2)
		TBR(2)	–	–	–	–	–	–
Softening point, minimum (°C)	AG:PT/T131	55	–	–	55	–	55	55
		55	–	–	–	–	–	–
Viscosity @ 175 °C (Pa.s)	ASTM D2196	TBR(2),(3)						
	ASTM D7741/D7741M	1.5–4.0(4)						
Flash point, minimum (°C)	AG:PT/T112	250(5)						
Loss on heating, maximum (%)	AG:PT/T103	0.6(5)						

1 TBN denotes to be nominated by the contractor. Where the contractor desires to store CRM binder in excess of 10 hours (after the 60–minute reaction period) but not more than 4 days (96 hours) prior to usage, testing should be completed to confirm compliance with specification requirements.
2 TBR denotes to be reported.
3 Test results are used to demonstrate the minimum and maximum reaction (and storage) time for the crumb rubber modified binder.
4 Viscosity of the CRM at the time of use.
5 Reaction time does not apply to this property.

2.5 Current Practice in Australia

The implementation of CRM binder in asphalt and seals is well established in Australia. All of the Australian state and territory road agencies (SRAs) currently allow the use of CRM binder in road applications, although there are variations in specifications between jurisdictions.

The recommended usage, properties and performance of CRM binder is also referred to in a number of Austroads documents. The documents reviewed to determine current Australian practice regarding CRM binder are listed in Table 2.4.

Table 2.4: Australian documents reviewed

Jurisdiction	Documents reviewed
Australian Asphalt Pavement Association (AAPA)	*Crumb Rubber Modified Open Graded and Gap Graded Asphalt Model Specification* (AAPA 2018)
Austroads	APRG Technical Note 10 *The Use of Recycled Crumb Rubber* (Austroads 1999) *Guide to the Selection and Use of Polymer Modified Binders and Multigrade Bitumens* (Austroads 2013) Test Method AGPT/T190 *Specification Framework for Polymer Modified Binders* (Austroads 2019) Guide to Pavement Technology Part 4F *Bituminous Binders* (Austroads 2017)
Western Australia (Main Roads)	Specification 511 *Materials for Bituminous Treatments* (Main Roads 2017b)
New South Wales (Roads and Maritime Services (RMS))	QA Specification R118 *Crumb Rubber Asphalt* (RMS 2019) QA Specification 3252 *Polymer Modified Binder for Pavements* (RMS 2018)
Northern Territory (Department of Infrastructure, Planning and Logistics (DIPL))	*Standard Specification for Roadworks* (DIPL 2017)
Queensland (Department of Transport and Main Roads (TMR))	PSTS112 *Crumb Rubber Modified Open Grade Asphalt Surfacing* (TMR 2016) MRTS30 *Asphalt Pavements* (TMR 2019) MRTS11 *Sprayed bituminous surfacing (excluding emulsion)* (TMR 2018)
South Australia (Department of Planning, Transport and Infrastructure (DPTI))	Part R25 *Supply of Bituminous Materials* (DPTI 2017)
Victoria (VicRoads)	Section 421 *Bitumen Crumb Rubber Asphalt* (VicRoads 2005) Section 408 *Sprayed Bituminous Surfacings* (VicRoads 2017)

It is important to note that the specifications regarding CRM binder usage in Tasmania are based on VicRoads standard specifications and as such, were not reviewed for this literature study. Furthermore, the AAPA (2018) and TMR (2016) documents were primarily based upon specifications originating in the USA, as discussed in Appendix A.

The following sections describe the current CRM binder practice outlined in the reviewed guidelines and documents, outlining any unique aspects or practices that may be relevant to updating Main Roads specifications.

2.5.1 Comparison of Australian Crumb Rubber Material Specifications

A summary of the crumb rubber material requirements specified by Austroads and each of the Australia SRAs is presented in Table 2.5. The Australian SRA's crumb rubber material specifications are generally similar to the Austroads requirements, although there is diversity in some respects, which may be attributed to local materials and experience. General observations from the comparison between the current Main Roads requirements and other Australian practice includes:

- Main Roads is the only SRA that specifies elongated particle content.
- Main Roads and DPTI do not have requirements for crumb rubber for asphalt, whereas VicRoads and TMR do not have requirements for crumb rubber in sprayed seals. RMS is the only SRA that has requirements for both.
- The Main Roads gradation for crumb rubber for sprayed sealed applications is similar to the Austroads gradation for asphalt mixes. RMS (Grade B) and VicRoads use a smaller crumb rubber gradation than Austroads, Main Roads and DPTI.
- TMR and DIPL are the only SRAs that do not have a published crumb rubber requirement.
- RMS is the only SRA that varies in the maximum particle length and is based upon the particles retained on the 0.60 mm sieve.

Table 2.5: Comparison of Australian crumb rubber material specifications

Property	Main Roads(1)	AAPA	Austroads		RMS		TMR(2),(3)	DPTI(1)	VicRoads(2)
			Size 16(1)	Size 30(2)	Grade A(1)	Grade B(2)			
Grading sieve size (mm) 2.36 (% passing)	100	100	100	100	100	–	100	100	–
1.18 (% passing)	100	TBN(5)	80 (min)	100	80–100	100	TBN(5)	100	100
0.60 (% passing)	60 (min)	TBN(5)	10 (max)	60 (min)	0–10	60–100	TBN(5)	70–100	80–100
0.30 (% passing)	20 (max)	TBN(5)	–	20 (max)	–	0–20	TBN(5)	–	–
0.150 (% passing)	–	TBN(5)	–	–	–	–	TBN(5)	0–5	0–20
0.075 (% passing)	2 (max)	TBN(5)	–	–	–	–	TBN(5)	–	–
Bulk density (max, kg/m^3)	350	Report	Report	Report	Report	Report	Report	350	350
Moisture content (max, %)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	–
Particle length (max, mm)	3.0	–	3.0	3.0	7.5(4)	–	–	3.0	3.0
Metallic content (max, % by mass)	0.1	0.1	0.1	0.1	0	0	0.1	0	–
Other foreign materials (max, % by mass)	0	0.1	0.1	0.1	–	–	0.1	0	–
Elongated particle content (max, %)	20	–	–	–	–	–	–	–	–

1 Sprayed seals.
2 Asphalt.
3 Unpublished supplementary specification.
4 Tenth percentile of length of particles retained on 0.60 mm sieve.
5 To be nominated by the contractor as part of the asphalt mix design submission.

2.5.2 Comparison of Australian CRM Binder Specifications

A summary of the CRM binder requirements specified by Austroads and each of the Australian SRAs is presented in Table 2.6. Generally, all the SRAs use the Austroads CRM binder specifications. However, TMR (Table 2.2 and Table 2.3) and RMS have specified their own CRM binders. It is also important to note that RMS (QA Specification R118) and VicRoads (Section 421) have separate requirements for asphalt mixes containing crumb rubber, although the class of binder is not specified, as summarised in Section 2.6.6. Furthermore, the construction requirements for CRM asphalt, both nationally and internationally are presented in Section 2.6.7.

General observations include:

- Main Roads currently only allows the use of one Austroads class CRM binder, i.e. S45R for sprayed seal applications.
- The Austroads class CRM binders are only used for sprayed seal applications in the SRA specifications reviewed.
- RMS is the only SRA that has specified their own CRM binder for sprayed seals.
- TMR has developed two CRM binders for asphalt, in supplementary specification PSTS112.

Table 2.6: Comparison of Australian CRM binder specifications

Property	Austroads				RMS
	A27RF(1)	S15RF(2)	S18RF(3)	S45R(4)	S20RF
Mix process	Dry	Wet (HV)	Wet (HV)	Wet	Wet (HV)
Viscosity at 165 °C (max, Pa.s).	–	–	–	4.5	–
Torsional recovery at 25 °C, 30 s (min, %)	–	25	30	25–55	30
Softening point (min, °C)	–	55	62	55–65	62
Nominal rubber concentration (%)	25–30	15	18	–	20
Rubber content by analysis (min, %)	–	–	–	10	16
Consistency at 60 °C (min, Pa.s)	–	Report	Report	1000	Report
Consistency at 6% at 60 °C (min, Pa.s)	–	–	–	Report	–
Elastic recovery at 60 °C, 100 s (min, %)	–	–	–	25	–
Stiffness at 15 °C (max, kPa)	–	–	–	180	–
Compression limit at 70 °C, 2 kg (min, mm)	–	–	–	0.2	–
Segregation (max, %)	–	–	–	8	–
Flash point (min, °C)	–	–	–	250	–
Loss on heating (max, % mass)	–	–	–	0.6	–

Note: HV = high viscosity wet mixing process.
1 Not included in any SRA specification.
2 Included in the following SRA specifications: TMR, RMS, DPTI and VicRoads.
3 Included in the following SRA specifications: TMR, DPTI and VicRoads.
4 Included in the following SRA specifications: Main Roads, TMR, RMS, DPTI and VicRoads.

2.6 Selected International Practice

Although the use of CRM binder internationally is well-established in the USA and South Africa, its use in Canada, Europe and New Zealand is relatively limited. In Europe, the CRM binders used in asphalt applications have typically been limited to experimental sections, primarily due to lack of demand from industry and government (Fornai et al. 2016). Furthermore, although the use of PMBs is well established in New Zealand, the use of crumb rubber has not been used to any extent in normal road pavement and surfacing maintenance or construction (Wu, Herrington & Neaylon 2015). While interest in the use of CRM binder in Canada has increased in recent years, applications are limited to trials and trial specifications (Cheng & Hicks 2012).

The review of selected international practice regarding the use and specification of CRM binder was limited to the USA, South Africa and Canada. The documents reviewed are listed in Table 2.7.

Table 2.7: International documents reviewed

Region	Documents reviewed
United States of America	ASTM International D6114/D6114M-09 *Standard Specification for Asphalt-Rubber Binder* (ASTM 2009)(2) *Asphalt Rubber Usage Guide* (Caltrans 2003) *Standard Specifications for Road and Bridge Construction* (ADOT 2008) *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* (TxDOT 2014) *Standard Specifications* (Caltrans 2018)
South Africa	Manual 19 *Guidelines for the Design, Manufacture and Construction of Bitumen-rubber Asphalt Wearing Courses* (SABITA 2016) Technical Guideline 1: *The use of Modified Bituminous Binders in Road Construction* (SABITA 2015)
Canada	*Summary of Rubber Modified Asphalt Product Specifications around the World* (Cheng & Hicks 2012)(1)

1 Not a published specification. Includes recommended amendments to provincial specifications.
2 Withdrawn as of 2018. ASTM requires standard to be updated by the end of the eighth year since last approval date.

2.6.1 United States of America

The use of CRM binder has been established in the USA since the 1960s, originating in Arizona, USA (Cheng & Hicks 2012). However, the level of experience and usage varies between the state jurisdictions. Specifications from the American Society for Testing and Materials (ASTM) and the leading state Departments of Transportation, including Arizona, California and Texas were reviewed.

American Society for Testing and Materials

The properties of crumb rubber and CRM binder are specified in the ASTM *Standard Specification for Asphalt-Rubber Binder* D6114/D6114M-09. Notably, the grading requirements for the crumb rubber material are not specified beyond the nominal size of the particles (100% passing 2.36 mm sieve). ASTM also includes the performance requirements for three types of CRM binder, where each type is classified according to the stiffness of the base binder. The CRM binder types also include usage recommendations based on climate, where Type I is for hot climates and Type III for cold climates. The ASTM specifications for the crumb rubber material are summarised in Table 2.10 and the CRM binder requirements are presented in Table 2.11.

It is important to note that ASTM D6114/D6114M-09 was withdrawn by ASTM in January 2018. This was withdrawn as the ASTM regulations require standards to be updated at the end of the eighth year since the last approval date (2009). As no update was made to the specification it was withdrawn by ASTM with no replacement.

Arizona

The ADOT *Standard Specifications* (ADOT 2008) include requirements for crumb rubber material and CRM binder properties. ADOT specifies two types of crumb rubber material, Type A with coarser grading between 2.0 mm and 1.18 mm and Type B with finer grading between 1.18 mm and 0.075 mm. Additionally, ADOT specifies three types of CRM binders for asphalt based on the climatic zone it will be applied in (Way, Kaloush and Biligiri 2011). Table 2.8 summarises the difference between the three types of CRM binders for asphalt.

Table 2.8: ADOT specifications for crumb rubber modified binders for asphalt (CRA) 1, 2 and 3.

	CRA Type 1	CRA Type 2	CRA Type 3
Climate zone	Hot	Mild	Cold
Grade of base asphalt cement (Performance Grade recommended)	PG 64-16	PG 58-22	PG 52-28
Penetration grade (suggested grade)	Pen 60/70	Pen 85/110	Pen 120/200

Source: Way, Kaloush and Biligiri (2011).

ADOT utilises CRM binder in GGA and OGA. Table 2.10 presents the crumb rubber material requirements and Table 2.11 summarises the CRM binder requirements. It is important to note that ADOT does not specify performance requirements for CRM-OGA. The requirements for GGA are summarised in Table 2.12, whilst the key construction specifications are presented in Table 2.13.

California

CRM binders used on state-controlled roads in California are required to conform with the California Department of Transportation (Caltrans) *Standard Specifications* (Caltrans 2018). The *Standard Specifications* include provision for one type of CRM binder, used for sprayed seals, GGA and OGA. Notably, Caltrans has separate requirements for crumb rubber derived from scrap tyres and high natural crumb rubber. Caltrans requires that a blend of 76% scrap tyre crumb rubber and 24% high natural crumb rubber is used to modify bitumen. The characteristic differences between scrap tyre crumb rubber and high natural crumb rubber is summarised in Table 2.9.

Table 2.9: Caltrans crumb rubber characteristics

Characteristic	Scrap tyre crumb rubber	High natural crumb rubber
Acetone extract (%)	6–16	4–16
Rubber hydrocarbon (%)	42–65	50 (min)
Natural rubber content (%)	22–39	40–48
Carbon black content (%)	28–38	–
Ash content (%)	8.0 (max)	–

Source: Caltrans (2018).

Furthermore, Caltrans specifies that an asphalt modifier must be blended with the binder at the production site. The Caltrans requirements for crumb rubber material and CRM binder are summarised in Table 2.10 and Table 2.11, respectively. Similar to ADOT, although Caltrans allows the use of CRM binder in OGA, there are no specified performance requirements. The requirements for GGA are summarised in Table 2.12 with the construction requirements presented in Table 2.13.

Texas

The Texas Department of Transportation's (TxDOT) *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* (TxDOT 2014) describe the requirements for crumb rubber materials and CRM binder. TxDOT uses CRM binder in sprayed seals, stone mastic asphalt (SMA), OGA, thin bonded friction courses and crack sealer. The crumb rubber material is categorised into three grades (A, B and C), where Grade A has the coarsest gradation and Grade C has the finest. Grades A and B crumb rubber may be used for crack sealant materials while Grade B is used for seals and Grade C for asphalt mixes. The CRM binder specifications are based on ASTM D6114. Table 2.10 presents the crumb rubber material requirements and Table 2.11 summarises the CRM binder requirements. The mix design requirements for SMA and

OGA containing CRM binder are presented in Table 2.12, while the construction requirements are presented in Table 2.13.

2.6.2 South Africa

South Africa has successfully used CRM binder for almost 40 years, primarily as part of a stress absorbing membrane (SAM) and OGAs. The SABITA (2016) Manual 19 *Guidelines for the Design, Manufacture and Construction of Bitumen-rubber Asphalt Wearing Courses* outlines the CRM binder requirements in South Africa. Manual 19 states that CRM binder is typically manufactured with a 70/100 penetration grade bitumen, although other grades of bitumen may be blended to achieve penetration or viscosity requirements. The rubber is obtained from the processing and recycling of rubber tyres, in a dry, free flowing state free from contaminants.

Technical Guide 1 (SABITA 2015) also recommends that crumb rubber contains in excess of 30% carbon black to reinforce the properties of bitumen and antioxidants in the rubber, contributing to the durability of the CRM binder. Blending may be carried out using the wet, high-viscosity method or the dry process. However, CRM binder used for spray seals must be blended using the wet process. Furthermore, a heavy extender oil should be added to the penetration grade bitumen before the addition of crumb rubber.

The requirements for the CRM binders in South Africa are presented in Table 2.10 and Table 2.13, respectively.

2.6.3 Canada

In Canada, CRM binder has had limited application to date (Hicks, Tighe & Cheng 2012). In 2012, Cheng and Hicks recommended a number of changes to the current asphalt specifications in Ontario to allow the use of CRM asphalt products. It is important to note that these recommendations have not currently been adopted into the published Ministry of Transportation of Ontario (MTO) specifications.

The recommended specifications allow CRM binder to be manufactured with a penetration grade binder (58-28) using the wet process terminal blending and the wet process field blend. The trial specifications allow CRM binder to be used in GGA and OGA. The requirements for the crumb rubber material, CRM binder, CRM asphalt and construction requirements according to the amended MTO specifications are presented in Table 2.10 to Table 2.13, respectively.

2.6.4 Crumb Rubber Specification Comparison between Main Roads and International Practice

Table 2.10 summarises the review of selected international specifications and documentation regarding the material requirements for crumb rubber, compared to current Main Roads practice. International crumb rubber requirements generally address the same criteria as Main Roads. General observations from the comparison between current Main Roads requirements and international practice include:

- The international practices reviewed permit the use of crumb rubber in asphalt mixes and sprayed seals, with the exception of the MTO which did not specify CRM binder for sprayed seal applications.
- South Africa and TxDOT (Grade C) permit the use of a particle size smaller than that of Main Roads.

- The maximum bulk density for the international road agencies, where specified, was generally in the range of 1100 to 1200 kg/m^3 whereas the maximum allowed by Main Roads is 350 kg/m^3. However, it is important to note that the maximum bulk density specified by Sabita varies in two published documents, at 300 to 400 kg/m^3 in TG1 (Sabita 2015) and 1100 to 1200 kg/m^3 in Manual 19 (Sabita 2016). These significant differences in quoted ranges relate to the test method used to determine the maximum bulk density. When comparing maximum bulk density, the methods used should be similar.
- ASTM, ADOT, Caltrans and South Africa allow the addition of mineral powder (typically calcium carbonate) to prevent rubber particles from sticking together.
- Caltrans is the only road agency that requires crumb rubber derived from tyres to be blended with natural crumb rubber for modification of the binder.

Table 2.10: International crumb rubber material specification comparison

Property	Main Roads(1)	MTO(2)	SABITA(1),(2)	ASTM(1),(2)	ADOT		Caltrans		TxDOT	
					Type A(1)	Type B(2)	Tyre crumb rubber(1),(2)	Natural crumb rubber(1),(2)	Grade B(1)	Grade C(2)
Grading sieve size (mm) 2.36 (% passing)	100	100	–	100	100	–	100	–	–	–
2.00 (% passing)	–	100	–	–	95–100	100	98–100	100	100	–
1.18 (% passing)	100	80–100	–	–	0–10	65–100	45–75	95–100	70–100	100
1.00 (% passing)	–	–	100	–	–	–	–	–	–	–
0.60 (% passing)	60 (min)	40–60	40–70	–	–	20–100	2–20	35–85	25–60	90–100
0.42 (% passing)	–	–	–	–	–	–	–	–	–	45–100
0.30 (% passing)	20 (max)	5–15	–	–	–	0–45	0–6	10–30	–	–
0.150 (% passing)	–	0–10	–	–	–	–	0–2	0–4	–	–
0.075 (% passing)	2 (max)	–	0–5	–	–	0–5	0	0–1	0–5	–
Bulk density (max, kg/m^3)	350	–	1100–1250*	1100–1200	–	1100–1200	1100–1200	1100–1200	–	–
Moisture content (max, %)	1.0	–	–	0.75	–	–	–	–	–	–
Particle length (max, mm)	3.0	5.0	6.0	–	–	–	4.75	4.75	–	–
Metallic content (max, % by mass)	0.1	–	0	0.01	0	0	0.01	0.01	0	0
Other foreign materials (max, % by mass)	0	–	0	0.25	0	0	0	0	0	0
Fibre content (max, % by mass)	0	–	0	0.5[1] 0.1[2]	0.1	0.5	0.05	0.05	0	0
Mineral powder (max, % by mass)	–	–	4	4	4	4	3	3	–	–

1 Sprayed seals.
2 Asphalt.
3 300–400 kg/m^3 in SABITA (2015).

2.6.5 CRM Binder Specification Comparison between Main Roads and International Practice

The specification requirements for the international CRM binders compared to Main Roads are summarised in Table 2.11. It is important to note that care must be taken when comparing Australian and international requirements as differences in test methods, design practice and industry experience may influence comparisons. General observations from the comparisons between current Main Roads requirements and international specifications include:

- The international agencies reviewed permit the use of crumb rubber in asphalt mixes and sprayed seals, with the exception of Canada which does not specify CRM binder for sprayed seal applications. Main Roads currently does not specify CRM binder for asphalt mixes.
- There is limited crossover in the required performance properties between Main Roads and the international practice reviewed.
- Softening point for CRM binder used by Main Roads is similar to the international requirements.
- The minimum rubber content of the CRM binder used by Main Roads is significantly lower than the quantity of CRM used internationally.
- South Africa and Caltrans allow the use of extender oil to improve the characteristics of the binder.

Table 2.11: International CRM binder properties comparison

Property	Main Roads(1)	MTO(2),(3)	SABITA		ASTM and TxDOT(1),(2),(4)	ADOT(1),(2)	Caltrans(1),(2)
			S-R1(1)	A-R1(2)			
Mix process	Wet	Wet (HV)	Wet (HV)	Wet (HV)	Wet (HV)	Wet (HV)	Wet (HV)
Penetration at 25 °C	–	25–70	–	–	25–75	–	25–70
Penetration at 4 °C (min)	–	–	–	–	10 (Type I) 15 (Type II) 25 (Type III)	10 (Type 1) 15 (Type 2) 25 (Type 3)	–
Penetration retention at 4 °C (min)	–	–	–	–	75	–	–
Resilience at 25 °C (min, %)	–	18	13–35	13–40	25 (Type I) 20 (Type II) 10 (Type III)	25 (Type 1) 20 (Type 2) 15 (Type 3)	18
Compression/Recovery (%) (5 mins) (60 mins) (24 hours)	–	–	> 70 > 70 > 40	> 80 > 70 –	–	–	–
Softening point (min, °C)	55–65	52–74	55–65	55–65	57 (Type I) 54 (Type II) 52 (Type III)	57 (Type 1) 54 (Type 2) 52 (Type 3)	52–74
Viscosity at 190 °C (Pa.s)	–	1.0–4.0	2.0–5.0	2.0–5.0	–	–	1.5–4.0[1] 1.5–3.0[2]
Viscosity at 175 °C (Pa.s)	–	–	–	–	1.5–5.0	1.5–4.0	–
Flow (mm)	–	–	15–70	10–50	–	–	–

Property	Main Roads(1)	MTO(2),(3)	SABITA		ASTM and TxDOT(1),(2),(4)	ADOT(1),(2)	Caltrans(1),(2)
			S-R1(1)	A-R1(2)			
Grade of base binder	–	PG 58-28	PG 70/100[5]	PG 70/100[5]	–	PG 64-16 (Type 1) PG 58-22 (Type 2) PG 52-28 (Type 3)	–
Rubber content (min, %)	10	18–20	–	18–24	15	20	18–22
Extender oil (max, %)	–	–	3	3	–	–	2.5–6.0

Note: HV = high viscosity wet mixing process.
1 Sprayed seals.
2 Asphalt.
3 Not a published specification, proposed amendments to current specifications only.
4 Type I binders typically include stiffer grades of base binder, generally used in hot climates (–1 to 43 °C). Type II binders typically include softer grades of base binder, generally used in moderate climates (–9 to 43 °C). Type III binders typically include softest grade of base binder, generally used in cold climates (–9 to 27 °C).
5 Typically used, not a requirement.

2.6.6 CRM Asphalt Mix Design Requirement Comparison between Australian and International Practice

The OGA mix design requirements specified by the national and international practice reviewed are summarised in Table 2.12. General observations include:

- The method of compaction varies between jurisdictions, both Marshall and gyratory methods are used.
- Marshall compaction of 50 blows per face are specified.
- The target binder content typically varies between 5.5% and 9.5%.
- Design air voids content is generally between 18.0% and 25.0%.
- The asphalt mix design requirements are generally based on volumetric requirements.

Table 2.12: Comparison of Australian and international OGA CRM asphalt mix design requirements

Property	AAPA	TMR	SABITA	Caltrans	ADOT	TxDOT
Method of compaction	Marshall	Marshall	Marshall	Gyratory	Marshall	Gyratory
Number of compaction blows	50 blows per face	50 blows per face	50 blows per face	N/A	50 blows per face	N/A
Binder content (%)	6.0 (min)	TBD	5.5	TBD	8.0–9.5	7.0–9.0
Air voids content (%)	20 (min)	18 (min)	20–25	N_{design} = 4.0	12–15	–
Gyratory voids at 300 gyration (min, %)	–	–	–	–	–	–
Voids in mineral aggregate (min, %)	–	–	–	13.5–19.5(1)	–	–
Active filler (min, %)	–	–	1.0	–	–	1.0
Asphalt particle loss (max, %)	20	20	–	–	–	20
Asphalt binder drain off (max, %)	0.3	0.3	–	–	–	0.1
Indirect tensile strength (min, kPa)	–	–	–	–	–	–
Immersion index (min, %)	–	–	75	–	–	–
Static creep (min)	–	–	–	–	–	–
Dynamic creep (min)	–	–	–	–	–	–
Binder film thickness (min, microns)	18 (AS/NZS 2891.8)	17 (Q317) 18 (AS/NZS 2891.8)	15	–	–	–
Tensile strength ratio (min, %)	–	–	–	–	–	–
Hamburg wheel tracking test (min, no. of passes at 12 mm rut depth)	–	–	–	10000–25000(2)	–	–
Hamburg wheel tracking test (min, no. of passes at the inflection point)	–	–	–	10000–15000(2)	–	–
Moisture susceptibility, dry strength (min, kPa)	–	–	–	690	–	–
Moisture susceptibility, wet strength (min, kPa)	–	–	–	483	1034	–

1 Depending on gradation.

2 Depending on PG binder.

2.6.7 CRM Asphalt Construction Requirement Comparison between Australian and International Practice

The key construction requirements outlined for CRM asphalts as specified by the national and international practice reviewed are summarised in Table 2.13. It is important to note that the review compares the construction requirements for each of the permitted asphalt mix types in each jurisdiction, and thus care must be taken when comparing different types of mixes.

The comparison of construction requirements shows the following observations:

- The mix production temperature ranges vary between jurisdictions, although the CRM blending temperature shows similarities.
- The TMR supplementary specification requirements for mix production temperature are the same as those specified by ADOT, and the CRM blending temperature is similar to South Africa.
- The compaction temperature requirements vary between the jurisdictions, where ADOT permits temperatures to drop as low as 104 °C.
- The lower ambient pavement temperatures range from 12−15 °C, with an upper range of 18−30 °C.
- The in situ air void contents are generally the same across the jurisdictions, with a range of 12.0%−25.0%.
- The compaction density requirements are varied between jurisdictions, which may be a result of the different methods used to determine field density.

Table 2.13: CRM asphalt construction requirements compared to current Main Roads specifications for OGA

Property	Main Roads (OGA)[1]	AAPA	TMR	Sabita	Caltrans	ADOT	TxDOT
Mix production temp. (°C)	170	165–190	175–205 (CRM blending) 163–190	170–210 (CRM blending)	163	<163 (discharge)	160–218
Compaction temp. (°C)	155–170 (delivery temp.)	–	–	190–210 (mixing/laying)	143–160	121	–
Ambient/pavement temp. (min, °C)	15–20	13 (air) 15 (asphalt)	20	–	7 (air) 10 (asphalt)	18 (air) 30 (asphalt)	–
In situ air voids (%)	16–21	–	–	20–25 (OGA)	4% at N_{design}	4–9	–
Compaction density (min, %)	93 of characteristic percent Marshall density	–	–	–	–	–	97 of laboratory-moulded density

2.7 Discussion of Literature Review

This chapter reviewed national and international experience with CRM binder technology, to include spray seals, HMA and WMA. The study identified that Main Roads requirements for CRM binder are generally in accordance with Austroads and other national SRAs, however, Main Roads does not currently permit the use of CRM binder in asphalt mixes. This is also reflected in comparison with international practice. Significant findings from the investigation include:

- The production of CRM binder is undertaken in two stages, crumb rubber manufacture and blending with virgin binder. Blending may be undertaken using two general processes, the dry process and the wet process.
- National and international literature indicates that the utilisation of crumb rubber is a high-value, sustainable reuse of tyre waste that can benefit the environment and improve the performance of seals and asphalt.
- International literature indicates that the use of CRM can be successfully combined with WMA technologies.
- The main barriers to implementation are related to emissions and worker health, leaching, and the relatively high initial cost compared to unmodified bitumen.
- Research conducted through the NACoE program, in conjunction with TMR shows that CRM binder can be successfully used in OGA. The research through NACoE also included the development of a supplementary specification, which may be applicable to a trial with Main Roads.
- Comparison of the current practice in Australia regarding the use of crumb rubber and CRM binder indicated that Main Roads practice is generally in accordance with Austroads and the other SRAs.
- Review of selected international practice indicated that the manufacturing, mix design and construction of CRM asphalt generally follows the same principles, although the specification values for each property may vary between each jurisdiction. Notably, the asphalt mix design requirements are generally based on volumetric requirements.
- Although asphalt mix design requirements are generally based on volumetric requirements, it is interesting to note that 50 blows Marshall compaction per face are specified. Main Roads currently specifies 75 blows Marshall compaction per face for OGA with A20E binder.

  Concerns over aggregate breakdown with the Marshall hammer during the development years of stone mastic asphalt (SMA) in the USA, lead to the use of 50 blows Marshall compaction per face after a study by Brown and Manglorkar (1993). SMA and OGA is classified as stone skeleton mixes (Jooste et al. 2000) for which 50 blows Marshall compaction per face is generally accepted In the USA and South Africa.

3 LABORATORY EVALUATION

This section outlines the laboratory evaluation undertaken as part of the three stages of this project.

3.1 Development of CRM Binder

Binder testing in ARRB's Vermont South laboratory included the development of a CRM binder that complies with the supplementary specification PSTS112 *Crumb Rubber Modified Open Grade Asphalt Surfacing* (TMR 2016). The development of PSTS112 was discussed in Section 2.4.2 of this report.

3.1.1 Base Binder

The base binder samples of C170 supplied to ARRB's Vermont South laboratory was tested for conformance against Specification 511 (Main Roads 2017). The test results are summarised in Table 3.1. The binder conformed to all specification properties for it to be considered a C170 binder.

Table 3.1: Base binder property verification test results

Test Method	Binder property	C170 sample*			Specification 511	
		Test 1	Test 2	Average	Minimum	Maximum
AS 2341.2	Dynamic viscosity by capillary tube at 60 °C (Pa.s)	211.4	214.5	213.0	160	230
	Dynamic viscosity by capillary tube after RFTO at 60 °C (Pa.s)	373.1	368.1	370.6	–	–
	Percentage increase	176.5	171.6	174.0	–	300
AS 2341.12	Penetration at 25 °C (pu)	66.7	67.6	–	62	–
AG:PT/T111	Brookfield viscosity at 135 °C (Pa.s)	0.3834	0.3834	0.3834	0.25	0.45

*Sample number 5031.

3.1.2 Crumb Rubber Properties

Recycled crumb rubber was sourced from Tyrecycle and supplied to ARRB's Vermont South laboratory. The supplied crumb rubber was not tested for conformance as outlined in AGPT/T190 (2019), as a certificate to state conformance was supplied.

3.1.3 Crumb Rubber Blend

It is important to note that there are two ways in which proportioning can be applied. Proportioning can be based on parts or percentage of mass of total binder. It has been the practice in Australian jurisdictions in the past to define blended binder based on parts. 'Percentage' and 'parts' are sometimes used interchangeably without realising the difference. The difference in calculation is illustrated in the example (Table 3.2).

Table 3.2: Example calculations of 'percentage' and 'parts' by mass of total binder

Percentage by mass of total binder	Parts by mass of total binder	Difference
Prepare a 18% crumb rubber modified binder Say total mix of modified binder = 3200 g 0.18 x 3200 = 576 g rubber 0.82 x 3200 = 2624 g binder 2624 g binder + 576 g rubber = 3200 g total modified binder	Prepare 18 part crumb rubber modified binder Say total mix of modified binder = 3200 g For every 100 g binder, 18 g of rubber is required, i.e. 27 (for 2700 g binder) x 18 = 486 g rubber 2700 g binder + 486 g rubber = 3186 g total modified binder	In terms of percentage by mass of total binder: 486 / 3200 = 15%

Draft specification PSTS112's (TMR 2016) (Section 2.4.2) requirements were developed based on the Wet Process – High Viscosity blending of crumb rubber into a base binder. It specifies a minimum crumb rubber content of 17% by mass of total binder but notes that crumb rubber binder blends manufactured using Wet Process – High Viscosity blending, typically contain 20% crumb rubber.

A crumb rubber content of 18% by mass of total binder was targeted, since high shear viscosity blending was not used in the laboratory. ARRB's Vermont South laboratory used a low shear paddle mixer to mix the crumb rubber into the binder.

However, ARRB's laboratory proceeded with proportioning by parts and not percentage. The results reported below reflect proportioning by parts. The results based on proportioning by percentage are reported thereafter.

Initial testing, conducted by ARRB's laboratory during 2017 and early 2018, evaluated four CRM binder blends against the Draft specification PSTS112 (TMR 2016). The combinations of crumb rubber content and blending oil content are summarised in Table 3.3. These combinations were tested after 60 minutes reaction time to determine which combinations comply with the property requirements of PSTS112 for CR1 and CR2 binders. Where property requirements were applicable, all CRM binder blends satisfied at least one type's requirement, if not both.

Table 3.3: Resulting properties per blend after 60 minutes reaction time

Property	Test Method	Bitumen blend				CR1	CR2
		18 parts rubber + no oil	18 parts rubber + 3 parts oil	18 parts rubber + 5 parts oil	20 parts rubber + 6 parts oil		
		60 mins	60 mins	60 mins	60 mins	Reaction time	Reaction time
Penetration at 25°C, 100 g, 5 sec, 0.1 mm (mm)	AS 2341.12	38	47	51	56	N/A	N/A
Penetration at 4°C, 200 g, 60 sec, 0.10 mm (mm)	AS 2341.12	27	Not tested	Not tested	32	Minimum 10	Minimum 15
Resilience at 25°C, percent rebound	ASTM D5329	25.8	33.3	26.1	29.7	Minimum 25	Minimum 20
Torsional recovery at 25 °C, 30s (%)	AGPT/T122	27.3	23.1	21.7	27.3	To be reported	To be reported
Softening point (°C)	AGPT/T131	63.4	58.3	**56.1**	58.6	Minimum 57	Minimum 55
Viscosity at 175 °C (Pa.s)	ASTM D2196 (AGPT/T111 used)	2.59	1.69	1.74	2.15	To be reported	To be reported
	ASTM D7741 / D7741M	Not tested				1.5–4.0	1.5–4.0
Flash point (°C)	AGPT/T112	Not tested				Minimum 250	Minimum 250

Property	Test Method	Bitumen blend				CR1	CR2
		18 parts rubber + no oil	18 parts rubber + 3 parts oil	18 parts rubber + 5 parts oil	20 parts rubber + 6 parts oil		
		60 mins	60 mins	60 mins	60 mins	Reaction time	Reaction time
Loss on heating (%)	AGPT/T103	0.11	0.14	0.21	0.16	Maximum 0.6	Maximum 0.6
Consistency (Pa.s)	AGPT/T121	1574	1196	838	1194		
Consistency 6%	AGPT/T121	1159	878	658	807		
Stiffness at 15 °C (kPa)	AGPT/T121	> 187	> 187	173.8	178.8		

Consistency and stiffness testing were included in the initial testing to compare with the requirements of S45R (CRM binder for spray seal application) as outlined in Specification 511 (Main Roads 2017b). S45R contains approximately 15% rubber. Since there are no asphalt rubber binder requirements, it was used as a benchmark. Consistency results adhered to the minimum 1000 Pa.s, except for the 18 parts rubber + 5 parts oil blend. Consistency 6% at 60 °C gives an indication of rut resistance of binders in asphalt and is required to be reported only. Stiffness at 15 °C is an indicator of medium temperature behaviour for sealing grades. A maximum of 180 kPa is specified (Main Roads 2017b), which the 18 parts rubber + no oil and 18 parts rubber + 3 parts oil blends exceed. These initial test results compared to requirements for S45R indicate that some blending oil may be beneficial to enable adherence to requirements.

Penetration measured at various temperatures and critical limits have been used to indicate the level at which pavement distresses are expected. At 25 °C the standard penetration test is used to evaluate the intermediate temperature consistency, while at 4 °C it is used to measure the low temperature characteristics. However, the low temperature characteristics of CRM binder are typically governed by the properties of the base binder. The addition of crumb rubber may be used to increase the high temperature stiffness of the base binder, thus widening the service temperature range (Widyatmoko & Elliot 2007). The penetration at 4 °C tests were conducted last and only conducted for the 18 parts rubber + no oil blend and the 20 parts rubber + 6 parts oil blend, the two selected blends.

It should be noted that AGPT/T111 *Handling viscosity of polymer modified binders (Brookfield Thermosel)* was used to determine the viscosity at 175 °C and not ASTM D2196 *Standard test methods for rheological properties of non-newtonian materials by rotational viscometer* as per PSTS112. Viscosity testing using a rotational handheld viscometer (ASTM D7741 / D7741M) was not conducted because ARRB's laboratory does not have the equipment.

Testing proceeded on two selected crumb rubber blends, namely the 18 parts rubber plus no oil and 20 parts rubber plus 6 parts oil. The test results of the crumb rubber blends at the required reaction times are summarised in Table 3.6. Both blends satisfy the property requirements of CR1 and CR2 binder.

The loss on heating test was conducted on the 20 parts rubber plus 6 parts oil CRM binder blend at more reaction times than for the 18 parts rubber plus no oil, to evaluate the influence of the blending oil on mass loss. Mass loss over extended reaction time did not appear to be influenced by the presence of blending oil in this instance.

Table 3.4: Resulting properties for two selected blends over full reaction time

Property	Test method	Bitumen blend												CR1	CR2
		18 parts rubber + No oil						20 parts rubber + 6 parts oil							
		60 mins	90 mins	120 mins	240 mins	360 mins	11 hrs	60 mins	90 mins	120 mins	240 mins	360 mins	11 hrs	Reaction time	Reaction time
Penetration at 25 °C, 100 g, 5 sec, 0.1 mm (mm)	AS 2341.12	38	–	–	42	–	44	56	–	–	58	–	58	N/A	N/A
Penetration at 4 °C, 200 g, 60 sec, 0.10 mm (mm)	AS 2341.12	27	–	–	28	–	26	32	–	–	32.5	–	32	Minimum 10	Minimum 15
Resilience at 25 °C, percent rebound	ASTM D5329	25.8	–	–	45.7	–	42.5	29.7	–	–	39.3	–	42.5	Minimum 25	Minimum 20
Torsional recovery at 25C, 30s (%)	AGPT/T122	27.3	–	–	39.8	–	38.4	27.3	–	–	35.6	–	39.8	To be reported	To be reported
Softening point (°C)	AGPT/T131	63.4	–	–	65.0	–	65.0	58.6	–	–	60.9	–	62.3	Minimum 57	Minimum 55
Viscosity at 175 °C (Pa.s)	ASTM D2196 (AGPT/T111 used)	2.59	1.42	1.36	1.47	2.59	3.71	2.15	1.06	1.16	2.06	3.22	5.24	To be reported	To be reported
	ASTM D7741 / D7741M	Not tested						Not tested						1.5–4.0	1.5–4.0
Flash point (°C)	AGPT/T112	Not tested						Not tested						Minimum 250	Minimum 250
Loss on heating (%)	AGPT/T103	0.11	–	–	–	–	–	0.16	–	–	0.07	–	0.17	Maximum 0.6	Maximum 0.6

The Australian Asphalt Pavement Association (AAPA), published a draft specification, *Crumb rubber modified open graded and gap graded asphalt model specification*, in June 2018. Since the laboratory work of 2017 were based on proportioning by parts and not percentage, the resulting percentage crumb rubber by mass of total binder was lower than the targeted 18%. Therefore, a new blend was developed. The developed CRM binder blend was evaluated against properties of a Class CR1 binder or Class CR2 binder, as well as the properties listed in Table 2-8 of AAPA (2018) based on proportioning by percentage mass of total binder.

Table 3.7 contains a summary of CRM binder blend' properties. The limits as per the PSTS112 (TMR 2016) and AAPA (2018) documents are included in the table for reference.

To determine the viscosity at 175 °C, the recommendation in AGPT/T190 (2019) regarding the appropriate spindle size for testing rubber modified spray grade binder was followed. Therefore, spindle SC4-29 was used instead of spindle SC4-31. The gap between the spindle SC4-29 and cup is 4 to 5 mm, enabling rubber particles to pass through easier.

PSTS112 (TMR 2016) required the viscosity at 175 °C to be between 1.5 and 4.0 Pa.s at every reaction time specified. The AAPA (2018) document reduced the number of reaction times specified to only two for which the viscosity at 175 °C must be between 1.5 and 4.0 Pa.s. The CRM binder blend complied to the AAPA (2018) requirements but would have failed the PSTS112 (TMR 2016) requirement at 90 and 120 minutes reaction time.

Table 3.5: Resulting properties for two selected blends over full reaction time

Property	Test method	18% by mass + no oil						CR1	CR2	AAPA Table 2–8
		60 mins	90 mins	120 mins	240 mins	360 mins	11 hrs	Reaction time	Reaction time	Reaction time 60 & 240 mins
Penetration at 4 °C, 200 g, 60 sec, 0.10 mm (mm)	AS 2341.12	19	–	–	20	–	21	Minimum 10	Minimum 15	Minimum 15
Penetration at 25 °C, 100 g, 5 sec, 0.10 mm (mm)	AS 2341.12	41	–	–	38	–	43	NA	NA	To be reported
Resilience at 25 °C, percent rebound	ASTM D5329	37.7	–	–	42.9	–	46.7	Minimum 25	Minimum 20	Minimum 20
Torsional recovery at 25C, 30s (%)	AGPT/T122	22.8	–	–	30.0	–	33.9	TBR	TBR	To be reported
Softening point (°C)	AGPT/T131	62.8	–	–	67.0	–	68.5	Minimum 57	Minimum 55	Minimum 55
Viscosity at 175 °C (Pa.s)	AGPT/T11 (used spindle #29)	2.379	*1.435*	*1.076*	1.579	2.453	3.829	To be reported	To be reported	1.5–4.0

3.2 Development of Trial OGA Mix

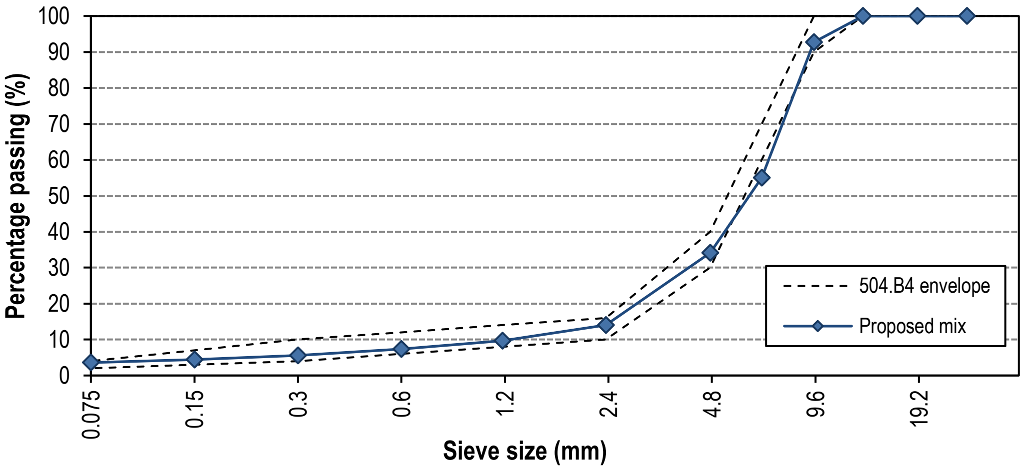
The development of a trial OGA mix was undertaken at ARRB's Vermont South laboratory. All materials used in the development were sourced from a local supplier in Perth.

3.2.1 Main Roads Specification 504 for OGA

Granite aggregate fractions of 10 mm, 7 mm, 5 mm and dust, as well as hydrated lime, were supplied to ARRB's Vermont South laboratory. Tests, as outlined in Main Roads' Specification 504 *Asphalt Wearing Course* (Main Roads 2016), were conducted to confirm aggregate properties and particle size distribution (PSD). These results are contained in Appendix D.

The aggregate fractions were used to produce a laboratory OGA mix that falls within the envelope specified in Table 504.B4 (Main Roads 2016). This was achieved only after the 10 mm fraction was screened, removing all particles passing the 2.36 to 0.075 sieves (Appendix E). Figure 3.1 shows the PSD produced in the laboratory.

Figure 3.1: OGA mix conforming to Specification 504.B4



Sieve size (mm)	Proposed mix	Specification 504.B4	
		Minimum	Maximum
26.50	100	100	100
19.00	100	100	100
13.20	100	100	100
9.50	93	90	100
6.70	55	–	–
4.75	34	30	40
2.36	14	10	16
1.18	10	8	14
0.600	7	–	–
0.300	6	4	10
0.15	4	–	–
0.075	3.6	2	4

Marshall mix design testing was conducted on the OGA mix containing 4.5% A20E binder as specified by Main Roads (2016), using 75 blows Marshall compaction per face. The results indicated a conforming OGA mix, as summarised in Table 3.6.

Table 3.6: Marshall mix design results on Specification 504.B4 OGA conforming mix

Design element	Test method	Lab results	Specification 504.B4	
			Minimum	Maximum
Binder content (%)	AS/NZS 2891.3.3	4.5	4.2	4.8
Bulk density (using vacuum method) (t/m^3)	WA 733.2	2.147	–	–
Maximum density (water displacement) (t/m^3)	AS/NZS 2891.7.1	2.564	–	–
Air voids in mix (%)	WA 733.2	16.3	16	21
Voids in mineral aggregate (VMA) (%)	WA 733.2	23.4	–	–
Voids filled with bitumen (VFB) (%)	WA 733.2	30.5	–	–
Stability (Marshall) (kN)	AS/NZS 2891.5	11.3	4	–
Flow (Marshall) (mm)	AS/NZS 2891.5	3.2	2	4
Film thickness (µm)	AG:PT/T237	11.5	–	–
Absorption of binder (%)	AS/NZS 2891.8	1.1	–	–

Testing continued after it was shown that the aggregate provided could be combined to yield a conforming OGA mix.

3.2.2 Substituting A20E Binder with CRM Binder

Using the OGA mix developed in section 3.2.1, the A20E binder was replaced with the 18% CRM binder. The binder content was increased, and Marshall mix design testing was conducted at 5.0% and 5.5% CRM binder content. These binder contents were selected to accommodate the CRM binder, which is typically used at a higher binder content than conventional binder mixes due to its higher viscosity. Since the PSD was not adjusted, but only the binder substituted, the 0.5% and 1.0% increase in binder content was considered within the limits of the mix to result in the least impact on the volumetrics of the conforming A20E mix. The selected binder contents are on the low side of PSTS112 (TMR 2016), which requires the mix design to be tested at 5.0%, 6.0%, 7.0% and 8.0%, as well as lower than AAPA (2018) that requires a minimum of 6.0% of binder by mass of total mix.

Marshall mix design testing was conducted on the mix, using 50 blows Marshall compaction per face. The results are summarised in Table 3.7. The mix containing 5.0% CRM binder complied with the void content requirement, while the mix containing 5.5% CRM binder had voids below the minimum of 16% voids required.

Table 3.7: Marshall mix design results with CRM binder on conforming mix

Design element	Test method	Lab results		Specification 504.B4	
				Minimum	Minimum
Binder content (%)	AS/NZS 2891.3.3	5.0	5.5	–	–
Bulk density (using vacuum method) (t/m^3)	WA 733.2	2.092	2.150	–	–
Maximum density (water displacement) (t/m^3)	AS/NZS 2891.7.1	2.543	2.524	–	–
Air voids in mix (%)	WA 733.2	17.7	**14.8**	16	21
Voids in mineral aggregate (VMA) (%)	WA 733.2	25.8	24.1	–	–
Voids filled with bitumen (VFB) (%)	WA 733.2	31.3	38.5	–	–
Stability (Marshall) (kN)	AS/NZS 2891.5	6.9	7.6	4	–
Flow (Marshall) (mm)	AS/NZS 2891.5	2.8	4.1	2	4
Film thickness (micrometer)	AG:PT/T237	13.4	15.1	–	–

Design element	Test method	Lab results		Specification 504.B4	
				Minimum	Minimum
Absorption of binder (%)	AS/NZS 2891.8	1.0	1.1	–	–

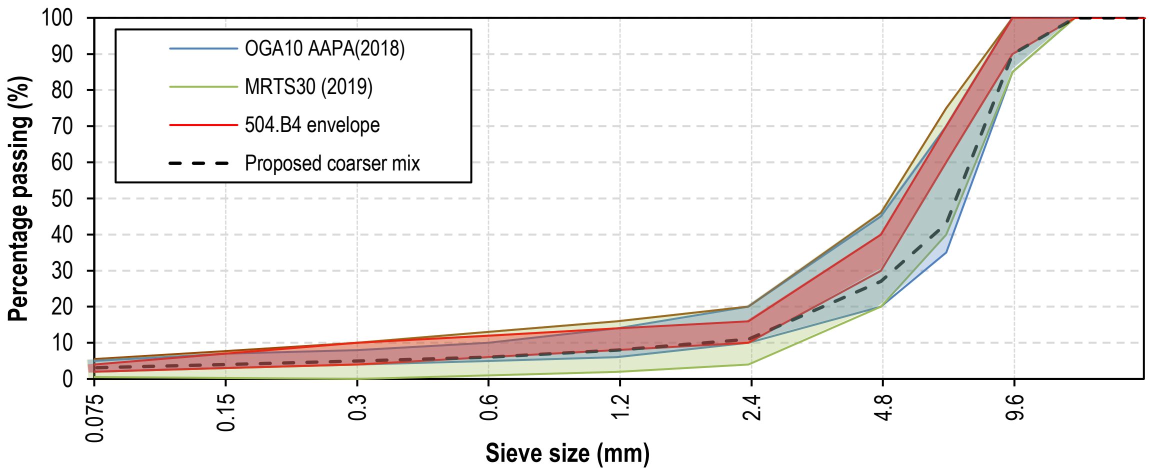
Based on the laboratory results, the A20E polymer modified binder could be replaced with 18% CRM binder at 0.5% higher binder content.

3.2.3 *Investigating a Coarser OGA Mix*

The use of CRM binder in hot mixes is typically limited to gap and open gradations rather than DGA due to the void space required to accommodate enough of the CRM binder to significantly improve performance (Caltrans 2003). Based on experience in Arizona, the typical OGA grading envelope was adjusted to increase the VMA to allow a much higher binder content, thus increasing the rutting, crack and ravelling resistance (Way, Kaloush & Biligiri 2011).

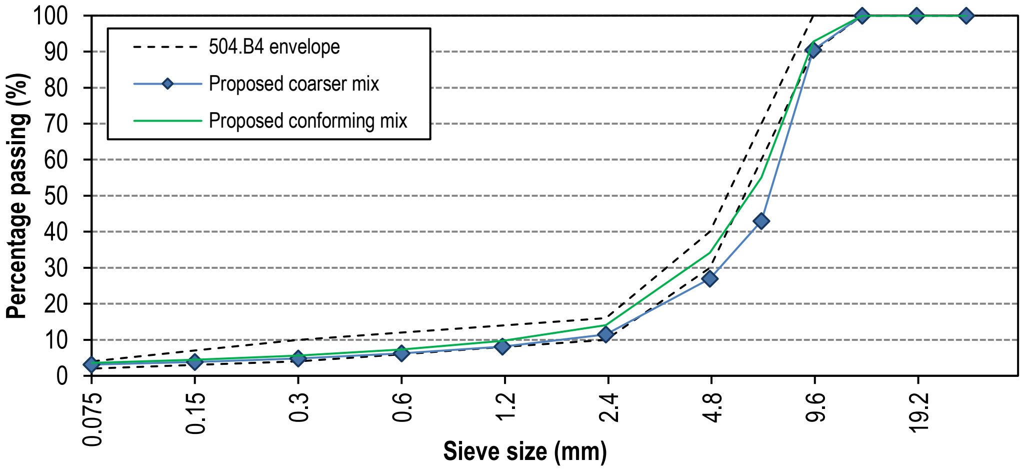
A coarser, optimised PSD than the conforming mix was investigated. Both TMR (MRTS30 2019) and AAPA (2018) specify coarser PSD envelopes than Main Roads (Figure 3.2). The proposed coarser PSD is on the coarser side of both the TMR (MRTS30 2019) and AAPA (2018) envelopes.

Figure 3.2: Proposed coarser OGA PSD compared with QTMR and AAPA PSD envelopes



The proposed coarser PSD is shown in Figure 3.3, together with the proposed conforming PSD.

Figure 3.3: Coarser OGA PSD tested



Sieve size (mm)	Proposed mix	Specification 504.B4	
		Minimum	Maximum
26.5	100	100	100
19	100	100	100
13.2	100	100	100
9.5	90	90	100
6.7	43	–	–
4.75	27	30	40
2.36	11	10	16
1.18	8	8	14
0.6	6	–	–
0.3	5	4	10
0.15	4	–	–
0.075	3.1	2	4

Marshall mix design testing was conducted on the mix using the 18% crumb rubber blended binder at 5.0% and 5.5% content. The results are summarised in Table 3.8. The mix containing 5.0% CRM binder yielded air voids in the mix within the tolerance. The mix containing 5.5% CRM binder yielded air voids just higher than the minimum requirement and the reported flow result was just above the maximum requirement.

Table 3.8: Marshall mix design results with CRM binder on coarser PSD mix

Design element	Test method	Lab results		Specification 504.B4	
				Minimum	Minimum
Binder content (%)	AS/NZS 2891.3.3	5.0	5.5	–	–
Bulk density (using vacuum method) (t/m^3)	WA 733.2	2.058	2.108	–	–
Maximum density (water displacement) (t/m^3)	AS/NZS 2891.7.1	2.561	2.524	–	–
Air voids in mix (%)	WA 733.2	19.6	16.5	16	21
Voids in mineral aggregate (VMA) (%)	WA 733.2	27.2	25.8	–	–
Voids filled with bitumen (VFB) (%)	WA 733.2	27.8	36.1	–	–
Stability (Marshall) (kN)	AS/NZS 2891.5	5.7	6.5	4	–
Flow (Marshall) (mm)	AS/NZS 2891.5	2.8	4.1	2	4

Design element	Test method	Lab results		Specification 504.B4	
				Minimum	Minimum
Film thickness (micrometer)	AG:PT/T237	14.3	17.4	–	–
Absorption of binder (%)	AS/NZS 2891.8	1.23	0.95	–	–

Based on the laboratory results, the coarser, optimised PSD did yield an increase in air voids of approximately 2%, also at a mix binder content of 5.0%.

The demonstration trial was agreed to consist of the following sections:

1. Specification 504 conforming OGA with 4.5% A20E binder content
2. Specification 504 conforming OGA with 5.0% CRM binder content (18% crumb rubber)
3. Coarser OGA with 5.0% CRM binder content (18% crumb rubber).

4 SPECIFICATION 516 – CRUMB RUBBER OPEN GRADED ASPHALT

Main Roads developed a new specification for the trial works, rather than updating the existing asphalt wearing course specification which contains open graded asphalt with A20E binder.

Draft Specification 516 *Crumb Rubber Open Graded Asphalt* was developed, and the content of the trial specification builds on information contained in:

- Queensland Department of Transport and Main Roads (QTMR) 2016. Crumb rubber modified open graded asphalt surfacing, Supplementary Specification PSTS112, June 2016, Version 3.
- Australian Asphalt Pavement Association (AAPA) 2018. Crumb Rubber Modified Open Graded and Gap Graded Asphalt Pilot Specification, Version 1.0, June 2018.
- Main Roads Western Australia 2017. Specification 504 Asphalt Wearing Course.
- Main Roads Western Australia 2017. Specification 511 Materials for Bituminous Treatments.

Appendix B contains the trial specification that was used for the design, production and construction of the demonstration trial.

5 CRM OGA DEMONSTRATION TRIAL

Fulton Hogan was the industry partner that conducted the design, production and construction of the CRM OGA demonstration trial. Fulton Hogan is also the industry partner on WARRIP Project 2019-002: *Transfer of appropriate crumb rubber modified bitumen technology to WA – Stage 2*, which focusses on CRM GGA. This project and the latter reached the binder development phase simultaneously.

This section documents the process followed as outlined in draft Specification 516.

5.1 Development of CRM Binder

Fulton Hogan developed the CRM binder for both this project and WARRIP Project 2019-002. The trial specifications for both projects required a minimum quantity of 18% crumb rubber by mass of total binder.

The base binder used for this project was a C170 grade binder supplied by Puma (Fulton Hogan 2018). The rheological properties reported are summarised in Table 5.1.

Table 5.1: Base bitumen rheological properties

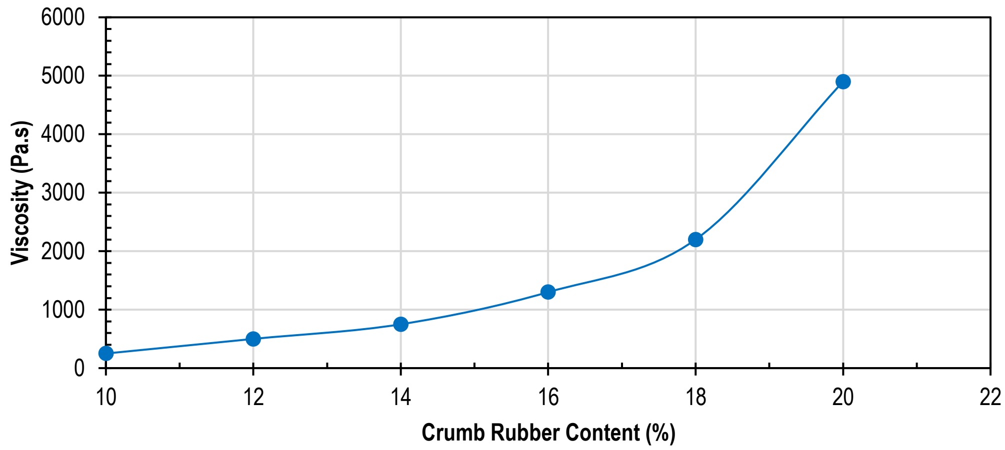
Property	C170	Minimum	Maximum	Test method
Viscosity at 60 °C, Pa.s	190	160	230	AS 2341.2
Viscosity at 135 °C, Pa.s	0.367	0.3	0.5	AS 2341.2 or AS 2341.3 or AS 2341.4
Penetration at 25 °C (100 g, 5 s), 0.1mm	67	55	78	AS 2341.12
Density at 15 °C, kg/m³	1053	1000	–	AS 2341.7
Flash point, °C	340	250	–	AS 2341.14
Matter insoluble in toluene, percent	0.2	–	1	AS 2341.8
Rolling Thin Film Oven Test	Conducted	–	–	AS 2341.10
Viscosity of residue at 60 °C as percentage of original	176	–	300	AS 2341.2 or AS 2341.3
Ductility at 15 °C, mm	Not reported	400	–	AS 2341.11
Durability value, days	12.6	9 (Refer cl 511.06.03)		AS/NZS 2341.13 or WA 716.1
Softening point, °C	48(1)	Not specified	Not specified	AGPT/T131

1 Softening point not specified but tested for internal use by Fulton Hogan.

Source: Fulton Hogan (2018).

Although the specifications require a minimum of 18% of crumb rubber by mass of total binder for modification, Fulton Hogan (2018) conducted initial testing at 175 °C on the effect of rubber content on the viscosity of the crumb rubber modified (CRM) binder. Figure 5.1 shows a sharp increase in viscosity beyond 18% crumb rubber content.

Figure 5.1: Rubber content (by mass of total binder) versus viscosity (Pa.s)



Source: Fulton Hogan (2018).

Nonetheless, Fulton Hogan (2018) proceeded to develop 20% and 18% CRM binders. Both high and low shear blending was used to investigate the effect of the mixing process. Table 5.2 summarises the 20% CRM binder results and Table 5.3 summarises the 18% CRM binder results.

The method of blending does not appear to influence the results significantly at 20% or 18% and low shear blending was used for the remainder of the project to blend the CRM binder.

It was also agreed that when determining the viscosity using AGPT/T111, the L series Brookfield together with spindle SC4-29 should be used to enable the rubber crumb to pass through the opening between the spindle and the cup.

The trial specification states that the CRM binder should comply with the requirements of Table 516.1 (indicated in Table 5.2 and Table 5.3) without the inclusion of a warm mix additive. The CRM binder tested and reported in this section does not contain any warm mix additive.

Table 5.2: 20% CRM binder results

Property	Unit	Blending time (minutes)						Table 516.1
		High shear			Low shear			
		60 min	240 min	*360 min*(2)	60 min	240 min	*360 min*(2)	Limits
Penetration at 4 °C, 100g(1), 60s	0.1 mm	17	12	*14*	17	8	*21*	Minimum 15
Penetration at 25 °C, 100g, 5s	0.1 mm	30	32	*45*	34	33	*43*	Report
Resilience at 25 °C	% rebound	72	72	*Not tested*	72	87	*71*	Minimum 20
Torsional recovery at 25 °C, 30s	%	53	57	*49*	52	55	*50*	Report
Softening point	°C	71	75	*71*	74	72	*72*	Minimum 55
Viscosity at 175 °C	Pa.s	4.41	6.98	*11.30*	4.92	31.30	*4.83*	1.5–4.0

1 Test method requires a 200 g weight. Results are expected to be higher with a 200 g weight.
2 Results reported for information only, not required at 360 minutes.
Source: Fulton Hogan (2018).

Table 5.3: 18% CRM binder results

Property	Unit	Blending time (minutes)						Table 516.1
		High shear			Low shear			
		60 min	240 min	*360 min(2)*	60 min	240 min	*360 min(2)*	Limits
Penetration at 4 °C, 100g(1), 60s	0.1 mm	15	13	*16*	12	15	*15*	Minimum 15
Penetration at 25 °C, 100g, 5s	0.1 mm	40	42	*48*	34	34	*41*	Report
Resilience at 2 5°C	% rebound	22	26	*18*	35	36	*23*	Minimum 20
Torsional recovery at 25 °C, 30s	%	51	44	*46*	49	51	*51*	Report
Softening point	°C	72	69	*72*	72	70	*72*	Minimum 55
Viscosity at 175 °C	Pa.s	3.13	3.17	*6.13*	2.53	3.17	*5.51*	1.5–4.0

1 Test method requires a 200 g weight. Results are expected to be higher with a 200 g weight.
2 Results reported for information only, not required at 360 minutes.
Source: Fulton Hogan (2018).

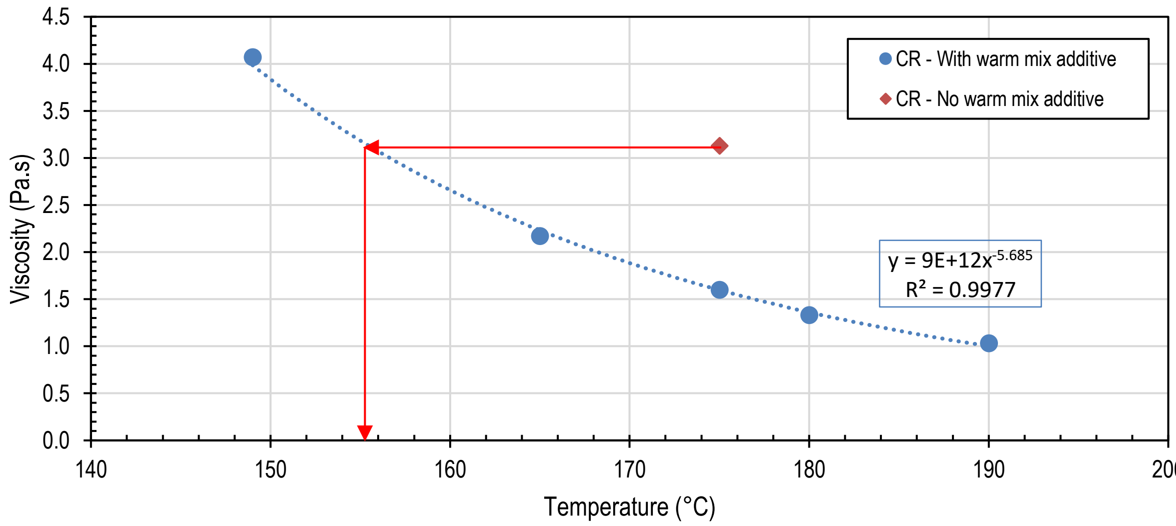
It was agreed that the 18% CRM binder blend would be used for the demonstration trial.

The penetration at 4 °C with a 200 g weight at 60 seconds test was conducted only on the selected 18% CRM binder blend after 60 minutes and resulted in 25 mm, above the minimum of 15 mm.

The trial specification allows the use of a warm mix additive and requires that the effect of adding a warm mix additive on the viscosity of the CRM binder should be evaluated. It outlines the procedure to determine the temperature at which the CRM binder with warm mix additive has the same viscosity as the CRM binder without warm mix additive at 175 °C. The temperature determined with the warm mix additive to achieve equivalent viscosity at 175 °C was used during production to conduct tests.

The results from this process are depicted in Figure 5.2 and show that at 155 °C the CRM binder with warm mix additive had the same viscosity, 3.1 Pa.s, as the CRM binder without warm mix additive at 175 °C.

Figure 5.2: Viscosity versus temperature with and without warm mix additive.



Some undigested rubber may not be accounted for during the extraction process and the correction factor is used to calculate the true binder content. The procedure described in Section 5 of SABITA Manual 19 (*Guidelines for the design, manufacture and construction of bitumen-rubber asphalt wearing courses* published by the South African Bitumen Association) was used to determine the correction factor to be used when determining the binder content after the extraction process. A correction factor of 0.8 was calculated.

5.2 Design of CRM OGA Mix

The PSDs and aggregate proportioning that was used during the laboratory evaluation discussed in Section 3.2 were provided to Fulton Hogan.

Table 5.4 contains the requirements as stated in Specification 511, as well as the aggregate properties for 10 mm sized aggregate. Note that the flakiness index in Specification 511 is replaced by the limit in Specification 517, which is 10% lower.

Table 5.4: Crushed aggregate properties for asphalt as required in Specification 511, Table 511.7

Property	Results for 10 mm aggregate	Requirement	Test method
Los Angeles Abrasion Value Granite and other rock types Basalt	20 *	 35% maximum 25% maximum	 WA 220.1 WA 220.1
Flakiness index	21	25% maximum	WA 216.1
Water absorption	0.4	2% maximum	AS 1141 6.1
Wet strength	182	100kN minimum	AS 1141.22
Wet/dry strength variation	14	35% maximum	AS 1141.22
Stripping test value Only applicable to regional plants	2	10% maximum	AS 1141.50
Degradation factor	88	50 minimum	AS 1141.25.2
Secondary mineral content	14	25% maximum	AS 1141.26
Petrographic examination	Suitable	Statement of suitability for use as an asphalt aggregate	

The mineral filler that was used during this project conformed to the requirements of the draft Specification 517 and the results are presented in Table 5.5 and Table 5.6. The Methylene blue value (MBV) contained in the AAPA (2018) pilot specification was determined and is also reported. The MBV is a function of the amount and characteristics of clay minerals present in the test specimen. At this stage it is not recommended to align with AAPA (2018) and include MBV testing as a requirement.

Table 5.5: Combined filler requirements (Table 517.3)

Property	Result	Test Method	Requirement
Voids in dry compacted filler (%)	36.6	AS/NZS 1141.17	≥ 28 and ≤ 45
Apparent density of filler (t/m3)	2.679	AS/NZS 1141.7	Report
Methylene blue value (mg/g)	2.5	AS/NZS 1141.66	≤ 10

Table 5.6: Filler PSD (Table 517.4)

Sieve size (mm)	Result	Percentage passing (by mass)
0.600	100	100
0.300	99	95–100
0.075	86	75–100

Recycled crumb rubber was sourced from Tyrecycle. The crumb rubber supplied was not tested for conformance, as a certificate to state conformance was provided. The crumb rubber that was used during this project conformed to the requirements of the draft Specification 517 (refers to Specification 511 (Main Roads 2017). The results are presented in Table 5.7.

Table 5.7: Properties of crumb rubber as required in Specification 511, Table 511.14

Property	Result	Requirement	Test method
Bulk density	278	< 350 kg/m³	AG:PT/T144 or WA 235.1
Iron or steel content	0%	≤ 0.1% by mass	AG:PT/T143 or WA 237.1
Particle shape	Not reported	Mean of measured particles Maximum 3 mm	AG:PT/T143
Moisture content	0.4	Maximum 1%	AG:PT/T143
Particle size distribution sieve size (mm)	**Percentage passing (by mass)**	**Requirement**	AG:PT/T143 or WA 237.1
2.36	100	100	
1.18	99.7	100	
0.60	76.4	60 minimum	
0.30	26.7	20 maximum	
0.075	1.1	2 maximum	

Fulton Hogan used the aggregate from their supplier to achieve a conforming PSD for the standard PSD limits and alternative PSD target as contained in the trial specification's Table 516.7 (Table 5.8). The alternative PSD reflects the coarser, alternative PSD considered during the laboratory evaluation.

The trial specification does not include any statement on PSD production tolerances. It is not clear if the Specification 504 production tolerances will apply or if the alternative PSD limit column in Table 516.7 (Table 5.8) will apply during production.

Table 5.8: Particle size distribution and binder content (Table 516.7)

Sieve size mm	% Passing by mass		
	10 mm Open Graded Asphalt (standard PSD limits)	10 mm Open Graded Asphalt (alternative PSD target)	10 mm Open Graded Asphalt (alternative PSD limits)
13.20	100	100	100
9.50	90–100	90	85–95
6.70	–	43	38–50
4.75	30–40	27	20–35
2.36	10–16	11	8–14

Sieve size mm	% Passing by mass		
	10 mm Open Graded Asphalt (standard PSD limits)	10 mm Open Graded Asphalt (alternative PSD target)	10 mm Open Graded Asphalt (alternative PSD limits)
1.18	8–14	8	5–11
0.30	4–10	5	2–8
0.075	2–4	3	1–5
Binder content	4.5% ± 0.3% (by percentage mass of total mix)	5.0%	5.0 ± 0.3%

The aggregate, mineral filler, crumb rubber and final mix properties are contained in Appendix E. All properties conformed to the trial specification.

The Marshall method of design was used, using 50 blows per face compaction effort. Table 5.9 summarises the Fulton Hogan design for 10 mm OGA (standard PSD) and 10 mm OGA (alternative PSD).

Table 5.9: Fulton Hogan 10 mm OGA (standard PSD) and 10 mm OGA (alternative PSD) mix design

Sieve size (mm)	10 mm OGA (standard PSD)	10 mm OGA (alternative PSD)
13.2	100.0	100.0
9.5	91.0	90.0
6.7	57.0	55.0
4.75	32.0	28.0
2.36	14.0	12.0
1.18	9.5	8.0
0.6	6.6	5.5
0.3	4.6	4.0
0.15	3.0	2.5
0.075	2.0	2.0
Binder content (BC) (%)	4.5	5.0
Bulk density (t/m^3)	1.959	1.976
Maximum density (t/m^3)	2.504	2.488
Air voids (standard PSD)	21.8	20.6
Voids in mineral aggregate (VMA) (%)	30.9	30.7
Voids filled withbBitumen (VFB) (%)	29.4	32.9
Stability (Marshall) (kN)	4.2	4.4
Flow (Marshall) (mm)	3.5	3.6

The trial specification allows for the use of warm mix additive, but states that:

> At the time of manufacture of the crumb rubber modified binder it shall comply with the requirements of Table 516.2, without inclusion of a warm mix additive, after a reaction time of 60 minutes.

The use of warm mix additive is in line with both TMR, AAPA and international practice, although the use of the additive during the mix design is not clear.

TMR allows the use of a warm mix additive in asphalt on any project as long as the technical specifications are met. MRTS30 (2019) states:

> When using warm mix asphalt additives, the prequalified asphalt contractor (PAC) must provide details of the additive(s) nominated in the mix design submission. In addition, evidence acceptable to the Asphalt Mix Design Registrar that the additive is designed, supplied and has proven performance for the purpose described in this Technical Specification must be provided.

AAPA (2018) states in clause 2.5.3 that the warm mix additive must be included in the asphalt mix design process, but in clause 3.1 states 'Where the proposed mix design incorporates additives listed under Clause 2.1, compliance shall be tested on the mix including these additives'. Clause 2.1 describes aggregate and mineral filler constituents and not warm mix additives.

The AAPA (2018) document builds on the Arizona Department of Transportation (ADOT) *Standard Specifications for Road and Bridge Construction* (2008) and the State of California Department of Transportation (Caltrans) Standard Specifications (2015). ADOT (2008) is silent on the use of warm mix additive during the asphalt mix design process, while Caltrans (2018) states in 39-2.01B(2)(c)

> For HMA with WMA additive technology, produce HMA mix samples for your mix design using your methodology for inclusion of WMA admixture in laboratory-produced HMA.

Whether warm mix additive should be included during the asphalt mix design process should be clarified in an updated version of the trial specification.

5.3 Construction of Demonstration Trial

5.3.1 Hazelmere Plant Trial

Fulton Hogan opted to construct a trial section on their premises at Hazelmere, Perth, on 1 March 2019. This plant trial was conducted to evaluate the workability of the CRM binder with the standard PSD during production and experiment with the rolling sequence and roller settings. Figure 5.3a to d show the plant trial operations.

Figure 5.3: Plant trial constructed at Hazelmere, Perth

a) Truck positioning to commence paving CRM OGA

b) First pull of CRM OGA

c) Second pull of CRM OGA

d) Compacted section of CRM OGA

The CRM binder was manufactured and tested for viscosity after a digestion period of 60 minutes. The production mix contained 0.5% of the warm mix additive, Evotherm®. The viscosity was measured with the Rion viscometer at approximately 175 °C, resulting in 1.6 Pa.s, which was between the required 1.5 to 4.0 Pa.s.

The construction of the CRM GGA trial section as part of WARRIP Project 2019-002 was completed first, which resulted in the construction of the CRM OGA trial three hours after the CRM binder was manufactured. This is within the 10–hour window that CRM binder can be stored at between 165 °C to 190 °C.

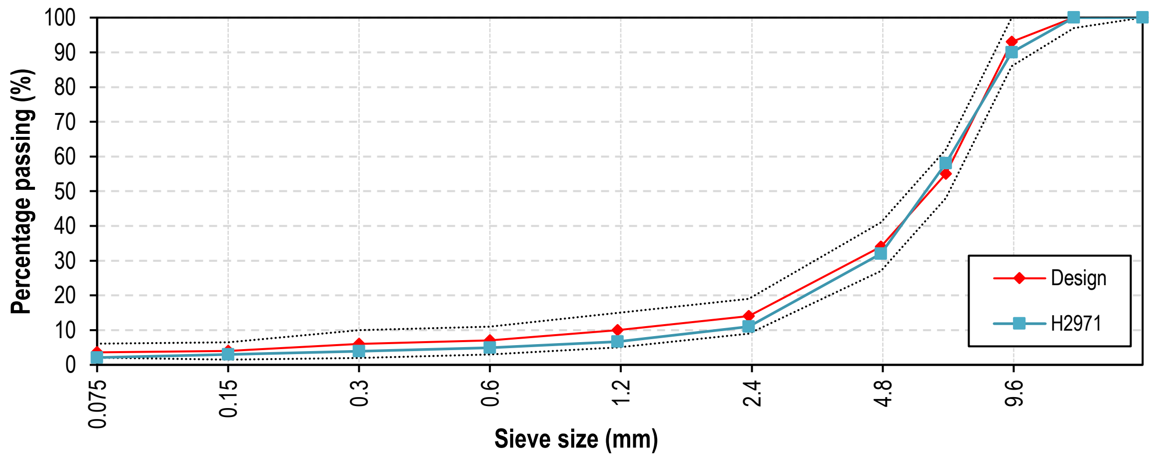
The profiled surface was cleaned, and a CRS170/30 tack coat applied prior to paving.

The CRM OGA mix results from the plant trial are summarised in Table 5.10. The mix contained a warm mix additive and therefore the delivery temperature was required to be between 155 °C to 170 °C. The delivery temperature was reported as 158 °C. The PSD result was within the tolerances from the design PSD. The target binder content was 5.0%, but the result indicated that it was closer to 5.5% after the crumb rubber conversion factor was applied (0.8 as determined during design stage).

Table 5.10: Summary of results from plant trial dated 1 March 2019

Date sampled	1/03/2019	
Asphalt temperature	158	
Compaction temp	148	
Sieve size (mm)	**Result**	**Requirements**
13.2	100.0	100
9.5	90.0	90–100
6.7	58.0	–
4.75	32.0	30–40
2.36	11.0	10–16
1.18	6.7	8–14
0.6	4.9	–
0.3	3.9	4–10
0.15	3.0	–
0.075	2.1	2–4

Date sampled	1/03/2019	
Asphalt temperature	158	
Compaction temp	148	
Sieve size (mm)	**Result**	**Requirements**
Binder content (BC) (%)	4.4	–
CRM BC (0.8 conversion factor) (%)	5.5	–
Bulk density (t/m^3)	1.984	–
Maximum density (t/m^3)	2.466	–
Air voids (standard PSD)	19.6	16–21*
Voids in mineral aggregate (VMA) (%)	29.9	–
Voids filled with bitumen (VFB) (%)	34.6	–
Stability (Marshall) (kN)	4.9	minimum 4 kN
Flow (Marshall) (mm)	3.6	2–4 mm



* Note – the maximum value can be exceeded but the minimum value is mandatory.

Cores were extracted to determine the compaction of the trial section. The compaction results are summarised in Table 5.11. A density requirement of 93% was achieved, with a reported mean of 97.5% compaction. The field core air voids were in line with the design air voids of 21.8%. The targeted layer thickness was 40 mm.

Table 5.11: Compaction results of the trial section paved at the Hazelmere plant trial

Core no.	Thickness (mm)	In situ voids (%)	Field density (t/m^3)	Density ratio (%)
1	47	21.2	1.943	97.9
2	37	21.7	1.932	97.4
3	36	21.5	1.937	97.6
4	33	21.1	1.947	98.1
5	30	24.0	1.875	94.5
6	31	25.7	1.832	92.3
7	39	21.2	1.944	98
8	40	18.0	2.022	101.9
9	39	21.6	1.933	97.4
10	36	19.5	1.985	100.1

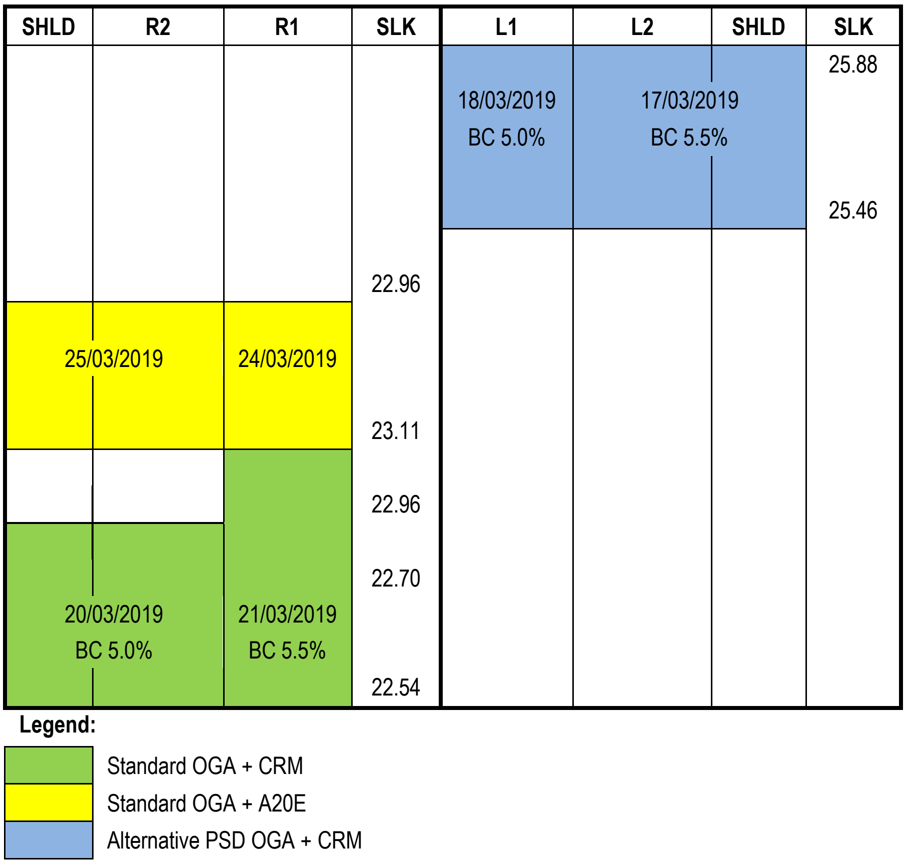
Core no.	Thickness (mm)	In situ voids (%)	Field density (t/m³)	Density ratio (%)
Mean	37	21.5	1.935	97.5
Standard deviation	4.9	2.1	0.052	2.6

5.3.2 Demonstration Trial

A demonstration trial consisting of four CRM OGA sections and a control section was constructed on the Kwinana Freeway, between 17 and 25 March 2019. The sections were located between Russel Road Interchange and Anketell Road Interchange. The lane kilometre and location of the trial sections are shown schematically in Figure 5.4, along with the date of construction and asphalt mix details.

Although the laboratory evaluation indicated that 5.0% binder content was the optimum binder content that resulted in increased air voids, sections with 5.5% binder content were constructed as well. The decision to increase the binder content of the CRM sections to 5.5% was based on results from the Hazelmere plant trial, where the binder content achieved was 5.5%.

Figure 5.4: Schematic of trial section locations on Kwinana Freeway



CRM OGA (alternative PSD)

Figure 5.5 to Figure 5.11 show the CRM OGA (alternative PSD) construction on the night of 17 March 2019.

Figure 5.5: Surface preparation complete on shoulder and L2, SLK 25.46, Kwinana Freeway

Figure 5.6: Spray truck positioning to spray on L2, SLK 25.46, Kwinana Freeway

Figure 5.7 shows the paver only a couple of metres into the lane. The worker pictured on the right of Figure 5.7 can be seen wearing personal monitoring equipment as part of emissions testing that was carried out during the night. This will be reported on in Section 6.

Figure 5.7: Placement of CRM OGA (alternative PSD) commencing on shoulder, SLK 25.46, Kwinana Freeway

Figure 5.8 shows a member of the paving team using a 3 m straight edge to ensure the joint between new and existing pavement surfaces were level.

Figure 5.8: Attention given to level of terminal transfers joint on shoulder, SLK 25.46, Kwinana Freeway

Figure 5.9 shows compaction with a vibrating steel wheel roller of 8 tonnes on the paved asphalt.

Figure 5.9: Compaction with vibrating steel wheel roller of eight tonne mass on shoulder, Kwinana Freeway

Fuming from the truck tipping into the paver can be seen in Figure 5.10. The temperatures at the discharge point were between 165 °C to 170 °C, and although this range is as specified for asphalt with warm mix additive (516.41.3), perceived fuming lead to lowering of the production temperature to 155 °C.

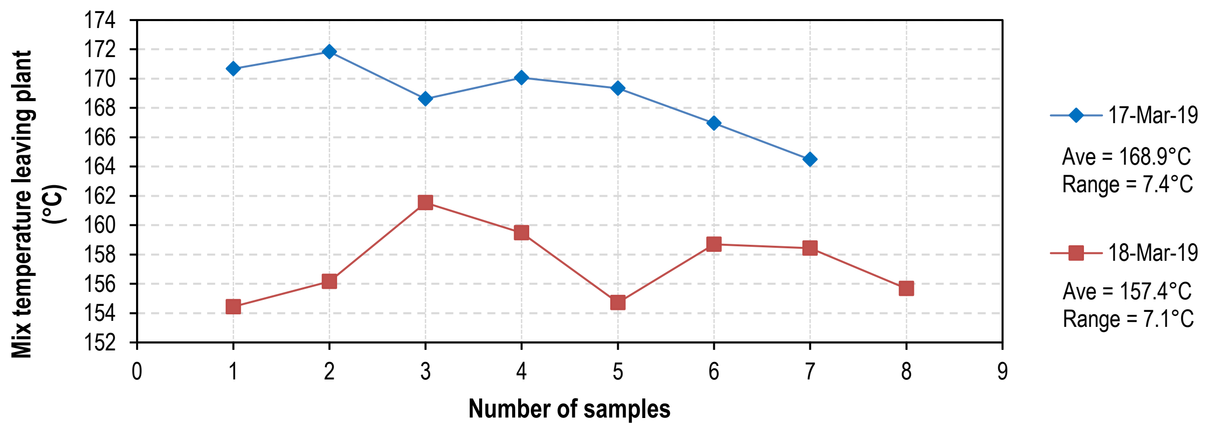
Figure 5.10: Visible fuming when truck loads paver with CRM OGA (alternative PSD) on Kwinana Freeway

Figure 5.11 shows the surface texture of the compacted shoulder CRM OGA with the adjacent lane being paved.

Figure 5.11: Compacted CRM OGA (alternative PSD) on shoulder and uncompacted pull on L2

The temperature of asphalt mix leaving the plant was recorded for each truck. Although Evotherm®, a warm mix technology was included in the CRM OGA (alternative PSD) mix, the production temperatures on 17 March 2019 was still high at an average of 168.9 °C. The inclusion of warm mix technology should enable a reduction in production temperature of 20 °C to 30 °C (West et al. 2014). On 18 March 2019, the average temperature was lower at 157.4 °C. Figure 5.12 shows the temperatures of the asphalt mix leaving for site.

Figure 5.12: CRM OGA (alternative PSD) results – mix temperature leaving plant



The results from the CRM OGA (Alternative PSD) sections are summarised in Appendix F. Figure 5.13 illustrates the resulting PSDs from the samples taken during the demonstration trials on 17 and 18 March 2019.

Figure 5.13: CRM OGA (alternative PSD) results – PSD retrieved

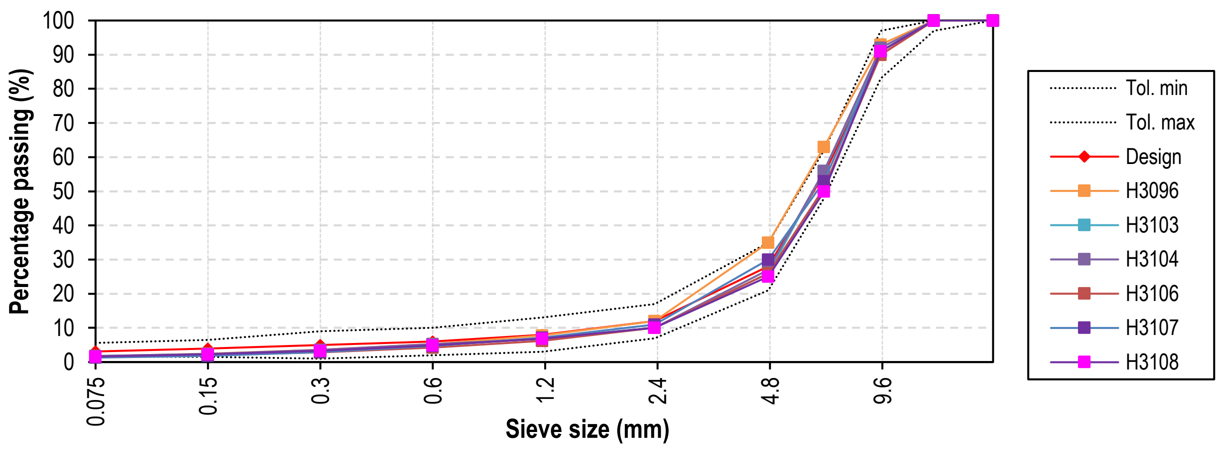


Figure 5.14 and Figure 5.15 illustrate the Marshall air void results compared with the CRM binder content. The correction factor to obtain the CRM binder content was 0.8 as determined during the design. It appears that the target binder content of 5.5% on 17 March 2019 and 5.0% on 18 March 2019 was not fully achieved, with the average binder content 5.2% and 5.3% respectively. The Marshall air voids were within the specification limits and higher than the 16.5% (at 5.5% binder content) reported during the laboratory evaluation.

Figure 5.14: 5.5% CRM OGA (alternative PSD) results – Marshall air voids compared to CRM binder content

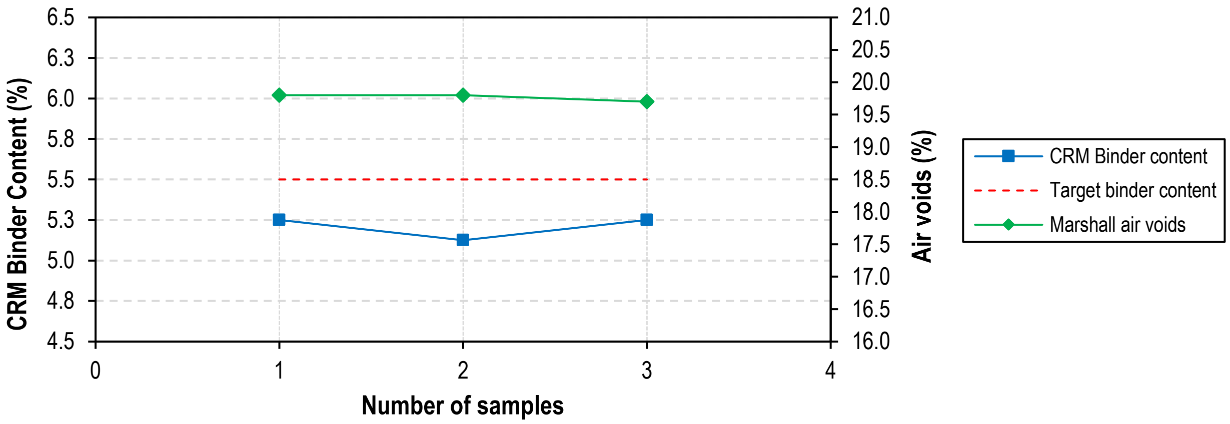


Figure 5.15: 5.0% CRM OGA (alternative PSD) results – Marshall air voids compared to CRM binder content

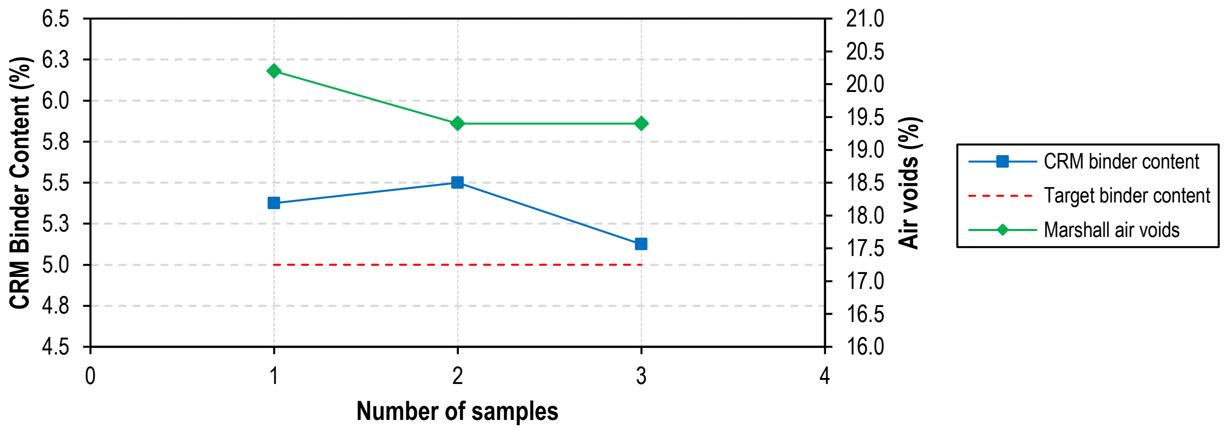


Figure 5.16 summarises the air voids determined from field cores for both the nights on which CRM OGA (alternative PSD) was constructed. The field cores had an average air voids content of 21.4%, ranging between 17.8% and 26.3% for 17 March 2019 and for 18 March 2019 had an average of 21.1%, ranging between 19.3% and 22.7%.

Figure 5.16: CRM OGA (alternative PSD) results – Field core air voids

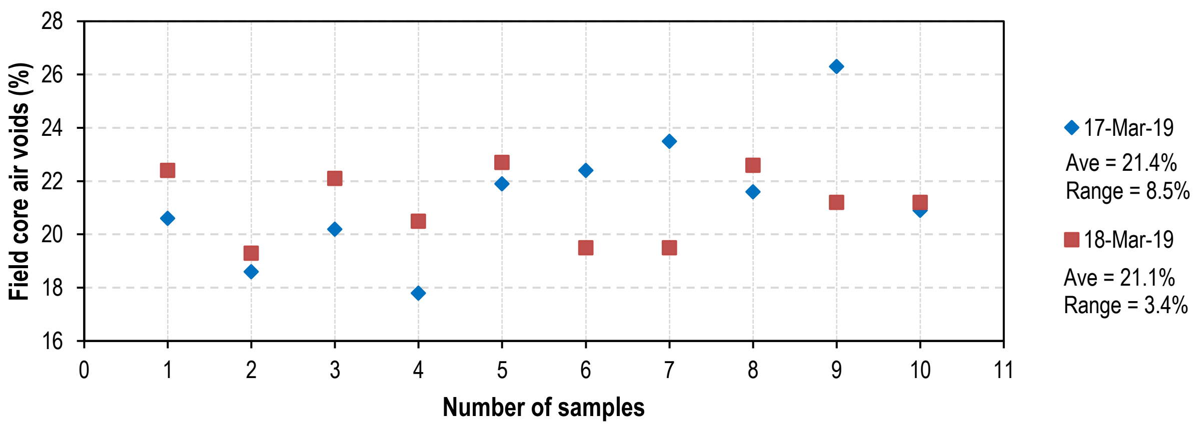
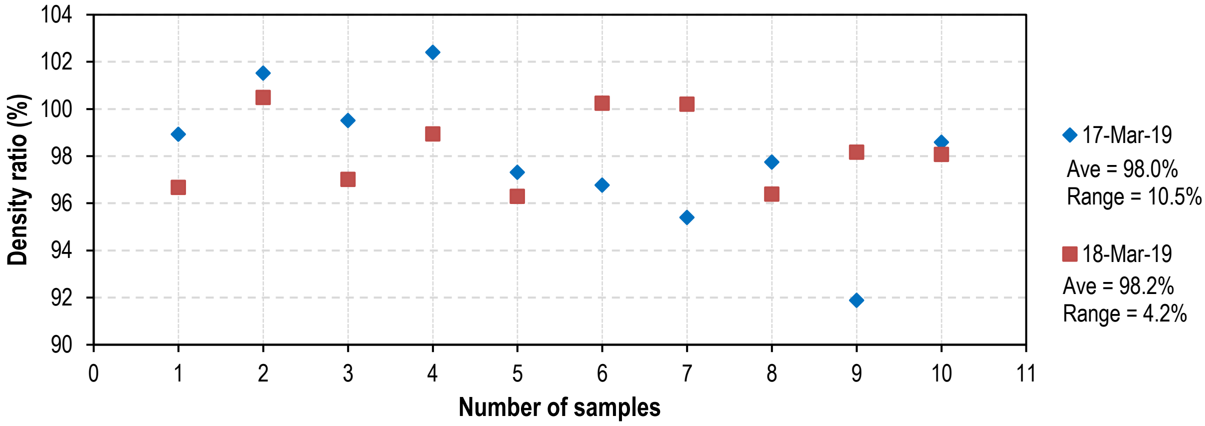


Figure 5.17 summarises the density ratio achieved for both the nights on which CRM OGA (alternative PSD) was constructed. On 17 March 2019, an average of 98.0%, ranging between 91.9% and 102.4% density ratio was achieved. On 18 March 2019, an average of 98.2%, ranging between 96.3% and 100.5% density ratio was achieved. These are above the characteristic percent Marshall density of 93% required.

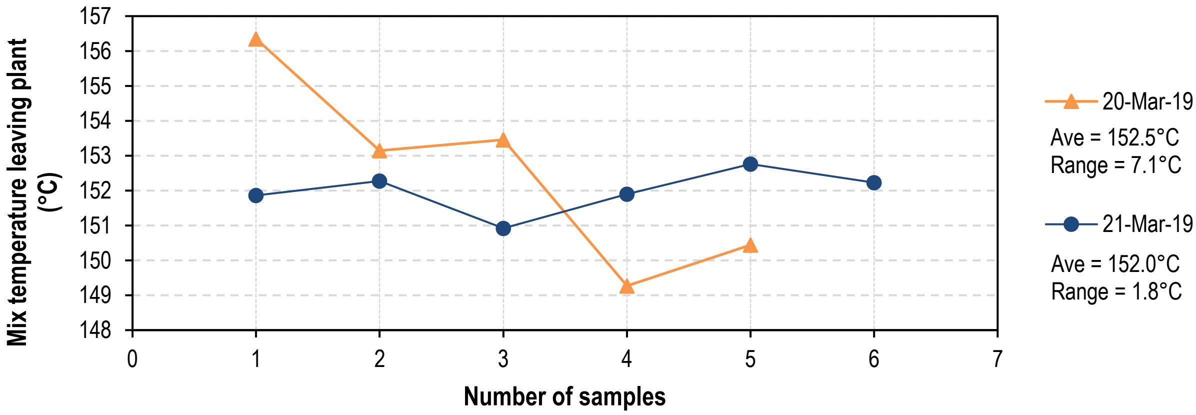
Figure 5.17: CRM OGA (alternative PSD) results – density ratio



CRM OGA (standard PSD)

The temperature of the asphalt mix leaving the plant recorded on 21 March 2019 for CRM OGA (standard PSD) mix, resulted in an average of 152.5 °C. On 22 March 2019, the average temperature was 152.0 °C. Figure 5.18 shows the temperatures of the asphalt mix leaving for the site.

Figure 5.18: CRM OGA (standard PSD) results – Mix temperature leaving plant



The results from the CRM OGA (standard PSD) sections are summarised in Appendix F. Figure 5.19 illustrates the resulting PSDs from the samples taken during the demonstration trials on 20 and 21 March 2019.

Figure 5.19: CRM OGA (standard PSD) results – PSD retrieved

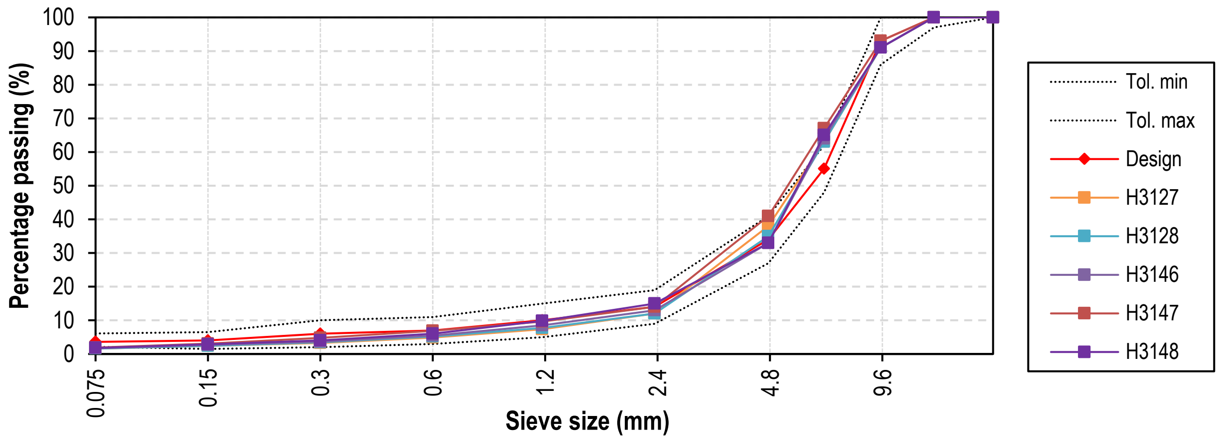


Figure 5.20 illustrates the Marshall air void results compared with the CRM binder content. The correction factor to obtain the CRM binder content was 0.8 as determined during the design. It appears that the target binder content of 5.5% was achieved on both nights and results are within the tolerance of 0.3%. Marshall air voids were higher than the 14.8% (at 5.5% binder content) measured during the laboratory evaluation.

Figure 5.20: 5.5% CRM OGA (standard PSD) results – Marshall air voids compared to CRM binder content

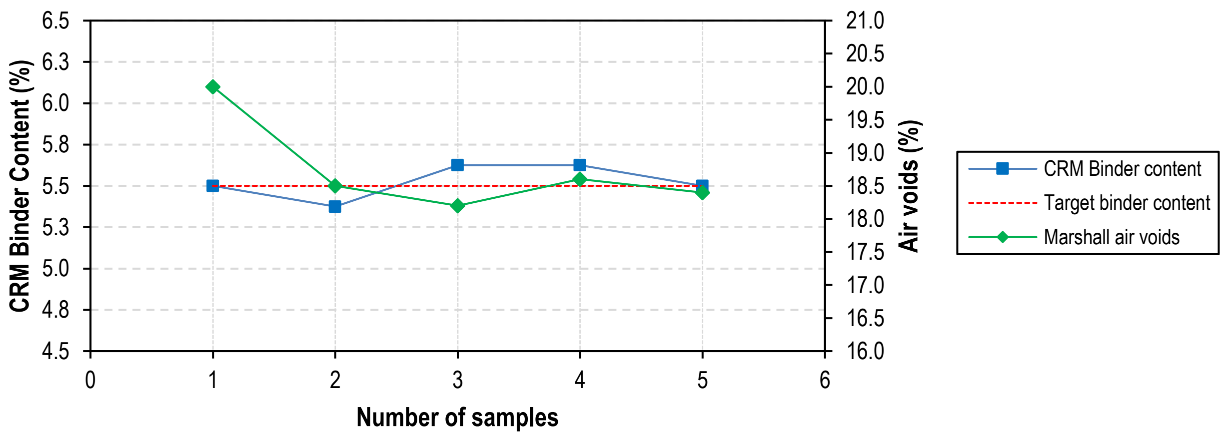


Figure 5.21 summarises the air voids determined from field cores for both the nights on which CRM OGA (standard PSD) was constructed. The average field core air voids were 22.1%, ranging between 20.7% and 23.2% for 20 March 2019. On 21 March 2019, the average field core air voids were 19.7%, ranging between 16.4% and 22.0%.

Figure 5.21: CRM OGA (standard PSD) results – field core air voids

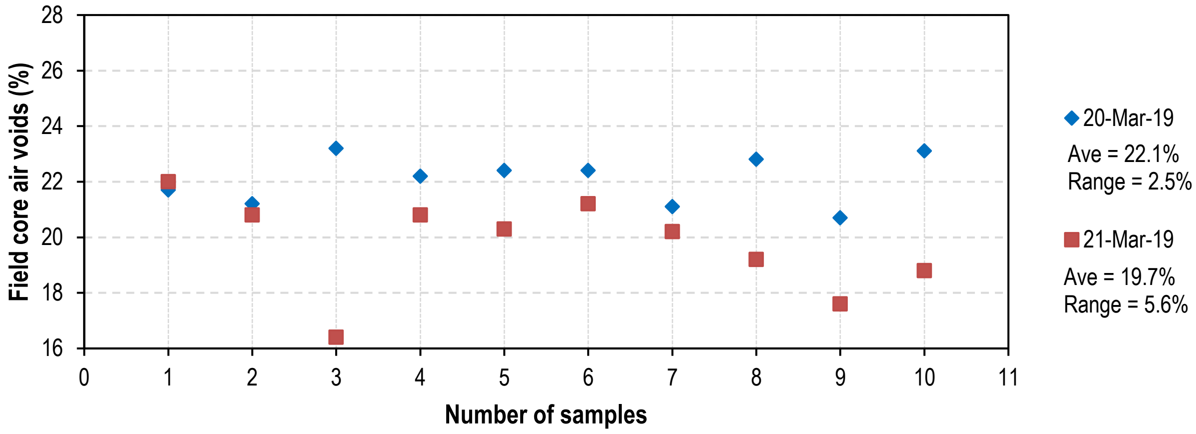
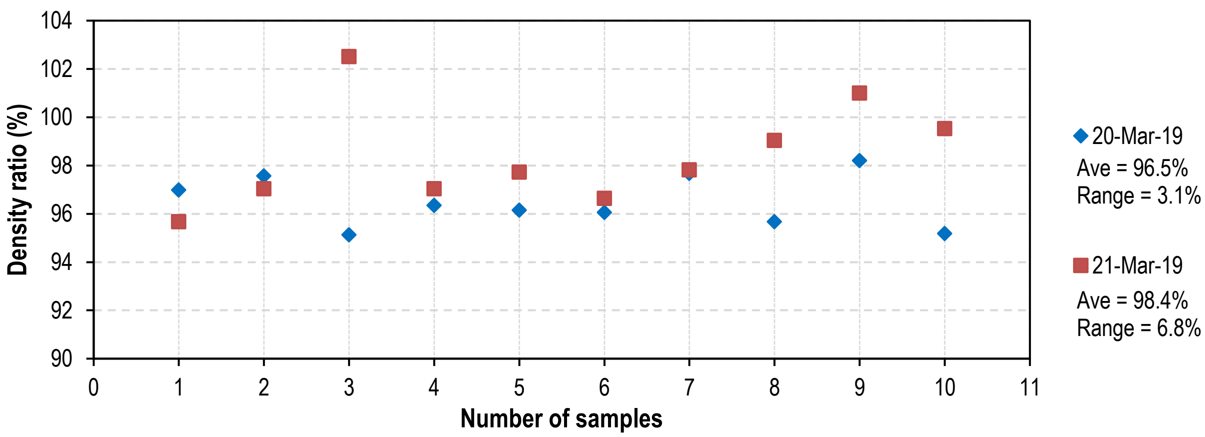


Figure 5.22 summarises the density ratio achieved for both the nights on which CRM OGA (standard PSD) was constructed. On 20 March 2019, an average of 96.5%, ranging between 95.1% and 98.2% density ratio was achieved. On 21 March 2019, an average of 98.4%, ranging between 95.7% and 102.5% density ratio was achieved. These are above the characteristic percent Marshall density of 93% required.

Figure 5.22: CRM OGA (standard PSD) results – density ratio



Standard OGA

The results from the OGA (standard PSD, A20E) sections are summarised in Appendix F. Figure 5.19 illustrates the resulting PSDs from the samples taken during the demonstration trials on 24 and 25 March 2019.

Figure 5.23: OGA (standard PSD, A20E) results – PSD retrieved

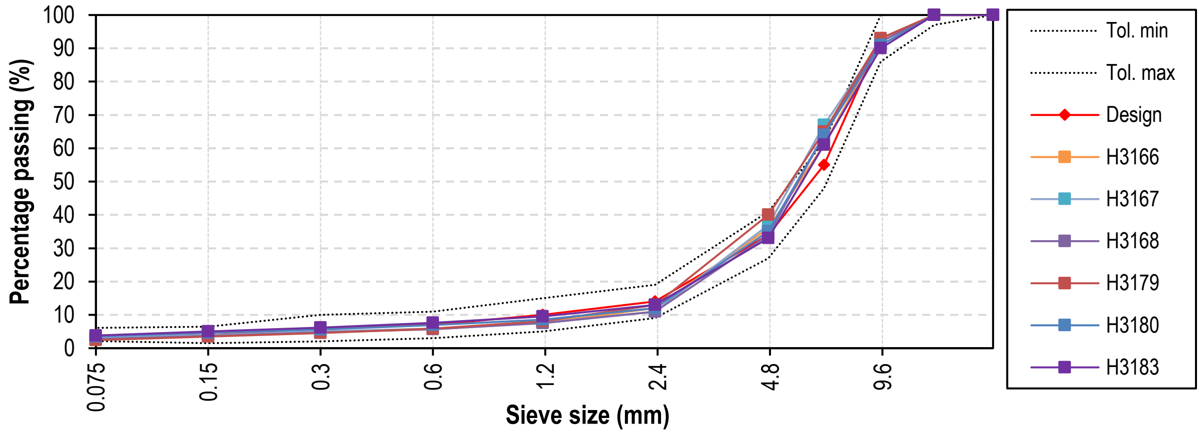


Figure 5.24 illustrates the Marshall air void results compared with the A20E binder content. It appears that the target binder content of 4.5% was generally on the lower end of the specification. Marshall air voids were higher than the standard measured during the laboratory evaluation.

Figure 5.24: OGA (standard PSD, A20E) results – Marshall air voids compared to CRM binder content

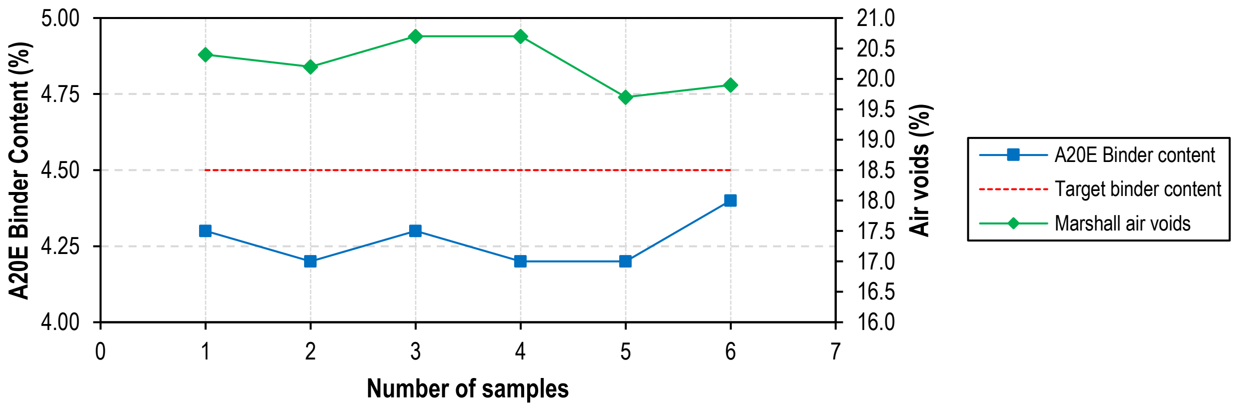


Figure 5.25 summarises the air voids determined from field cores for all three nights on which OGA (standard PSD, A20E) was constructed. The field core air voids for 24 March 2019 averaged 21.3%, ranging between 20.1% and 23.9%. On 25 March 2019, average field core air voids of 22.1%, ranging between 19.9% and 24.9% were reported.

Figure 5.25: OGA (standard PSD, A20E) results – field core air voids

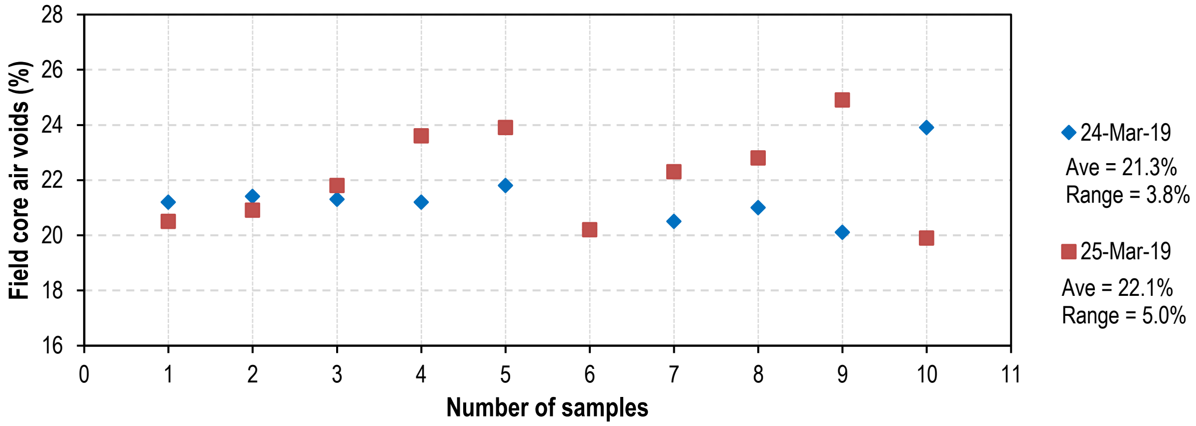
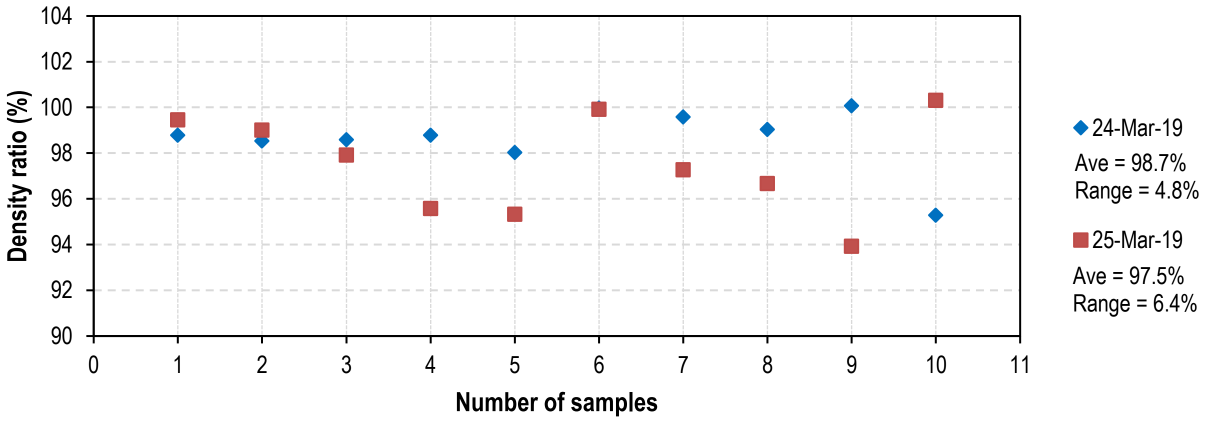


Figure 5.26 summarises the density ratio achieved for both the nights on which OGA (standard PSD, A20E) was constructed. On 24 March 2019, an average of 98.7%, ranging between 95.3% and 100.1% density ratio was achieved. On 25 March 2019, an average of 97.5%, ranging between 93.9% and 100.3% density ratio was achieved. These are above the characteristic percent Marshall density of 93% required.

Figure 5.26: OGA (standard PSD, A20E) results – density ratio



5.4 Comparison of OGA Results (2018-19 Surfacing Season)

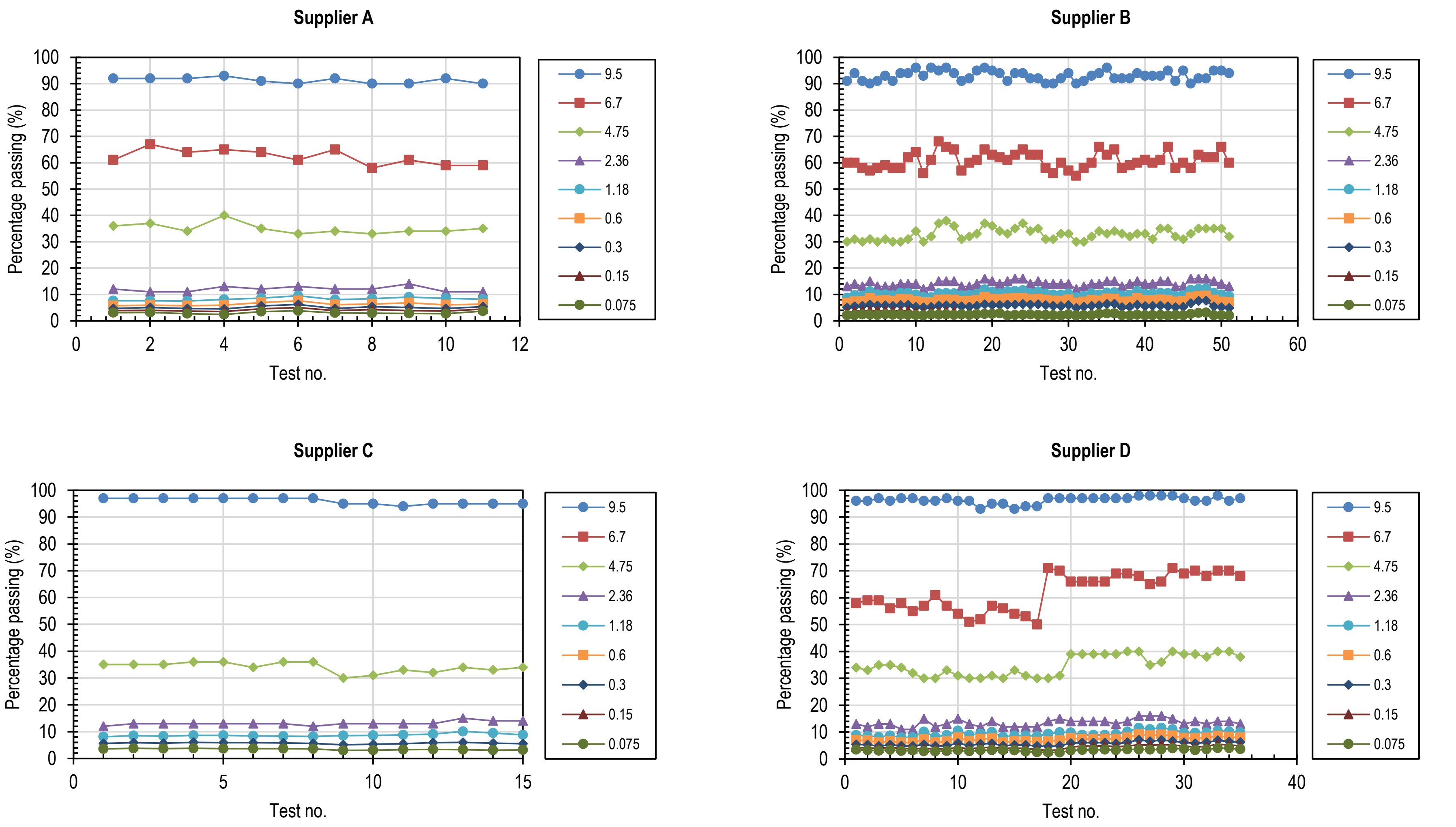
Four suppliers' 10 mm OGA wearing course results, with A20E binder, were evaluated to determine whether the air voids reported during the mix design process (Section 5.2) and those achieved during the demonstration trial (Section 5.3.2) were higher than that achieved in general.

Note that for two suppliers limited data sets were made available, with Supplier A represented by 11 data sets and Supplier C by 15 data sets. This lack of data may skew statistical representation of the results.

5.4.1 PSD

Figure 5.27 compares the 10 mm OGA PSD from the four suppliers. This indicates that all four suppliers generally produced a similar OGA mix, apart from Supplier D, which seems to have adjusted the mix design, by increasing percentage passing all sieve sizes, mid-surfacing season.

Figure 5.27: Comparison of OGA mix PSD of Perth suppliers.

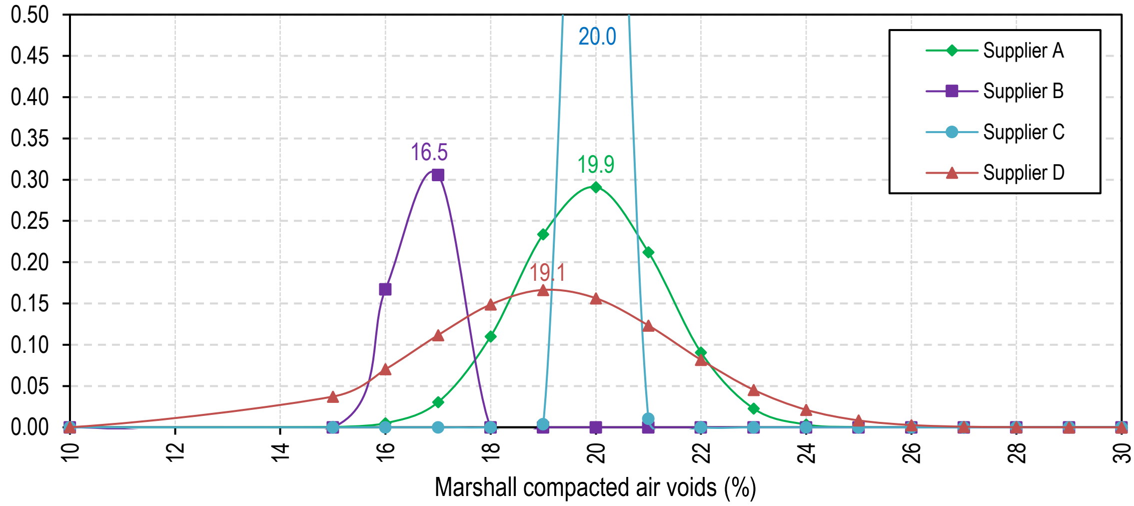


5.4.2 Marshall Compacted Air Voids

The reported air voids determined from the quality assurance testing on laboratory compacted specimens, using Marshall compactive effort of 75 blows, were evaluated.

The concept of probability density functions (PDFns) were used (Cromhout 2018) to evaluate the reported results. The variation in reported air voids derived from laboratory compacted samples for the four suppliers is shown in Figure 5.28.

Figure 5.28: PDFns of the Marshall compacted air voids reported by suppliers



The first aspect of the PDFns observed is the peakedness or flatness of the PDFns. With a high peak, it implies the average or median values have relatively low standard deviation around that value and the results therefore do not have large outlier extremes on the ends of the normal curve. If flat with a low peak, it implies the average or median values have relatively large standard deviations with high percentages or probabilities for values to occur on the extremes of the PDFn. Note that it may also reflect the limited data sets used in the analysis.

It can also be observed from Figure 5.28 that Suppliers A, C and D reported laboratory air voids generally higher than Supplier B. The average or median value of each supplier is indicated on the graph. The design air voids are specified in Specification 504 (Main Roads 2017a) to be between 16% and 21%. Supplier B and Supplier C's data has lower standard deviations around the average value.

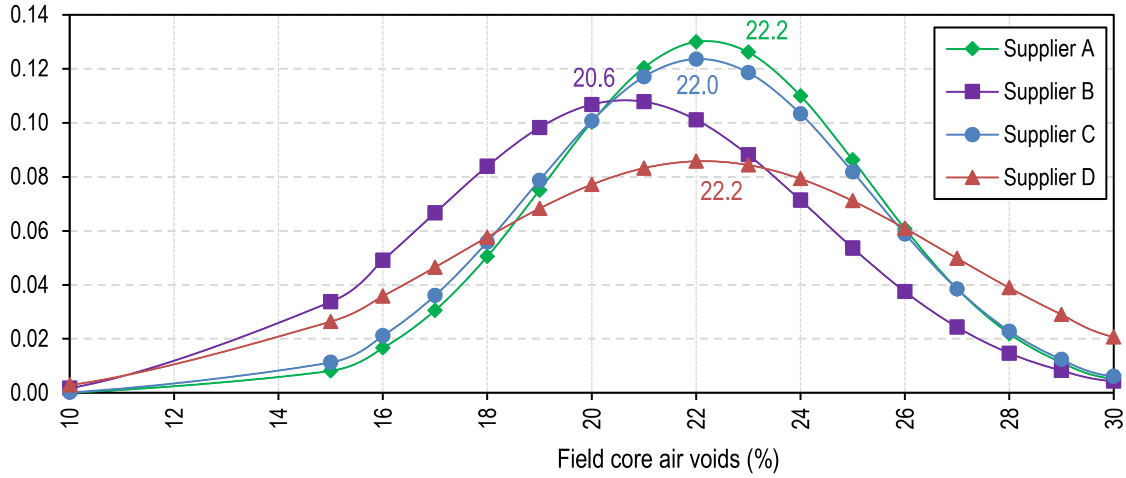
The reported higher laboratory air voids are consistent with the laboratory air voids reported in Section 5.2, although design air voids were determined after 50 blows (Specification 516 (Main Roads 2018b)) and not 75 blows (Specification 504 (Main Roads 2017a)).

5.4.3 Field Core Air Voids

The same method was used to evaluate the reported field core air voids from the quality assurance testing conducted by the four suppliers. Figure 5.29 shows the PDFns of the reported field core air voids of the four suppliers. The average or median value of each supplier is indicated on the graph.

The peakedness of the PDFns of the suppliers are closer to one another than for the Marshall compacted air voids, with all four suppliers showing a similar normal curve with larger standard deviation around the average or median. Suppliers A, C and D reported field core air voids generally higher than Supplier B.

Figure 5.29: PDFns of the field core air voids reported by suppliers



The reported field core air voids are consistent with the field core air voids reported in Section 5.3.2 during the demonstration trial.

6 EMISSION MONITORING

As discussed in Section 2.3.1, one of the major concerns that has been consistently raised since the introduction of crumb rubber to asphalt mixes at high temperatures is that it may lead to increased hazardous emissions, which may have an adverse effect on the health of production staff at asphalt plants and road workers. The use of warm mix additives aim to result in lower emissions, whilst also increase the workability of the mix.

As reported in Section 0, production temperatures on the night of 17 March 2019 ranged between 164.5 °C and 171.8 °C. These recorded temperatures are in the general hot-mix asphalt production temperature range, thus not making use of the warm mix additive in the mix to its full potential. Figure 6.1 shows visible fuming when a load of CRM OGA was tipped into the paver on the night of 17 March 2019. In general, fuming was observed on each night of CRM OGA paving.

Figure 6.1: Visible fuming with load of mix tipped into paver (1st truck on site)

6.1 Worker Details and Measured Analytics

Three of Fulton Hogan's staff were fitted with personal exposure monitoring devices on the night of 17 March 2019. Emission Assessments Pty Ltd conducted the Ambient Air and Occupational Hygiene Monitoring. The staff selected were those deemed to be in closest contact with the asphalt mix during construction, namely the truck controller, paver operator and leading hand at the screed.

During the demonstration trial, the following samples were taken:

- Inhalable dust – personal exposure monitoring through static sampling attached to the worker's shirt lapel.
- Volatile organic compound (VOC) emissions – personal exposure monitoring through static sampling attached to the worker's shirt lapel and for the static sampler (ambient), a canister open to the atmosphere was used.
- Polycyclic aromatic hydrocarbon (PAH) emissions – personal exposure monitoring through static sampling attached to the worker's shirt lapel.

Sampling was undertaken in accordance with:

- Australian Standard AS 3640-2009 Workplace atmospheres – *Method for sampling and gravimetric determination of inhalable dust*
- NIOSH Method 2549 Issue 1: (1996) *Volatile Organic Compounds Screening*
- NIOSH Method 5506 Issue 3: (1998) *Polynuclear Aromatic Hydrocarbons.*

6.2 Results of Monitoring

The results have been assessed according to *Occupational Safety and Health Regulations 1996* WA Regulation 3.37 (a) and (b) for atmospheric contaminants and against the exposure standards in *the Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment (NOHSC:1003, 1995b*). The results were reported by Emissions Assessment in Report Number 11819-170, contained in Appendix H.

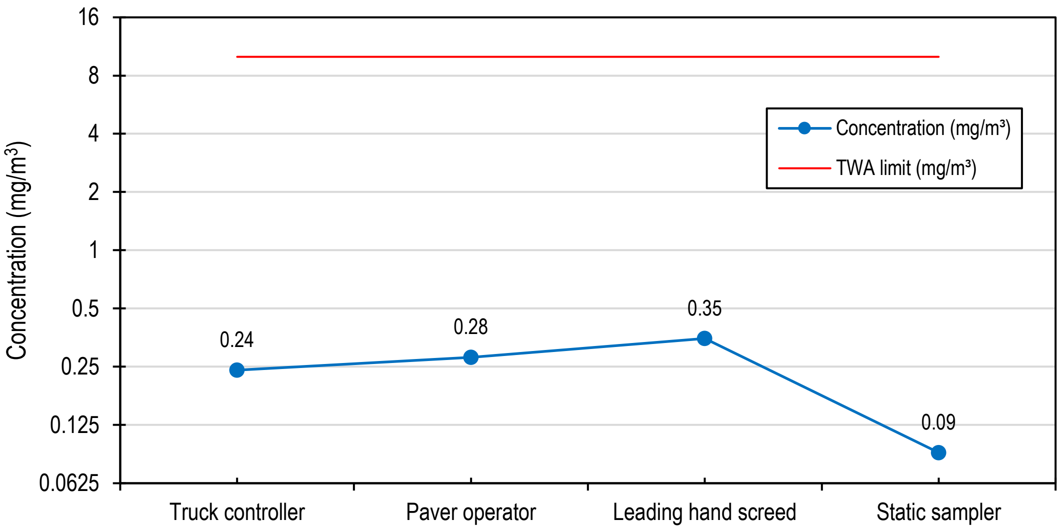
Exposure standard means an airborne concentration of a particular substance in the worker's breathing zone, exposure to which, according to current knowledge, should not cause adverse health effects nor cause undue discomfort to nearly all workers. The exposure standard in this instance was reported in time-weighted average (TWA) in milligrams of substance per cubic metre of air at 25 °C and one atmosphere pressure (mg/m^3) (NOHSC:1003, 1995b).

Weather conditions during the monitoring period were approximately 22 °C with 58% relative humidity.

6.2.1 Results of Inhalable Dust Monitoring

Figure 6.2 shows the results of the personal exposure monitoring of inhalable dust. Results are well below the maximum limit of 10 mg/m^3.

Figure 6.2: Results of personal exposure monitoring inhalable dust



6.2.2 Results of Volatile Organic Compounds (VOCs) Monitoring

Table 6.1 summarises the results of the personal exposure monitoring of VOCs. The table only contains reportable compounds, the full list of compounds measured is contained in Appendix H. The levels of compounds measured are well below the limit.

Table 6.1: Results of personal exposure monitoring VOCs

Compound	Truck controller	Paver operator	Leading hand screed	Static sampler	Limit[1]
m and p Xylenes (ug/m^3) [2]	167	104	93	66	350 000
1,2,4 Trimethylbenzene (ug/m^3) [2]	48	119	41	43	37 000

1 NOHSC:1003 (1995).
2 1 ug/m^3 = 0.001 mg/m^3.

6.2.3 Results of Polycyclic Aromatic Hydrocarbon (PAH) Monitoring

Table 6.2 summarises the results of the personal exposure monitoring of PAHs. The table only contains reportable compounds, the full list of compounds measured is contained in Appendix H. The levels of compounds measured are well below the limit.

Table 6.2: Results of personal exposure monitoring PAHs

Compound	Truck controller	Paver operator	Leading hand screed	Static sampler	Limit[1]
Naphthalene (ug/m^3) [2]	1.3	1.9	1.3	1.9	52 000

1 NOHSC:1003 (1995).
2 1 ug/m^3 = 0.001 mg/m^3.

6.3 Conclusion of Emission Assessments Monitoring

Emission Assessments Pty Ltd concluded the following:

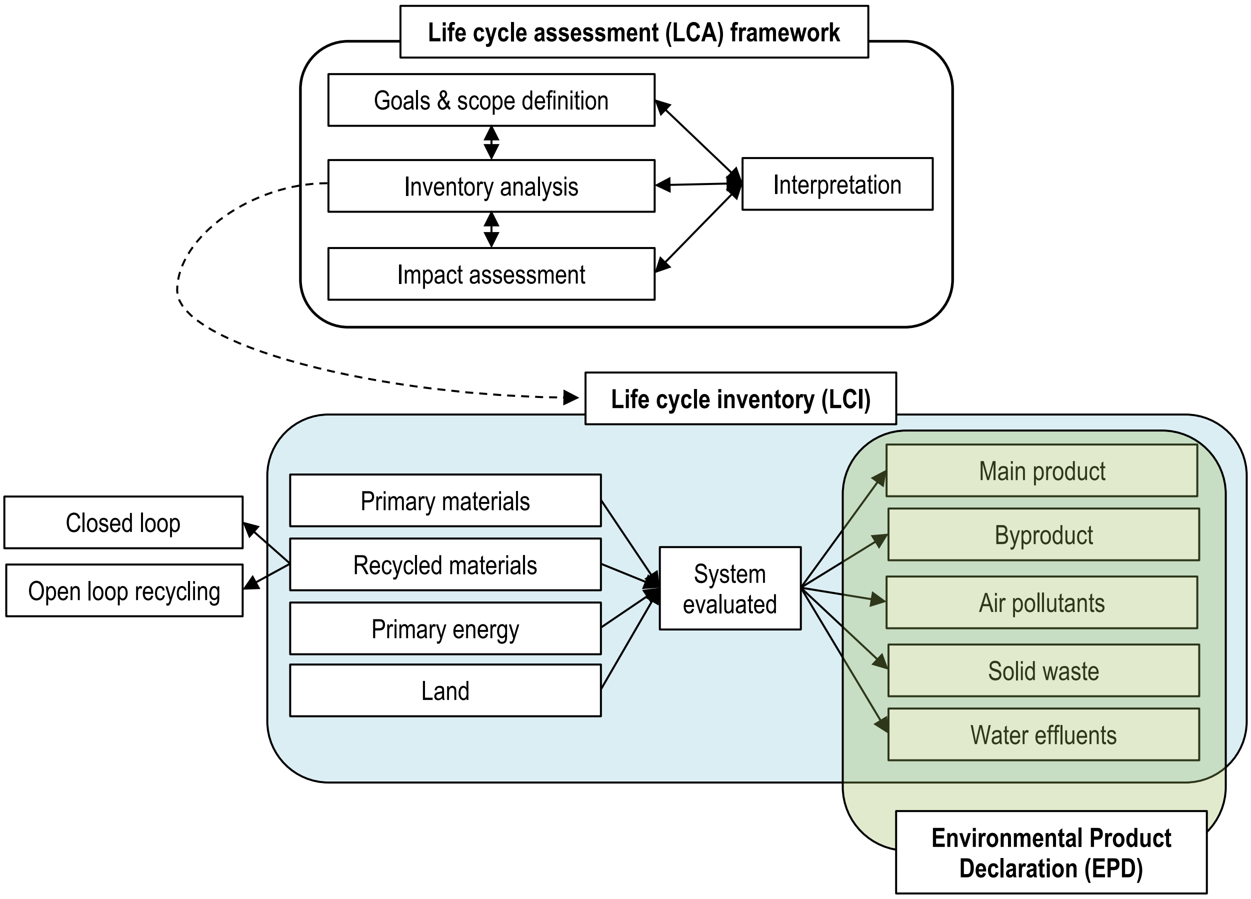
> The results of the Occupational Hygiene Survey would indicate the levels of airborne contaminants at the work site are being adequately controlled with regard to the impact on the workers' personal exposure.

7 SUSTAINABILITY ASSESSMENT

7.1 Sustainability and Life Cycle Assessment (LCA)

The generally accepted definition of sustainable development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs (United Nations General Assembly 1987). Life Cycle Assessment (LCA) is a globally accepted methodology for evaluating sustainability of products or services. Life cycle inventory (LCI) data is used to assess the impact of the product or service (Saboori, Harvey and Jones 2015). Some industries promote the development of Environmental Product Declarations (EPDs), which summarise the LCI related to the product or service to use in evaluation of LCAs. Figure 7.1 summarises the LCA framework and LCI data's part in the process.

Figure 7.1: LCA framework and LCI breakdown.



Source: Saboori and Jones (2015).

As part of WARRIP Project 2017-001, *Development of specifications and technical guidelines for warm mix asphalt*, sustainability tools, carbon calculator tools, environmental product declarations and life cycle inventory databases were evaluated and discussed in detail. A WA Carbon Savings Estimation Tool was developed using the principles of LCA with data provided by an Australian asphalt supplier, the AusLCI database and general values reported in NCHRP studies (West et al. 2014).

7.2 WA Carbon Savings Estimation Tool

To estimate the reduction in carbon emissions that may result from producing asphalt mixtures containing CRM binder and at lower temperatures, containing warm mix additives, a comparison between reported Australian asphalt supplier data, the AusLCI database and NCHRP (West et al. 2014) findings were considered.

The combinations of asphalt layer and CRM binder and/or warm mix additives are summarised in Table 7.1. Furthermore, the emissions and energy assumptions used for calculations are presented in Table 7.2.

Table 7.1: Asphalt layer configuration used for evaluation

Pavement layer	Quantity (kT)	Temperature reduction (°C)
OGA (10 mm nominal size aggregate) + no WMA	10*	0
OGA (10 mm nominal size aggregate) + WMA	10*	20
OGA (10 mm nominal size aggregate) + no WMA + 18% CR	10*	0
OGA (10 mm nominal size aggregate) + WMA + 18% CR	10*	20

*10 kT assumed for comparative purposes.

Table 7.2: Emissions and energy assumptions for calculations

Category	Value	Reference
Energy savings (GJ/tonne/Δ°C)	0.00375 0.0023	Australian asphalt supplier data West et al. (2014)
Emissions from HMA standard mix (CO_2e/kg)	6.48	ISCA (2019)
Natural gas consumption asphalt plant HMA (MJ/tonne)	454.00 300.00(3)	Australian asphalt supplier data AusLCI (n.d.)
Emissions from natural gas distributed in pipeline, CO_2, CH_4 and N_2O (CO_2e/GJ)	51.53	DEE (2016)
Diesel consumption asphalt plant HMA (MJ/tonne)	8.49	AusLCI (n.d.)
Emissions for diesel oil, CO_2, CH_4 and N_2O (CO_2e/GJ)	70.20	DEE (2016)
Electricity consumption asphalt plant HMA (kWh/tonne)(1)	6.00	AusLCI (n.d.)
Emissions for electricity consumption (CO_2e/kWh)	0.72	DEE (2016)
Emissions for lime production (CO_2e/tonne)	675	DEE (2016)
Correction factor for the production of hydrated lime(2)	0.97	EPA (2009)
Emissions from crumb rubber asphalt production (CO_2e/kg)	2.16	IERE (2009)

1 With a +/- 100% variation between plants.
2 Assuming 90% of hydrated lime produced is lime with a water content of 90%.
3 With a +/- 60% variation between plants.

Emissions savings calculated are presented in Figure 7.2 and Figure 7.3. The calculated reduction in emissions, using the assumptions presented in Table 7.2, for asphalt using warm mix additives is between 2% and 4%. However, when CRM binder is used in the asphalt, the reductions in emissions range between 43% and 47%. When both warm mix additives and CRM binder is used in the asphalt, the reductions in emissions range between 45% and 49%.

Figure 7.2: Emissions from evaluated combinations

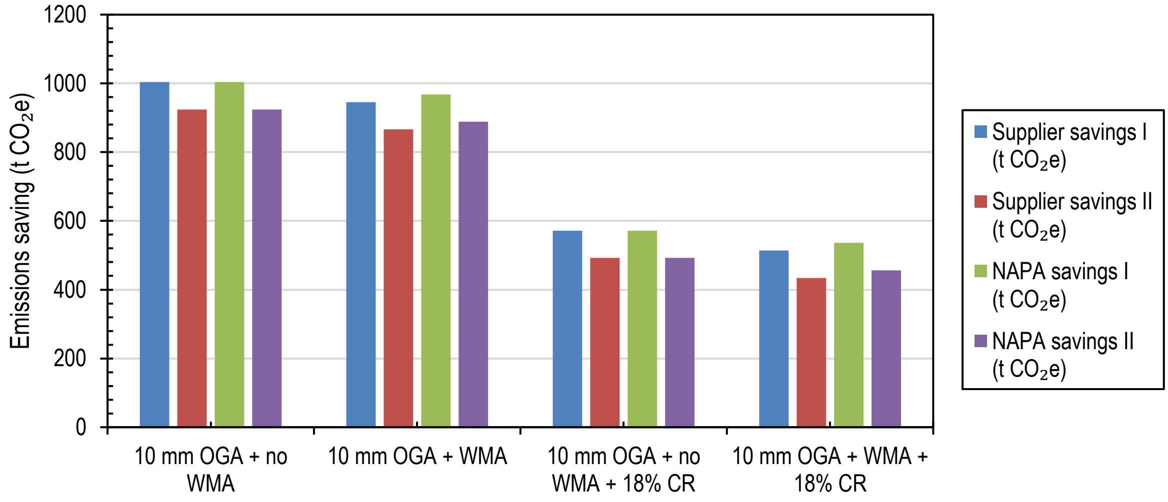
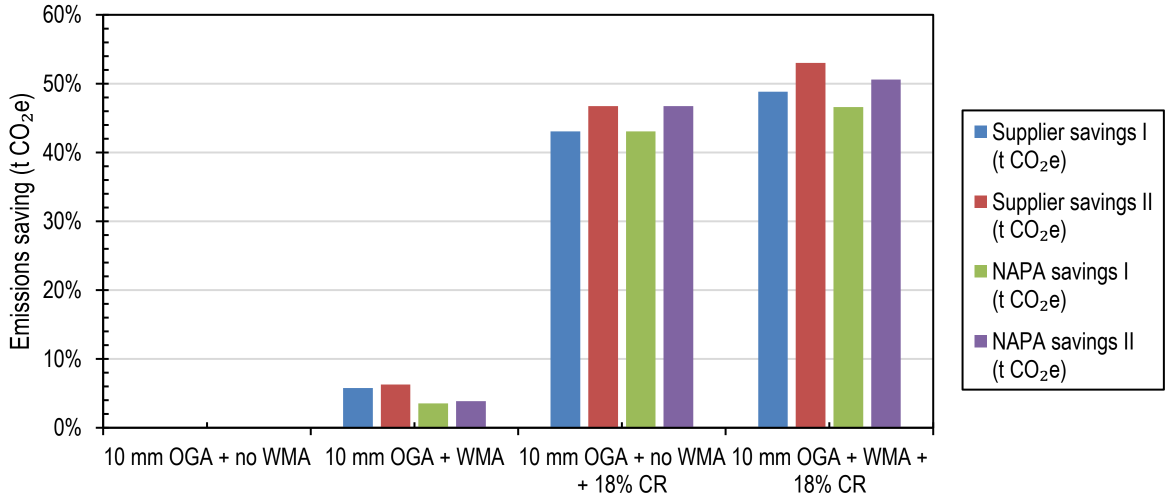


Figure 7.3: Emissions saved compared to 10 mm OGA (standard PSD, A20E)



The range of reductions in emissions is as a result of the varying data sources used for the calculation. It is important to note that the effect of different WMA additives was not considered in the analysis, instead a temperature reduction of 20 °C was used as the baseline temperature reduction.

8 COMPARATIVE ‘SPLASH & SPRAY’ STUDY

8.1 Background

Pilkington defined splash as ‘the mechanical action of a vehicle’s tire forcing water out of its path. Splash is generally defined as water drops greater than 1.0 mm in diameter, which follow a ballistic path away from the tire’ and spray as being formed ‘when water droplets, generally less than 0.5 mm in diameter and suspended in the air, are formed after water has impacted a smooth surface and been atomized’ (Flintsch et al. 2012).

Splash and spray cause a significant nuisance to motorists, and, under some conditions, can cause a momentary loss of visibility. Accident studies on this topic agree that there is a small but measurable increase in accident risk related to splash and spray (FHWA 2014).

Factors influencing splash and spray are water film thickness (determined by geometry, pavement texture and rain intensity) and vehicle characteristics such as speed, tire properties, tire/road interaction, vehicle loading and aerodynamics and spray suppression devices (Flintsch et al. 2012)

Measurement of splash and spray can be through collection or optical methods. Optical methods include contrast change, light attenuation, subjective observation and occlusion (FHWA 2014).

As described in this report, a CRM binder was used in an OGA. OGA is used in WA to reduce noise and improve drainage, i.e. reduce splash and spray.

Due to the timing of the construction of the demonstration trial outside of the WA rainfall season, a subjective observation measurement could not be completed at the time of reporting.

8.2 FHWA Splash and Spray Assessment Tool

The *Splash and spray assessment tool development program* (FHWA 2014) included a subjective observation study, which could be used in future to assess splash and spray perceptions. Table 8.1 contains the questionnaire matrix.

Table 8.1: Splash and spray questionnaire matrix

1.	How obstructed was your view of the vehicle ahead?						
	1	2	3	4	5	6	7
	Very little						Very much
2.	How much concentration would this driving condition require?						
	1	2	3	4	5	6	7
	Very little						A lot
3.	How confident would you feel in this driving condition?						
	1	2	3	4	5	6	7
	Not confident						Very confident
4.	How much control do you feel you would have in this driving condition?						
	1	2	3	4	5	6	7
	Very little						A lot
5.	How risky would it feel to drive in this condition?						
	1	2	3	4	5	6	7

Not risky	Very risky

Responses are then rated by obstruction, concentration, confidence, control and risk.

9 CONCLUSIONS

The use of CRM binder in high-performance sprayed seals has been routine practice in Western Australia (WA) for over 30 years. However, widespread utilisation has been restricted by placement issues such as fume generation. The use of CRM binder for asphalt materials has not been previously investigated in WA. Internationally, the use of CRM binder in open-graded asphalt (OGA) and gap-graded asphalt (GGA) is accepted practice, with utilisation in dense-graded asphalt (DGA) less established.

Main Roads currently specifies the use of Austroads class S45R binder, containing crumb rubber for sprayed seal applications.

A review of literature and current practice indicated the following, addressing some Main Roads concerns with the technology:

- National and international literature indicates that the utilisation of crumb rubber is a high-value, sustainable reuse of tyre waste that can benefit the environment and improve the performance of seals and asphalt.
- International literature indicates that the use of CRM binder can be successfully combined with WMA technologies. This was indicated to address one of the main barriers to implementation, namely emissions and worker health.
- Research conducted through the NACoE program, in conjunction with TMR, shows that CRM binder can be successfully used in OGA. The research through NACoE also included the development of a supplementary specification and construction of a trial section.
- Review of selected international practice indicated that the manufacturing, mix design and construction of CRM asphalt generally follows the same principles, although the specification values for each property may vary between each jurisdiction.

A laboratory evaluation at ARRB's Vermont South laboratory, included the development of a CRM binder that conforms to the supplementary specification PSTS112 *Crumb rubber modified open grade asphalt surfacing* (TMR 2016) and subsequently to AAPA's *Crumb rubber modified open graded and gap graded asphalt model specification* (2018).

A CRM binder with crumb rubber content of 18 and 20 parts, as well as 18% by mass of total binder was developed at ARRB's laboratory. The binder complied to the AAPA (2018) specification and, apart from viscosity at 90 and 120 minutes reaction time, to PSTS112 (TMR 2016).

Using materials supplied by a local Perth supplier, an OGA mix conforming to Main Roads' Specification 504 *Asphalt Wearing Course* (Main Roads 2016) was designed. Laboratory mixes were prepared with the standard binder specified (i.e. A20E polymer modified binder, and the CRM binder. Laboratory results indicated that the A20E polymer modified binder could be replaced with 18% CRM binder at 0.5% higher binder content.

A coarser PSD compared to the conforming mix was also investigated to assess if the air voids could be increased, while using the 18% CRM binder. Based on the laboratory results, the coarser and optimised PSD did result in an increase in air voids of approximately 2%, also at a mix binder content of 5.0%.

The demonstration trial undertaken as part of this project consisted of the following sections:

1. Specification 504 conforming OGA with 4.5% A20E binder content

2. Specification 504 conforming OGA with 5.0% CRM binder content (18% crumb rubber)
3. Coarser OGA with 5.0% CRM binder content (18% crumb rubber).

For the purpose of the demonstration trial, Main Roads developed Draft Specification 516 *Crumb Rubber Open Graded Asphalt*. This document builds on information contained in:

- Queensland Department of Transport and Main Roads (QTMR) 2016. *Crumb rubber modified open graded asphalt surfacing*, Supplementary Specification PSTS112, June 2016, Version 3.
- Australian Asphalt Pavement Association (AAPA) 2018. *Crumb Rubber Modified Open Graded and Gap Graded Asphalt Pilot Specification,* Version 1.0, June 2018.
- Main Roads Western Australia 2017. *Specification 504 Asphalt Wearing Course.*
- Main Roads Western Australia 2017. Specification 511 Materials for Bituminous Treatments.

Fulton Hogan was the industry partner that conducted the design, production and construction of the crumb rubber open grade demonstration trial. Fulton Hogan was also the industry partner on WARRIP Project 2019-002: *Transfer of appropriate crumb rubber modified bitumen technology to WA – Stage 2*, which focussed on CRM GGA. This project and the latter reached the demonstration trial phase simultaneously and the binder was developed for both to contain 18% crumb rubber. The developed binder complied with all the draft specification requirements.

The draft specification called for the Marshall design method to be used. Standard PSD OGA and alternative PSD OGA mixes were successfully designed, complying with all the draft specification requirements.

Whether warm mix additive should be included during the asphalt mix design process was flagged as an ambiguity. The use of warm mix additive is in line with both TMR, AAPA and international practice, although the use of the additive during the mix design is not clear. The draft specification calls for the CRM binder to adhere to requirements without a warm mix additive, but it is not clear whether the mix containing CRM binder should adhere to requirements without warm mix additive as well. It is recommended that CRM binder and CRM asphalt mixes meet requirements with the inclusion of warm mix additives.

A plant trial at Fulton Hogan's Hazelmere premises built confidence in production, rolling sequence and roller setting. This was followed by the construction of a demonstration trial between 17 March 2019 and 25 March 2019 on the Kwinana Freeway between Russel Road Interchange and Anketell Road Interchange.

Although 5.0% and 5.5% CRM binder content was targeted for the CRM OGA sections with standard and alternative PSD, the resulting CRM binder content was 5.5% for both nights of standard PSD and 5.2% and 5.3% respectively, for the alternative PSD.

The average field core air voids were 21.4%, 21.1%, 22.1% and 19.7% respectively for the dates CRM OGA was placed. The average field core air voids were slightly higher than the corresponding dates' Marshall air voids at 19.7%, 19.6%, 19.3% and 18.4%. Both the average field core air voids and Marshall air voids showed no clear distinction between standard and alternative PSD.

Even though the Marshall compaction effort was reduced from 75 blows per face (as per Specification 504) to 50 blows per face (as per draft specification), comparing the 2018-19 surfacing seasons' air voids to the demonstration trial did not indicate a significant difference.

The reported field core air voids for the OGA (Alternative PSD) averaged 21.4% for 17 March 2019 and 21.1% for 18 March 2019. The average field core air voids reported for the OGA (Standard PSD) was 22.1% for 20 March 2019 and 19.7% on 21 March 2019. Average field core air voids reported for the OGA (Standard PSD, A20E) was 21.3% for 24 March 2019 and 22.1% on 25 March 2019. All the reported field core air voids compared well with the 2018-19 surfacing season, with suppliers reporting mean field core air voids of 20.6%, 22.0% and 22.2%.

During the demonstration trial, the following samples were taken for monitoring of emissions:

- Inhalable dust – personal exposure monitoring through static sampling attached to the worker's shirt lapel.
- Volatile organic compound (VOC) emissions – personal exposure monitoring through static sampling attached to the worker's shirt lapel and for the static sampler (ambient), a canister open to the atmosphere was used.
- Polycyclic aromatic hydrocarbon (PAH) emissions – personal exposure monitoring through static sampling attached to the worker's shirt lapel.

The results of the monitoring indicate the levels of airborne contaminants at the work site were being adequately controlled with regard to the impact on workers' personal exposure. Almost negligible levels of exposure were recorded for inhalable dust, VOC and PAH emissions.

A WA Carbon Savings Estimation Tool that was developed as part of WARRIP Project 2017-001, was used and indicated an estimated reduction in emissions of between 2% and 4% if warm mix additives were solely used. A further reduction in estimated emissions of between 43% and 47% could be achieved if CRM binder was used. In combination, reduction in estimated emissions of between 45% and 49% can be achieved.

Splash and spray assessment could not be conducted due to the timing of the construction. A subjective splash and spray questionnaire matrix was included for possible future assessment.

10 RECOMMENDATIONS

10.1 Draft Specification 516

The draft Specification 516 was used during the development of the binder, mix design and construction of the demonstration trial.

The following recommendations may improve the draft specification:

- Table 516.1 reflects the binder design profile as in AAPA (2018), which adopted the requirements of ADOT Type 2. Given WA's hot climate and generally stiffer C170 binder, it may be more relevant to adopt ADOT Type 1 requirements. Further testing of CRM binders developed in WA to validate this will be required.
- Table 516.6 specifies air voids with standard PSD and alternative PSD.
    - Air voids with standard PSD must be between 16.0% and 21.0%, although the note states that the maximum of 21.0% can be exceeded. It is recommended that this maximum requirement should be discarded. From both the demonstration trial and 2018-19 surfacing season's air void results, it is clear that this value is generally exceeded.
- It is recommended that the alternative PSD and binder content should be further explored through laboratory testing. There was no clear distinction between the alternative PSD and standard PSD during the demonstration trial, nor between 5.0% and 5.5% CRM binder content.
- Clause 516.41.3 states that CRM OGA with warm mix additive should be delivered to site at between 155 °C and 170 °C. It is recommended that these limits should be reduced to fully harness the reduction in emissions possible. Warm mix additives should enable delivery temperatures between 140 °C and 150 °C and should be trialled in field trials to confirm the possible reduction.

10.2 Future Work

The following projects may be considered following on the work from this project.

10.2.1 Investigating the use of CRM in dense graded asphalt (DGA).

The use of CRM binder in DGA is less established than its use in OGA, GGA or SMA mixes. The aim of the proposed investigation is to evaluate the performance of DGA with CRM binder that is almost fully digested. The use of CRM binder in DGA will increase the use of recycled crumb rubber.

The level of digestions should be noted and apart from the standard Marshall testing, performance testing such as Hamburg Wheel Tracking, resilient modulus testing, durability testing, flexural stiffness and fatigue testing should be conducted.

This may enable more lane-km to harness the potential benefits of CRM binder, if sufficient rubber is still present to enable benefits such as increased resistance to cracking and longer in-service life due to thicker film thickness of the binder.

10.2.2 Investigate crumb rubber technology to prolong the shelf-life and performance of CRM binder.

During 2010, representatives from Sasol Wax, Stormipex and Hamburg University conceived a concept where rubber crumbs are pre-reacted. The manufacturing of CRM asphalt with this component, later called the New Crumb Rubber Technology, progressed to successful trials shortly afterwards in Germany. The aforementioned, as well as a review of projects and work conducted in South Africa between 2010 and 2015 indicated the following benefits:

- reduced volatile organic components during manufacturing and application
- reduction in binder production temperature, from 200 °C to 180 °C
- less sensitive to changes in bitumen properties and widens application range to other sources and grades
- used successfully with warm mix additives, e.g. in the trial quoted increased softening point and reduced flow properties of modified binder
- increased shelf life as it reaches steady state after 2.5 to 3 hours. Long life bitumen rubber can be handled at 150 °C and the product remains unchanged for as long as 7 days (Muller and Lambert 2015).

An investigation into this technology is proposed, as a starting point, to confirm the influence on binder types and CR combinations commonly available in WA. This should include viscosity testing before and after RTFOT and PAV, as well as viscosity over an extended period of time to test the 7 day stability claim by the suppliers.

Warm mix additives commonly used in WA can be added and similar testing conducted to evaluate the combined use of NCRT and additives on the performance of the binder.

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APPENDIX A DERIVATION OF TMR AND AAPA SPECIFICATIONS

A.1 Crumb Rubber Material Specification

At the time, it was understood that only Size 30 rubber was readily available in Australia (Table A 1). Industry also suggested that there was little control over the grading of the rubber particles supplied. It was therefore agreed to not be too prescriptive for the grading given that the modified binder must still meet a number of other specification criteria (such as viscosity, softening point, resilience etc.). The other rubber properties are consistent with the requirements in AGPT/T190 (2019).

Table A 1: Properties of crumb rubber

Test	Method	Size 16	Size 30
Grading	AGPT/T143		
passing 2.36 mm		100	100
passing 1.18 mm		80 min.	100
passing 600 µm		10 max.	60 min.
passing 300 µm		–	20 max.
Particle length (mm) max.	AGPT/T143	3	3
Bulk density (kg/m^3)	AGPT/T143	Report	Report
Water content (%) max.	AGPT/T143	1	1
Foreign materials – other than iron (%) max.	AGPT/T143	0.1	0.1
Foreign materials – metallic iron (%) max.	AGPT/T143	0.1	0.1

Source: AGPT/T190 (2019).

Section 39-2.03A(4)(e)(ii)(C) of the California specification (Caltrans 2015) specifies that 100% rubber obtained from scrap tyres should pass the 2.36 mm sieve and 100% high natural rubber should pass the 2 mm sieve (Table A 2). The current grading specified by TMR and AAPA is therefore similar to the grading adopted by California.

Table A 2: Crumb rubber modifier for asphalt rubber binder

Quality characteristic	Test method	Requirement
Scrip tire crumb rubber gradation (% passing no. 8 sieve (2.36 mm))	California Test 385	100
High natural crumb rubber gradation (% passing no. 10 sieve (2.00 mm))	California Test 385	100
Wire in CRM (max, %)	California Test 385	0.01
Fabric in CRM (max, %)	California Test 385	0.05
CRM particle length (max, in)	–	3/16 (4.76 mm)
CRM specific gravity	California Test 208	1.1 – 1.2
Natural rubber content in high natural crumb rubber (%)	ASTM D297	40.0 – 48.0

Source: Caltrans (2015).

Note that Section 37-2.05B(2)(d) (Caltrans 2015) dealing with bituminous seals, contains gradation requirements, distinguishing between a gradation limit, operating range and contract compliance. The gradation limit from Section 37-2.05B(2)(d) (Caltrans 2015) is contained in Table A 3.

Table A 3 presents a comparison of the crumb rubber material requirements between the TMR (2016), AAPA (2018), ASTM (2009), ADOT (2008) and Caltrans (2015) specifications. This indicates that the sole grading requirement of 100% passing the 2.36 mm sieve was derived from the ASTM specification.

Table A 3: Crumb rubber material specification comparison

Property	AAPA(3),(4)	TMR(3),(4)	ASTM(1),(2)	ADOT		Caltrans	
				Type A(1)	Type B(2)	Tyre crumb rubber(1),(2)	Natural crumb rubber(1),(2)
Grading sieve size (mm) 2.36 (% passing)	100	100	100	100	–	100	–
2.00 (% passing)	–	–	–	95–100	100	98–100	100
1.18 (% passing)	TBN(4)	TBN(4)	–	0–10	65–100	45–75	95–100
0.60 (% passing)	TBN(4)	TBN(4)	–	–	20–100	2–20	35–85
0.30 (% passing)	TBN(4)	TBN(4)	–	–	0–45	0–6	10–30
0.150 (% passing)	TBN(4)	TBN(4)	–	–	–	0–2	0–4
0.075 (% passing)	TBN(4)	TBN(4)	–	–	0–5	0	0–1
Bulk density (max, kg/m^3)	Report	Report	1100–1200	–	1100–1200	1100–1200	1100–1200
Moisture content (max, %)	1.0	1.0	0.75	–	–	–	–
Particle length (max, mm)	3.0	3.0	–	–	–	4.75	4.75
Metallic content (max, % by mass)	0.1	0.1	0.01	0	0	0.01	0.01
Other foreign materials (max, % by mass)	0.1	0.1	0.25	0	0	0	0
Fibre content (max, % by mass)	–	–	0.5(1) 0.1(2)	0.1	0.5	0.05	0.05
Mineral powder (max, % by mass)	–	–	4	4	4	3	3

1 Sprayed seals
2 Asphalt
3 Unpublished specification.
4 To be nominated by the contractor as part of the asphalt mix design submission.

A.2 CRM Binder Specification

The binder specification adopted by TMR and AAPA for asphalt applications is primarily based on the Arizona specification. The main reason for this was that at the time the project team believed that the Arizona specification would be easier to implement in Australia compared to the California specification, primarily due to the lower temperatures for binder manufacturing and handling (storage, safety, fuming and environmental concerns).

The Californian specification requires the CRM binders to be blended and stored at a temperature of between 190 °C–220 °C. The binder can be stored at this elevated temperature for up to 4 hours (after 45 min reaction period) where after heating should be discontinued. In contrast, the Arizona specification requires that the temperature during blending and storage must be between 163 °C−190 °C. This lower temperature allows for the binder to be stored up to 10 hrs (after 1 hr reaction period) at temperatures between 163 °C–190 °C.

The original TMR Pilot Specification included 2 grades of binder, i.e. CR1 and CR2. However, the latest version only includes a CR2 binder consistent with the AAPA specification. In Arizona, CR1 binders are used for hot climates, CR2 binders for moderate climates and CR3 binders for cold climates.

Historic experience in Australia suggests that binders modified with crumb rubber quantities in excess of 18% becomes increasingly difficult to handle during production (using local equipment and practices) and it was therefore decided to reduce the minimum rubber content to 18% rather than 20%.

Researchers noted that the binders provided for the three NACoE demonstration projects (i.e. 2 x open graded asphalt and 1 x gap graded asphalt) were targeting the lower end of the viscosity limits (i.e. 1.5 Pa.s at 175 °C), with crumb rubber contents of approximately 18%. The target viscosity should be higher, from a performance point of view for gap graded asphalt, and possibly does not meet the intent of the Arizona and California specifications. It may therefore in future require contractors to target a higher viscosity range (say between 2.0 and 3.5 Pa.s at 175 °C).

The specified binder properties for AAPA, TMR, ASTM, ADOT and Caltrans are summarised in Table A 4. Comparisons indicate that the AAPA binder properties were primarily based upon the TMR CR2/ADOT Type 2 requirements, with the exception of the minimum rubber content, which was based upon the Caltrans requirements. Additionally, the comparison also indicates that the TMR binder properties were based upon the ADOT Type 1 (hot climates) and Type 2 (moderate climates).

Table A 4: CRM binder properties comparison

Property	AAPA(2)	TMR(2)	ASTM	ADOT(1),(2)	Caltrans(1),(2)
Mix process	Wet (HV)	Wet (HV)	Wet (HV)	Wet (HV)	Wet (HV)
Penetration at 25 °C	Report	–	25–75	–	25–70
Penetration at 4 °C (min)	15	10 (CR1) 15 (CR2)	10 (Type I) 15 (Type II) 25 (Type III)	10 (Type 1) 15 (Type 2) 25 (Type 3)	–
Penetration retention at 4 °C (min)	–	–	75	–	–

Property	AAPA[(2)]	TMR[(2)]	ASTM	ADOT[(1),(2)]	Caltrans[(1),(2)]
Resilience at 25 °C (min, %)	20	25 (CR1) 20 (CR2)	25 (Type I) 20 (Type II) 10 (Type III)	25 (Type 1) 20 (Type 2) 15 (Type 3)	18
Softening point (min, °C)	55	57 (CR1) 55 (CR2)	57 (Type I) 54 (Type II) 52 (Type III)	57 (Type 1) 54 (Type 2) 52 (Type 3)	52–74
Viscosity at 190 °C (Pa.s)	–	–	–	–	1.5–4.0[1] 1.5–3.0[2]
Viscosity at 175 °C (Pa.s)	1.5–4.0	1.5–4.0 (CR1) 1.5–4.0 (CR2)	1.5–5.0	1.5–4.0	–
Grade of base binder	–	–	–	PG 64-16 (Type 1) PG 58-22 (Type 2) PG 52-28 (Type 3)	–
Rubber content (min, %)	18–22	17% (min) 20% (typical)	15	20	18–22
Extender oil (max, %)	–	–	–	–	2.5–6.0

Note: HV = high viscosity wet mixing process.
1 Sprayed seals.
2 Asphalt.
3 Not a published specification, proposed amendments to current specifications only.
4 Type I binders typically include stiffer grades of base binder, generally used in hot climates (–1 to 43 °C). Type II binders typically include softer grades of base binder, generally used in moderate climates (–9 to 43 °C). Type III binders typically include the softest grade of base binder, generally used in cold climates (–9 to 27 °C).
5 Typically used, not a requirement.

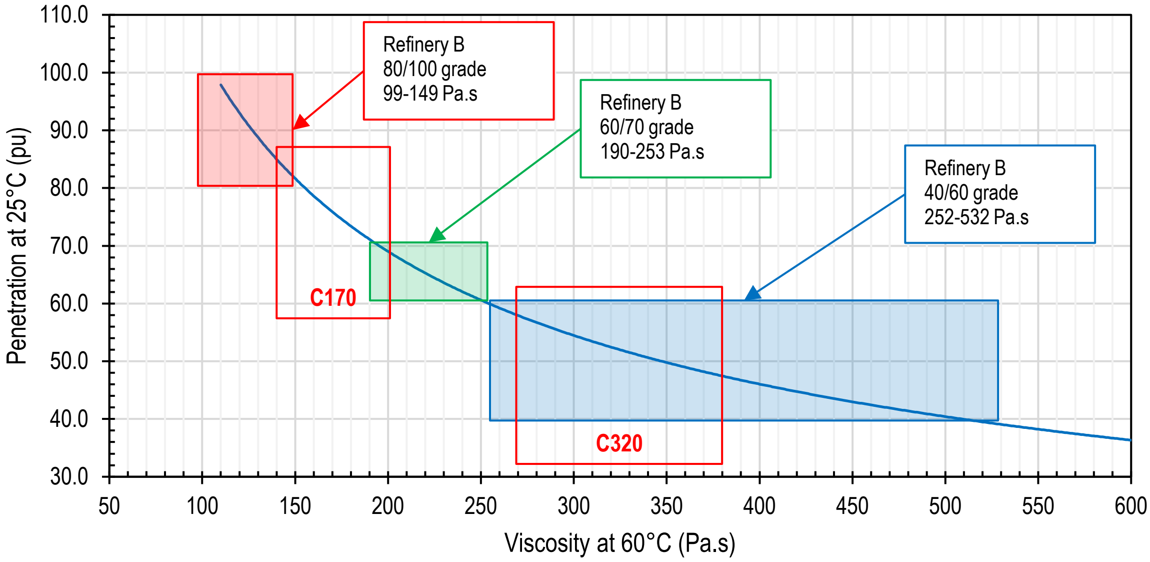
AAPA (2018) adopted only TMR CR2/ADOT Type 2, suitable for 'mild' climates (Way, Kaloush and Biligiri 2011). This may be due to the difference in binder grading systems being used in Australia and the USA. Australia used a penetration grade system up to 1980, when it changed specifications to a viscosity-based grading system. The USA adopted a performance grading (PG) system in the mid-1990s (Neaylon 2013).

Way, Kaloush and Biligiri (2011) (Table 2.8) suggested that the penetration grade corresponding to the PG grade of ADOT Type 2 is 85/110 pen and for ADOT Type 1 is 60/70 pen.

TMR CR1/ADOT Type 1 would be better suited to WA conditions, as it is described to be suitable for hot climates.

However, Asian refineries manufacture to various penetration grade specifications, none directly comparable to Australian viscosity grade specifications. Therefore, specific crudes and specific refineries and penetration grades must each be tested for conformance with the Australian specification. Dack (2012) illustrated in Figure A 1, a single crude refined at a single refinery, with the resulting product measured by viscosity and penetration. The red 'buckets' match the specification requirements of the Australian Standard for C170 and C320. The coloured squares match the specification requirements for penetration grades 40/60, 60/70 and 80/100. It can be seen here that 80/100 grade may, or may not, meet C170 requirements. A 60/70 grade also may or may not meet C170 requirements (Neaylon 2013).

Figure A 1: Penetration grade versus viscosity grade



Reproduced from Dack (2012).

This implies the adoption of ADOT Type 1 and/or Type 2 is a viable option for Australia. Adopting ADOT Type 2, would enable the use of Australian Standard C170, which may or may not be closer to an ADOT Type 2 binder.

A.3 CRM Asphalt Specification

The AAPA (and TMR) CRM GGA specification is based on the Californian mix design requirements (Table A 5). The main reason for this is that California is considered to have extensive experience in the use of CRM GGA and their specification includes a number of performance criteria, including permanent deformation, moisture damage and TSR. C170 is typically used as the base binder in Australia, which is 'comparable' to PG58 and PG64, but not to PG70. The more stringent rutting criteria for PG58/64 was therefore adopted.

Notably, this is inconsistent with the CRM binder properties (Table A 4) where the AAPA binder specifications were based upon the ADOT Type 2 CRM binder, using a PG 58-22 bitumen base.

An update to the TMR specification for CRM OGA aligned the voids and minimum binder requirements with AAPA.

Table A 5: Comparison of CRM asphalt mix design requirements

Property	AAPA		TMR (OGA)	ADOT (GGA)	Caltrans (GGA)
	OGA	GGA			
Method of compaction	Marshall	Gyratory	Marshall	Marshall	Gyratory
Binder content (%)	6.0 (min)	7.5 (min)	TBD	–	7.5 (min)
Air voids content (%)	20 (min)	4.0	–	4.5–6.5	4.0
Voids in mineral aggregate (min, %)	–	18–23	–	19	18–23
Active filler (min, %)	–	–	–	1.0	–
Asphalt particle loss (max, %)	20	–	20	–	–
Asphalt binder drain off (max, %)	0.3	–	0.3	–	–
Binder film thickness (min, microns)	18 (AS/NZS 2891.8)	–	17 (Q317) 18 (AS/NZS 2891.8)	–	–
Permanent deformation (min, number of passes at 12 mm rut depth)	–	20 000[1],[2]	–	–	15 000 (PG 58) 20 000 (PG 64) 25 000 (PG 70)
Moisture damage (min, number of passes at the inflection point)	–	10 000[1],[2]	–	–	10 000 (PG 58) 10 000 (PG 64) 12 500 (PG 70)
Moisture sensitivity TSR (%)	–	80[1]	–	–	70
Determine number of Marshall blows to 4% air voids, or, Determine number of gyrations to 4% air voids	–	Report[1]	–	–	–

1 Testing undertaken on plant produced asphalt samples.
2 Undertaken using Q325 (Hamburg wheel tracking test).

A.4 CRM Asphalt Construction Requirements

The production temperatures were based on the ADOT requirements due to the preference for lower binder temperatures (refer discussion above).

The Caltrans specification for air voids range between 3%–9% and not 2.5%–5.5% shown in the table. A maximum 8% air voids was adopted by AAPA due to concerns raised by TMR and MRWA regarding air voids higher than 8%.

Table A 6 presents a comparison of the CRM asphalt construction requirements. Notably, the comparison indicates that the AAPA specifications were based upon the ADOT GGA requirements.

Table A 6: CRM asphalt construction requirements

Property	AAPA		TMR (OGA)	ADOT (GGA)	Caltrans (GGA)
	OGA	GGA			
Mix production temp. (°C)	165–190	165–190	175–205 (CRM blending) 163–190	163–190	190–218 (CRM blending)
Compaction temp. (°C)	–	–	–	104	121–138
Ambient/pavement temp. (min, °C)	13 (air) 15 (asphalt)	13 (air) 15 (asphalt)	20	18	13–18
In situ air voids (%)	–	3–8	–	4–9	2.5–5.5
Compaction density (min, %)	–	–	–	–	–

APPENDIX B DRAFT SPECIFICATION 516 – CRUMB RUBBER OPEN GRADED ASPHALT

SPECIFICATION 516

CRUMB RUBBER OPEN GRADED ASPHALT

REVISION REGISTER			
Clause Number	**Description of Revision**	**Authorised By**	**Issue Date**
Whole document	New specification	MME	

CONTENTS

SPECIFICATION 516

CRUMB RUBBER OPEN GRADED ASPHALT

GENERAL

516.01 SCOPE

1. The work under this specification consists of the supply and application of crumb rubber open graded asphalt (hereafter referred to as asphalt) for pavement wearing courses.

2. Details of the location and extent of asphalt work are either summarised at Annexure 516A, or are indicated on the Drawings. ***Details***

3. The works shall include surface preparation, supply of materials, production, hauling, placing and compaction of asphalt to the areas as shown in the Drawings, or as otherwise directed by the Superintendent, including correction of existing pavement surfaces.

516.02 REFERENCES

1. Australian Standards, MAIN ROADS Western Australia Standards and MAIN ROADS Western Australia Test Methods and other test methods are referred to in abbreviated form (e.g. AS 1234, MRS 67-08-43 or WA 123). For convenience, the full titles are given below:

Australian Standards

AS 1141.11.1 Particle size distribution - Sieving method

AS 1160 Bituminous Emulsions for the Construction & Maintenance of Pavements

AS 1672 Building Limes

AS 2150 Hot Mix Asphalt

AS/NZS 2891.10 Moisture content of asphalt

AS/NZS 2891.11 Degree of particle coating

Main Roads Test Methods

WA 210.1 Particle Size Distribution of Aggregates

WA 212.1 Aggregate Moisture Content : Convection Oven Method

WA 212.2 Aggregate Moisture Content : Microwave Oven Method

WA 313.2 Surface Profile: Three Metre Straightedge

WA 313.4 Surface Profile: ARRB Profiler

WA 701.1 Sampling and Storage of Asphalt

WA 705.1 Preparation of Asphalt for Testing

WA 730.1 Bitumen Content & Particle Size Distribution of Asphalt & Stabilised Soil, Centrifuge Method

WA 731.1 Stability & Flow of Asphalt: Marshall Method

WA 732.2 Maximum Density of Asphalt: Rice Method

WA 733.2 Bulk Density and Void Content of Asphalt – Vacuum Sealing Method

Main Roads Specifications

Specification 201 QUALITY SYSTEMS

Specification 511 MATERIALS FOR BITUMINOUS TREATMENTS

516.03 DEFINITIONS

Terminology

1. "asphalt course" comprises one or more layers of a single asphalt type.
2. "asphalt layer" comprises a single paving run of uniform asphalt.
3. "asphalt wearing courses" is that part of the pavement upon which the traffic travels including any dense graded asphalt course immediately below a course of open graded asphalt.
4. "asphalt pavement" is a pavement, the predominate structural strength of which is provided by asphalt layers.
5. "reclaimed asphalt pavement (RAP)" is the material reclaimed from an asphalt wearing or intermediate course by cold planning and re-processed by crushing and/or screening for recycling into new asphalt.

516.04 – 516.05 NOT USED

PRODUCTS AND MATERIALS

516.06 BITUMINOUS BINDER

Open graded asphalt

1. The crumb rubber modified binder shall be designed to meet the requirements of Table 516.1 without the inclusion of a warm mix additive. The asphalt manufacturer shall submit test reports showing compliance with Table 516.1 with its asphalt mix design submission. A minimum quantity of 18% of crumb rubber by mass of total binder shall be used in the crumb rubber modified binder.
2. Bitumen used to manufacture the crumb rubber binder shall be Class 170 bitumen conforming to the requirements of Specification 511 MATERIALS FOR BITUMINOUS TREATMENTS.
3. Crumb rubber, bitumen and as required oils shall be combined, thoroughly mixed and digested for a minimum period of 60 minutes. The manufacturing process shall not result in a reduction in the size of the crumb rubber particles in the binder such as may occur through a high shear mill. The temperature of the crumb rubber modified binder during the digestion period shall not exceed 190°C.

TABLE 516.1 BINDER DESIGN PROFILE

Property	Test Method	Digestion Time				
		60min	120 min	240min	360min	Maximum (Note 1)
Penetration at 4°C, 200g, 60s , pu (minimum)	AS 2341.12	15	-	15	-	15
Penetration at 25°C, 100g, 5s , pu (minimum)	AS 2341.12	Report	-	Report	-	Report
Resilience at 25°C, % rebound (minimum)	ASTM D5329	20	-	20	-	20
Torsional Recovery at 25°C, 30s , %	AGPT/T122	Report	-	Report	-	Report
Softening Point, °C (minimum)	AGPT/T131	55	-	55	-	55
Viscosity at 175°C	ASTM D7411/D7741M or AGPT:T111 (Note 2)	1.5 – 4.0				

Note 1 – The asphalt manufacturer is to nominate the maximum period of time it intends to store the crumb rubber modified binder beyond 10 hours. The properties of the binder must comply with the table after this period of time.

Note 2 – For the ASTM method the viscometer used shall be a Rion Model VT-04 or VT-06 using the No. 1 rotor. The rotor shall be immersed in the binder to the marked depth for a minimum of 60 seconds to achieve temperature equilibrium. Three measurements shall be taken within a period of 1 minute with the three values not exceeding a range of 1.0 Pa.s. Compliance to be taken as the average of three values.

Viscosity with WMA

4. To evaluate the effect of adding a warm mix additive on the viscosity of the crumb rubber modified binder the asphalt supplier shall:

- Prepare in the laboratory a sample of the crumb rubber modified binder and split it into two portions.
- Test the first portion for viscosity at 175 ºC to confirm the viscosity conforms. If not make a new batch of binder.
- Add the warm mix additive to the second portion at the proposed proportion to be used and mix thoroughly with the binder.
- Test the second portion for viscosity at 175ºC, then 165ºC and reducing by 10ºC steps until the viscosity of the second portion is higher than the first portion.
- Plot viscosity versus temperature and determine the temperature at which the second portion has the same viscosity of the first portion at 175ºC.

The nominated test temperature for the binder with the warm mix additive shall be stated on the approved asphalt mix design and shall be the temperature of the binder to achieve a viscosity of 1.5 – 4.0 Pa.s at the time of asphalt production.

5. At the time of manufacture of the crumb rubber modified binder it shall comply with the requirements of Table 516.2, without inclusion of a warm mix additive, after a reaction time of 60 minutes. The initial batch shall be tested for all properties and subsequent batches shall be tested for all properties except loss on heating and flash point. Loss on heating shall be tested once per month and flash point every 12 months. ***Binder Testing Frequency***

TABLE 516.2 BINDER PROPERTIES AT PRODUCTION

Property	Test Method	Limits
Penetration at 4°C, 200g, 60s , pu	AS 2341.12	Minimum 15
Penetration at 25°C, 100g, 5s , pu (minimum)	AS 2341.12	Report
Resilience at 25°C, % rebound	ASTM D5329	Minimum 20
Torsional Recovery at 25°C, 30s , %	AGPT/T122	Report
Softening Point, °C	AGPT/T131	Minimum 55
Viscosity at 175°C	ASTM D7411/D7741M or AGPT:T111	1.5 – 4.0
Flash Point, ºC	AGPT/T112	Minimum 250
Loss on Heating, %	AGPT/T103	Maximum 0.6

6. **Prior to the use of crumb rubber modified bitumen the Contractor shall demonstrate compliance with the properties of the binder for each batch used on the Contract. Audit testing undertaken by the Principal shall not be used to demonstrate compliance.** ***HOLD POINT***

516.07 BITUMEN EMULSION

1. Bitumen emulsion to be used as the tack coat during the preparation of the surface prior to the laying of open or dense graded asphalt shall be Cationic Slow Setting emulsion grade CSS/170-60 or Cationic Rapid Setting emulsion grade CRS/170-60, both conforming to AS 1160, mixed 50:50 by volume with water.

516.08 AGGREGATE

1. Crushed aggregate, including its source rock, and screened or crushed laterite aggregate shall meet the requirements of Specification 511 MATERIALS FOR BITUMINOUS TREATMENTS. Coarse and fine aggregate used in the manufacture of asphalt shall only consist of crushed rock material.

2. Flakiness index shall be less than or equal to 25%.

516.09 – 516.10 NOT USED

516.11 MINERAL FILLER

1. Mineral filler shall meet the requirements of Specification 511 MATERIALS FOR BITUMINOUS TREATMENTS. In addition the combined filler being baghouse dust and hydrated lime shall comply with the requirements of Table 516.3. ***Mineral Filler***

TABLE 516.3 COMBINED FILLER REQUIREMENTS

Property	Test Method	Requirement
Voids in Dry Compacted Filler (%)	AS/NZS 1141.17	≥ 28 and ≤ 45
Apparent Density of Filler (t/m^3)	AS/NZS 1141.7	Report

2. Each added mineral filler shall meet the requirements for particle size distribution shown in Table 516.4 when tested in accordance with WA 210.1 or AS 1141.11.1. ***PSD***

TABLE 516.4 FILLER PSD

Sieve Size (mm)	Percentage Passing (by mass)
0.600	100
0.300	95 – 100
0.075	75 - 100

516.12 ADHESION AGENT

1. The adhesion agent shall meet the requirements of Specification 511 MATERIALS FOR BITUMINOUS TREATMENTS. ***Adhesion Agent***

516.13 CRUMB RUBBER

2. The crumb rubber shall be manufactured from end of life tyres from a Tyre Stewardship Australia accredited tyre recycler. Uncured or devulcanized rubber shall not be used as a source material. The crumb rubber shall meet the requirements of Specification 511 MATERIALS FOR BITUMINOUS TREATMENTS.

516.14 – 516.26 NOT USED

MIX DESIGN

516.27 SPECIFIED OPEN GRADED ASPHALT MIX DESIGN

516.27.01 MARSHALL DESIGN PARAMETERS

1. All open graded asphalt under this Contract shall be assessed in accordance with the standard procedures laid down for the Marshall method of design as shown in Table 516.5. The bulk density of laboratory prepared and field cored specimens shall be determined in accordance with WA 733.2.

TABLE 516.5 DESIGN PARAMETERS

Description	Test Method
Stability & Flow of Asphalt: Marshall Method	WA 731.1
Maximum Density of Asphalt: Rice Method	WA 732.2
Bulk Density & Void Content of Asphalt	WA 733.2

2. The design shall produce a material which satisfies the limiting values of the various Marshall properties listed in Table 516.6.

TABLE 516.6 MARSHALL PROPERTIES (50 BLOW COMPACTION)

Parameter	Minimum	Maximum
Marshall Stability	4kN	-
Marshall Flow	2.00mm	4.00mm
Air Voids (WA 733.2) with standard PSD	16.0%	21.0% (Note)
Air Voids (WA 733.2) with alternative PSD	18.0%	-

Note – the maximum value can be exceeded but the minimum value is mandatory.

3. In addition to achieving all the specified property values, all asphalt shall have an adequate workability and shall be suitably resistant to segregation during handling and placing. ***Workability***

4. The conforming mix design described in this clause is for a mix produced using granite aggregates from the Perth region. ***Application***

5. Open graded asphalt shall consist of a mixture of coarse and fine aggregates, hydrated lime, mineral filler and crumb rubber modified binder. RAP shall not be used. The coarse and fine aggregates and filler where used, shall be measured and then mixed in such proportions as to satisfy the particle size distribution given in Table 516.7. ***Constituents***

TABLE 516.7 PARTICLE SIZE DISTRIBUTION AND BINDER CONTENT

Sieve Size mm	% Passing by Mass		
	10mm Open Graded Asphalt (Standard PSD limits)	**10mm Open Graded Asphalt (Alternative PSD target)**	**10mm Open Graded Asphalt (Alternative PSD limits)**
13.20	100	100	100
9.50	90 – 100	90	85 - 95
6.70	-	43	38 - 50
4.75	30 – 40	27	20 - 35
2.36	10 – 16	11	8 - 14
1.18	8 –14	8	5 - 11
0.30	4 – 10	5	2 - 8
0.075	2 –4	3	1 - 5
Binder Content	4.5% ± 0.3% (by percentage mass of total mix)	5.0%	5.0 ± 0.3%

6. **The Contractor shall provide proof to the Superintendent that the Asphalt Manufacturer can manufacture the open graded asphalt in accordance with specified requirements.** ***HOLD POINT***

516.28 – 516.29 NOT USED

MANUFACTURE AND TRANSPORT

516.30 CRUMB RUBBER MODIFIED BINDER

1. During manufacture of the crumb rubber modified binder the crumb rubber and bitumen are to be thoroughly mixed prior to the beginning of the reaction period. Mixing shall then continue with a reaction period of at least 1 hour. Crumb rubber floating on the surface or agglomeration of crumb rubber is evidence of insufficient mixing.

2. At the asphalt plant the crumb rubber modified binder shall be stored in a vertical insulated binder tank incorporating circulation including a continuous stirrer or may be stored in a mobile blending facility if the binder has been batched at the asphalt plant.

3. The binder shall be stored at a temperature between 165ºC to 190ºC. If during the first ten hours after completion of the reaction period the temperature of the binder drops below 165ºC the binder may be reheated to the required temperature of 165ºC to 190ºC. The binder shall not be held at a temperature between 165ºC to 190ºC for more than 10 hours after completion of the reaction period. Binder that is to be used at a time beyond 10 hours after completion of the reaction period shall be cooled to a temperature below 165ºC and reheated when needed. Binder shall only be reheated once. Binder shall be used within four days after completion of the reaction period.

4. For each batch of binder the Contractor shall provide the following information:
   - The temperature of the bitumen prior to addition of the crumb rubber
   - The source, grade and quantity of bitumen used
   - The crumb rubber content expressed as percent by weight of total binder
   - Times and dates of addition of the crumb rubber
   - A continuous record of temperature of the binder against time for each batch beginning at the time of addition of the crumb rubber and until the load has been completely used.

5. Immediately prior to use of the crumb rubber modified binder for asphalt production a sample shall be taken from the storage tank and tested for viscosity at 175ºC. The viscosity shall be measured for subsequent use of the binder in other shifts of asphalt production. Where an alternative temperature has been proposed with the approved asphalt mix design, as specified at 516.06, the viscosity shall be measured at the alternative temperature. The viscosity shall comply with the requirements of Table 516.8.

TABLE 516.8 VISCOSITY AT PRODUCTION

Property	Test Method	Requirement
Viscosity at 175ºC	ASTM D7741/D7741M, or AGPT:T111	1.5 – 4.0 Pa.s

516.31 MIXING PLANT

1. Asphalt shall be manufactured in a central mixing plant by either, batch mixing, continuous mixing or drum mixing. All mixing plant and equipment and associated facilities shall conform to the requirements of AS 2150 and shall be such as to prevent segregation of the asphalt at all stages. ***Plant***

2. A sampling cock shall be installed in the inlet pipe between the road tanker and binder storage tanks. An additional sampling cock shall be installed for sampling at the time of asphalt production between the binder tank and the mixing chamber to facilitate the sampling of any binder being used for asphalt production. ***Binder sampling cocks***

3. For the verification of weights or proportions and character of materials and determination of temperatures used in the preparation of the asphalt, the Superintendent shall have access at any time to all parts of the plant subject to safety considerations.

516.32 MANUFACTURE OF ASPHALT

1. The quantities of coarse and fine aggregates, mineral filler, adhesion agent and binder shall be accurately and positively controlled so as to produce the asphalt specified for use in the Works. RAP shall not be included in the production of any open graded asphalt. ***Control***

2. The mixing process shall be such as to produce a uniform distribution of aggregate sizes and a uniform coating of binder on a minimum of 95% of aggregate particles when tested in accordance with AS/NZS 2891.11. ***Mixing***

3. The particle size distribution and the percentage of bitumen shall be within the limits as specified in Table 516.7 for open graded asphalt when tested in accordance with WA 730.1. ***Particle Size Distribution***

4. The air voids, stability and flow shall be in accordance with Table 516.6 for open graded asphalt when tested in accordance with WA 731.1 and 733.2. ***Marshall properties***

5. The moisture content of the asphalt at the completion of the mixing process shall not be greater than 0.15% by mass when measured in accordance with AS/NZS 2891.10. ***Moisture Content***

6. In a batch mixer the volume of material shall be limited to an amount allowing the paddle tips to be seen when passing through the top vertical position during mixing. ***Volume of Material***

7. The temperature of the mixed asphalt shall be measured and recorded at the discharge point of the pugmill or mixing drum. The temperature of the asphalt shall not exceed 170°C unless otherwise directed by the Superintendent. ***Temperature at Discharge Point***

516.33 – 516.34 NOT USED

516.35 TESTING

1. The asphalt producer shall provide and maintain at a suitable location at the site of the mixing plant for the duration of the Contract a suitably equipped air conditioned testing laboratory accredited by the National Association of Testing Authorities of Australia (NATA) to perform the following tests: ***Testing Laboratory***

   WA 210.1, 212.1 or 212.2, 701.1, 705.1, 730.1, 731.1, 732.2, 733.2, AS/NZS 2891.10, AS/NZS 2891.11.

2. The laboratory shall be equipped with all testing equipment necessary to perform these tests. The asphalt producer shall operate and maintain the equipment in good condition in accordance with NATA requirements. ***Testing Equipment***

3. Asphalt and mineral filler shall be tested for the properties and at the testing frequency shown in Table 516.9. ***Testing Requirements***

TABLE 516.9 ASPHALT AND FILLER TESTING FREQUENCY

Property	Test Method	Minimum Testing Frequency	
Binder Content and PSD (Note 1)	WA 730.1	• Up to 50 tonnes • Up to 150 tonnes • Up to 350 tonnes • Up to 550 tonnes	1 test 2 tests 3 tests 4 tests
Maximum Density	WA 732.2		
Air Voids	WA 733.2		
Stability and Flow	WA 731.1		
Moisture Content	AS/NZS 2891.10	1 test with initial production in first shift and then once per week	
Uniform Coating of Binder	AS/NZS 2891.11	1 test with initial production in first shift and then once per week	
Voids in Dry Compacted Filler (%)	AS 1141.17	1 test with initial production in first shift and then once per week	
Apparent Density of Filler (t/m^3)	AS 1141.7		
PSD of Filler	AS 1141.11.1		

Note 1 – when determining binder content the test shall be adjusted using the procedure described in Section 5 of Sabita Manual 19 (Guidelines for the design, manufacture and construction of bitumen-rubber asphalt wearing courses published by the South African Bitumen Association).

4. Asphalt shall be sampled in accordance with WA 701.1 with samples tested immediately they are taken. The number of tests undertaken shall be evenly spread across the entire period of production for each asphalt mix being tested within a shift. ***Sample testing frequency***

5. The first sample of asphalt in a shift shall be taken from the first 50 tonnes of asphalt manufactured in the shift for each type of mix being manufactured. ***First sample***

6. If the result of a test sample does not conform to any specified requirements another sample of asphalt shall be taken immediately and tested immediately for a full test.

7. Results of testing shall be reported on a NATA endorsed test report within 24 hours of a sample being taken. The testing laboratory shall send all results directly to, amongst others, the Contractor, the Superintendent and a nominated representative at the Main Roads Materials Engineering Branch. ***Reporting***

516.36 NON-CONFORMANCE

1. **A hold point will apply when any mix test result indicating a non-conformance occurs. This hold point shall also apply to a mix produced prior to the non-conforming test result, but which has not been placed.** ***HOLD POINT***

516.37 TRANSPORT

1. The asphalt shall be transported from the asphalt plant to the Works in metal bodied trucks or trailers previously cleaned of all foreign materials. In long distance haul situations the asphalt should be transported in insulated vehicles sufficient to ensure arrival of the asphalt on site in a conforming condition. ***Vehicle Type***

2. The temperature of the asphalt in each truck load and each trailer load shall be measured using a calibrated digital probe thermometer before the truck leaves the site of the asphalt manufacturing plant. The thermometer shall have a digital display readable to 1°C and have a measurement of uncertainty of not more than 3°C. Infrared thermometers shall not be used to measure temperature. The temperature shall comply with the requirements of Clause 516.32.7. ***Temperature in Truck***

3. The temperature of the asphalt shall be recorded on a printout showing date, time and asphalt temperature for each truck load and each trailer load of mix dispatched. The printout shall be provided with the load delivery docket. ***Temperature Record***

4. Each load shall be covered with suitable material of sufficient size to prevent loss of heat from the mixture. ***Heat Loss***

5. The asphalt shall be delivered at a uniform rate within the capacity of the placing and compacting plant. ***Delivery Rate***

516.38 - 516.40 NOT USED

PLACING OF ASPHALT

516.41 GENERAL

1. **Prior to commencing asphalting, the Contractor shall submit to the Superintendent the proposed number and widths of asphalt runs, and the proposed joint layout.** ***HOLD POINT***

2. Asphalt shall not be placed if the truck delivery docket does not include a printout of the date, time and temperature of asphalt when the truck was dispatched.

3. Asphalt shall be delivered to the work site at temperatures as follows : ***Delivery Temperatures***

    - Open graded asphalt with warm mix additive 155°C to 170°C.

4. If a delay occurs of more than 30 minutes between successive truck deliveries to the paver, the paver shall be moved clear of the laid asphalt and a proper transverse joint formed. ***Delays***

5. Prior to commencing each day's operations, and also after any delay exceeding half an hour during the day, the screed shall be preheated for at least 15 minutes in order to eliminate drag marks and imperfections in the finished mat. ***Screed to be Preheated***

6. All kerbs, gullies, grates and other structures shall be protected at all times from damage or defacement by asphalt placement works and the site shall be left in a clean and tidy condition. ***Damage***

516.42 SURFACE PREPARATION

1. Prior to the placement of asphalt, the Contractor following shall carry out preparation work as detailed in the following clauses.

2. The Contractor shall sweep all road surfaces on which asphalt is to be placed under this contract to a clean condition with no appreciable amounts of loose materials or any other foreign matter remaining. Loose surface material against kerbing shall be removed by handwork if necessary. The surface to be paved shall be dry. ***Sweeping***

3. Where the surface to be covered is asphalt, all depressions more than 20mm deep shall be filled with a nominal 10 mm or 14mm dense graded asphalt and shall be screeded or raked and then compacted to similar density as the remainder of the surface to be paved. ***Surface Correction***

4. Where paving tape is shown in asphalt drawings the tape shall be Denso Paving tape 200mm wide, Flexiseal Tape HD 250mm wide or Bitac DS Multi-Laminate tape 250mm wide. The tape shall be applied to a surface that is clean, dry and all loose material has been removed beyond the width of the tape to be applied. Joins of the tape shall be overlapped and any air bubbles or creases in the tape shall be cut and flattened. ***Paving Tape***

516.43 EQUIPMENT

1. The asphalt must be placed by a self-propelled paver equipped with the ability to be operated with automatic thickness control and automatic joint matching facility. The paver must be equipped with a ski or laser control system and crossfall controller to maintain levels, and also suitable sensing equipment to provide longitudinal joint matching. It shall further be equipped with a vibrating or tamping screed capable of achieving 85% of final compaction. ***Requirements***

2. Where the use of a material transfer vehicle (MTV) is specified at Annexure 516B the MTV shall be a self-propelled machine capable of receiving asphalt from delivery trucks, storing the asphalt, heating asphalt in storage and transferring the asphalt to the paver without any contact with the paver. The MTV must have a minimum storage capacity of 15 tonnes and the paver must be fitted with a bin in its hopper to transfer asphalt directly to the feed conveyor of the paver. ***Material Transfer Vehicle***

516.44 TACK COAT

1. A tack coat using the dilute emulsion shall be applied to the prepared surface at the rate to obtain a rate of residual bitumen of 0.15 to 0.25L/m². The tack coat shall be sprayed in a uniform film over the entire road surface. ***Composition***

2. No asphalt shall be placed on the tack coat until the emulsion has broken and the water has substantially evaporated.

3. The Superintendent may direct the pavement area ahead of the paver to be resprayed and may specify the time to be allowed between the spraying of tack coat and the placing of asphalt. However, this area shall not exceed the requirements for half a day's placing of asphalt. ***Respraying***

4. The tack coat shall be applied with care to reduce the possibility of concrete kerbs, driveways and footpaths being sprayed with bitumen. Any such contamination shall be removed by the Contractor at no cost to the Principal. ***Contamination***

516.45 NOT USED

516.46 WEATHER CONDITIONS

1. Asphalt placement shall not commence or continue upon a surface which is not clean and dry, and only when the pavement temperature meets the requirements shown in Table 516.10 and rain is not imminent. ***Pavement Temperature***

TABLE 516.10 PAVEMENT TEMPERATURES FOR PLACEMENT

Minimum pavement temperature when wind speed < 20 km/hr	Minimum pavement temperature when wind speed ≥ 20 km/hr
15°C	20°C

2. The Superintendent may, if the weather or surface conditions are considered to be unsuitable, instruct the Contractor to cease laying operations. Any materials laid after this instruction is given will not be paid for and are to be removed at no cost to the Principal.

516.47 JOINTS

1. The number and extent of joints in asphalt layers shall be kept to a minimum and the paving pattern shall be designed accordingly in advance of the work ***Paving Pattern***

2. The main paving runs shall be laid first and any smaller or irregular adjacent areas later so that they can be matched to the main run.

3. Each joint shall be neat, thoroughly compacted, and have a surface finish equal in quality to that of the surrounding asphalt layer. ***Surface Finish***

4. Where the edge of the previously laid work has become distorted it shall be cut back a sufficient distance to provide the true cross section. ***Edges***

516.48 LONGITUDINAL JOINTS

1. Longitudinal joints shall be continuous and parallel to the pavement centreline. Joints in successive layers shall be offset by at least 150mm. Joints shall be located away from traffic wheel tracks. Where possible, joints in wearing courses shall be located beneath traffic line marking. The end of the previous run shall be lightly tack coated before the paving of the adjacent run proceeds. ***Position***

2. Temporary longitudinal ramps shall be provided for any asphalt course that has not been completed to the full carriageway width and is subjected to traffic. These ramps shall be cut back before the adjacent lane is laid. ***Temporary Ramps***

516.49 TRANSVERSE JOINTS

1. Transverse joints shall be at right angles to the direction of paving. They should be staggered by at least one (1) metre between successive layers and between adjacent runs.

2. The end of the previous run shall be lightly tack coated before the paving of the next run proceeds. ***Tack Coat***

3. Temporary transverse ramps shall be provided where traffic is to use the newly laid work prior to a run being completed. These ramps shall be cut back before the next run is laid. ***Temporary Ramps***

516.50 TERMINAL JOINTS

1. Terminal joints between the new and existing surfaces shall be formed by ramping with a nominal 5mm dense graded asphalt mix. The ramp shall extend over a sufficient distance to provide a slope of at least 1:100.

516.51 ASPHALT CONSTRUCTION DRAWINGS

1. Unless otherwise specified details for transverse joints, longitudinal joints and profiles shall be in accordance with the asphalt construction drawings available on the Main Roads website as listed in Table 516.11.

TABLE 516.11 LIST OF ASPHALT CONSTRUCTION DRAWINGS

Drawing Number	Title
201331-0031	Pavement Series – Typical details full depth asphalt transverse joints
201331-0032	Pavement Series – Typical details Granular transverse joints
201331-0033	Pavement Series – Typical details full depth asphalt longitudinal joints and profile
201331-0035	Wearing Course Series – Typical details OGA/DGA transverse joints
201331-0036	Wearing Course Series – Typical details DGA transverse joints
201331-0037	Wearing Course Series – Typical details SMA transverse joints
201331-0038	Wearing Course Series – Typical details longitudinal joints

516.52 - 53 NOT USED

516.54 COMPACTION

1. Self-propelled vibrating steel wheel rollers, each of mass not less than eight (8) tonnes, capable of varying the amplitude and/or frequency of vibration shall be used. All rollers shall be fitted with reticulation to water wheels to prevent pick up of asphalt and be fitted with scrapers to clean the wheels. ***Equipment***

2. Unless otherwise directed by the Superintendent rolling shall commence immediately after placing and compacting with the vibrating or tamping screed. The rolling shall start longitudinally at the sides and proceed towards the centre of the pavement, overlapping on successive passes by at least 150mm. Successive passes of the roller shall be of slightly different lengths.

3. Roller speed shall be uniform. Stops and starts shall be controlled so that displacement (shoving) of the asphalt mix does not occur when changing direction. Any shoving occurring as a result of changing direction, or from any other cause, shall be corrected at once by the use of rakes and of fresh asphalt when required. ***Roller stop/starts***

4. To prevent adhesion of asphalt to the roller, all wheels shall be kept properly moistened but excess of water shall be avoided. ***Moistened wheels***

5. Vibratory compaction shall be discontinued in areas where it is considered such vibrations could cause damage to adjacent buildings or structures. Under these conditions, initial compaction of the asphalt shall be achieved using the self-propelled static steel wheeled rollers of appropriate mass to meet the compaction requirements in Clause 516.55. ***Vibratory compaction***

6. The Contractor shall ensure the protection of services and property from deterioration or damage due to the works. ***Protection***

7. Rollers shall be kept in continuous operation as much as practicable and in such a manner that all parts of the pavement receive substantially equal compaction. In the event of a delay in the laying operation, rolling is to be carried out as close as practicable to the paving machine. Rollers shall not be parked on work carried out the same day. ***Continuous Operations***

8. A sufficient number of rollers shall be available on site commensurate with the rate of supply of asphalt and the output of the paving machine. ***Number of Rollers***

9. All joints must be filled and edges adjacent to kerbing and such other hand work as may be necessary must be rolled with a suitable pedestrian type roller. ***Joints***

10. Finish rolling shall be carried out while the material is still warm enough for the removal of tyre marks. ***Finish Rolling***

11. At places not accessible to the roller, thorough compaction must be ensured by means of hot tampers and at all joints with structures the surface mixture must be effectively sealed. ***Hot Tampers***

516.55 DENSITY REQUIREMENTS

1. The Characteristic Percent Marshall Density (Compaction) for any lot shall be deemed to be conforming if it attains a value of 93% or greater. Payment for conforming work shall be at the scheduled rate. ***Marshall Density***

2. Density shall be calculated on the basis of the results of tests of core samples of asphalt sampled from an asphalt layer, after laying and compaction, in accordance with WA 701.1. The density of the samples shall be determined in accordance with WA 733.2 and expressed as a percentage of the mean Marshall Density of all asphalt results from the same production shift in accordance with WA 731.1 and WA 733.2.

3. Core samples shall be taken within 24 hours of placement of a lot of asphalt. Results of testing shall be reported on a NATA endorsed test report within 48 hours of the core samples being taken. The testing laboratory shall send all density results directly to, amongst others, the Contractor, the Superintendent and a nominated representative at the Main Roads Materials Engineering Branch. ***Testing and Reporting of Results***

4. Where the Characteristic Percent Marshall Density is less than the specified density the Quality Level shall be deemed to be either Non-conformance or Conditional Conformance depending on the difference between the Characteristic Percent Marshall Density and the specified density. The tolerances applicable to Conditional Conformance are given in Table 516.12. A Pay Factor, as shown in Table 516.12, shall be applied for work at the appropriate conformance level in accordance with these tolerances. The Pay Factor shall reflect the lower level of serviceability of conditionally conforming asphalt. ***Pay Factors***

5. Conditional acceptance is NOT applicable where the contract does not include a separate scheduled rate for the placement of asphalt and the asphalt will be considered to either conform, where the Characteristic Percent Marshall Density Rc is greater than or equal to 93.0%, or be Non-conforming where the Rc is less than 93.0%. ***Scheduled Rates Not Included***

TABLE 516.12 PAY FACTORS

Characteristic Percent Marshall Density Rc (%)	Quality Level	Pay Factor
≥ 93.0	Conformance	1.0
< 93.0 and ≥ 91.0	Conditional Conformance	0.15 Rc - 12.95
< 91.0	Non-Conformance	N/A

6. Where any lot of asphalt work is deemed non-conforming the Contractor shall apply remedial action in accordance with the procedures contained in Specification 201 QUALITY SYSTEMS, and the lot shall be removed and replaced with fresh asphalt and retested. Removal shall be carried out so as not to damage the underlying layers or any road furniture such as gully gratings. Any such damage shall be repaired at no cost to the Principal. ***Non-conformance***

516.56 SURFACE REQUIREMENTS

1. The surface of the compacted asphalt shall be smooth and true to the specified crown and grades, be of uniform appearance, free of dragged areas, cracks, open textured patches and roller or paver marks. Any section of asphalt that is loose or broken, mixed with dirt or other impurities, or is in any way defective, shall be removed and replaced.

2. When using the 3 metre straight edge, in accordance with WA 313.2, the shape of the compacted asphalt shall be deemed to be conforming when the maximum deviation from a 3m straight edge, placed in any position on the surface of a layer does not exceed the limits specified in Table 504.12. A 3m straight edge shall be provided with each paver. ***Shape: 3m Straight-edge***

3. When using the ARRB TR Walking Profiler, in accordance with WA 313.4, the shape of the compacted asphalt shall be deemed to be conforming when the maximum deviation, measured in any direction and within any 3m long section of the surface does not exceed the limits specified in Table 504.13. ***Shape: ARRB Profiler***

TABLE 516.13 SURFACE SHAPE

Direction of Measurement	Maximum Deviation	Maximum rate of Change of Deviation
Longitudinal	3 mm	1.0 mm per 240 mm
Transverse	5 mm	1.0 mm per 240 mm

4. For construction works, the upper surface of the compacted asphalt shall be within 5mm of the final design levels. For construction work the thickness of the compacted asphalt layers shall be within 5mm of the specified thickness. On resurfacing works where the underlying levels vary, the minimum thickness of compacted asphalt shall be within 5mm of the specified thickness. The thickness of a Lot of asphalt shall be determined from the mean thickness of core samples taken for compaction testing. Thickness shall be measured in accordance with WA 705.1. ***Level and Thickness***

5. The plan location of the outer edge of the asphalt shall be within +25 mm of its true location and the rate of change of the edge from its true plan position shall not exceed 1 in 40. ***Position***

6. The Contractor shall test for compliance with the specified lines, levels, thickness and surface finish immediately after initial compaction. Any variations shall be corrected by removing or adding materials as may be necessary. Rolling shall then be continued as specified. After final rolling out, the smoothness of the course shall be checked again. ***Compliance***

7. Where work is deemed non-conforming the Contractor shall apply remedial action in accordance with the procedures contained in Specification 201 QUALITY SYSTEM, and the lot shall be removed and replaced with fresh asphalt and retested. ***Non-Conformance***

516.57 OPENING FINISHED WORKS TO TRAFFIC

1. **Prior to opening the finished asphalt surface to traffic, the Contractor shall certify to the Superintendent that the final road surface is completed in accordance with the Specification, and that the works are properly delineated and safe for public use.** ***HOLD POINT***

516.58 - 516.80 NOT USED

AS BUILT AND HANDOVER REQUIREMENTS

516.81 – 516.90 NOT USED

CONTRACT SPECIFIC REQUIREMENTS

516.91 – 516.99 NOT USED

ANNEXURE 516A

SCHEDULE OF WORKS

Section		Length (m)	Width (m)	Area (m²)	Depth (mm)	Asphalt Type (Dense/Open/ Intersection Mix)	Nom Agg. Size (mm)
From	To						

(Insert appropriate details of all asphalt treatments: for Main Roads Policy, refer Guidance Note 1. Supplement with drawings, Diagrams, etc. where necessary)

ANNEXURE 516B

SPECIFIC CONTRACT REQUIREMENTS

1. MATERIAL TRANSFER VEHICLE

A material transfer vehicle is required to be used for the following layers.

Location	Yes	No

2. ECHELON PAVING

Echelon paving is required to be used for the following areas.

Location	Yes	No

GUIDANCE NOTES

FOR REFERENCE ONLY – DELETE GUIDANCE NOTES FROM FINAL DOCUMENT

3. All edits to downloaded Specifications shall be made using *Track Changes*, to clearly show added/deleted text.

4. If **all** information relating to a clause is deleted, the clause number should be retained and the words **"NOT USED"** should be inserted.

5. The proposed documents with tracked changes shall be submitted to the Project Manager for review, prior to printing the final batch of documents. When this final printing is carried out, the tracked changes option is to be turned off.

6. Before printing accept all changes in the document, turn off *Track Changes* and refresh the Table of Contents.

7. The Custodian of this specification is Bituminous Products Consultant.

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1. GUIDANCE ON THE USE OF WEARING COURSE ASPHALT

1.1 Main Roads document number 6706-04-154 Guide for Surfacing Type Selection provides guidance on the use of various types of asphalt surfacings in different scenarios and speed zones.

2. 10mm OPEN GRADED ASPHALT

2.1 For new construction or reconstruction works granite open graded asphalt shall be used for both the trafficked lanes and the break down lane or shoulder. Red coloured granite open graded asphalt shall not be used for any application.

3. USE OF A MATERIAL TRANSFER VEHICLE

3.1 The requirement to use a MTV has to be specified at Annexure 516B. MTVs facilitate continuous paving by having a truck come in contact with the MTV to empty its load whilst asphalt is transferred into the paver by conveyor. Removing contact between a truck and paver overcomes bumps from the stop/start of the paver and reduces the likelihood of mix segregation near the end of a truckload. The outcome is more uniform temperature of the asphalt which will result in improved and more uniform compaction, improved ride and less incidence of segregated areas of asphalt.

MTVs are not suited to all asphalting applications as shown below. Where a MTV must be used includes:

- On a project where there will be high daily production outputs of asphalt, eg. widening of Tonkin and Leach Highways near Perth Airport (Gateway WA Project)
- Where there are long paving runs, eg Kwinana Fwy widening Roe to Armadale and Armadale to Russell
- Where improved ride quality is required, eg. Great Eastern Hwy from Graham Farmer Fwy to Tonkin Hwy (City East Alliance)

- Where asphalt is to be placed in adverse weather conditions such as low temperatures or strong winds, eg Winter paving

- When paving thin layers of asphalt containing a polymer modified binder.

MTVs may not be suited for the following scenarios:

- On a project where there will be small daily production outputs of asphalt, eg. small minor improvement works

- Where there are confined spaces

- Small areas of widening such as intersection channelisation including short turn pockets.

4. MINOR WORKS CONTRACTS

4.1 Where this document is used in a Minor Works contract with wearing course asphalt as the sole or primary work required, Authors should ensure that the following specifications are also included in the tender documentation:

a. Specification 100 General Requirements

b. Specification 604 Pavement Markings (if required)

(Note: Current Minor Works tender documentation contains its own Quality, Traffic and OSH specifications.)

4.2 CONTRACT SPECIFIC REQUIREMENTS – include any details provided or required by the Principal, such as:

i. (Setting Out information

ii. Working Hours and Days (if not already included in the tender document)

iii. Surface Preparation – e.g. normally sweeping only, but may include localised surface correction requirements

iv. Record Forms – to include any required details of proof and origin of asphalt supply, etc.

Insert appropriate Annexures and reference to Annexures to suit in conjunction with these additional provisions.

CONTRACT SPECIFIC REQUIREMENTS

The following clauses are to be placed under the CONTRACT SPECIFIC REQUIREMENTS, as required. After inserting the clause, change the clause number and heading to style "H2 SP" so it appears in the Table of Contents.

XXX.XX SUB HEADING (H2 SP)

1. Insert text (Main Table SP) ***Keyword SP***
2. Insert text (Main Table SP)

XXX.XX SUB HEADING (H2 SP)

1. Insert text (Main Table SP)
2. Insert text (Main Table SP)

AMENDMENT CHECKLIST

Specification No. **516** Title: **CRUMB RUBBER OPEN GRADED ASPHALT** Revision No: ________

Project Manager: ____________________ Signature: ________________ Date: ________

Checked by: ____________________ Signature: ________________ Date: ________

Contract No: ____________ Contract Description: ________________________________

ITEM	DESCRIPTION	SIGN OFF
Note: All changes/amendments must be shown in Tracked Changes mode until approved.		
1.	Project Manager has reviewed Specification and identified Additions and Amendments.	
2.	**CONTRACT SPECIFIC REQUIREMENTS** addressed? Contract specific materials, products, clauses added? (Refer Specification Guidance Notes for guidance).	
3.	Any unlisted materials/products proposed and approved by the Project Manager? If "Yes" provide details at 16.	
4.	Standard clauses amended? **MUST SEEK** approval from Manager Commercial.	
5.	Clause deletes shows as **"NOT USED"**.	
6.	Appropriate **INSPECTION AND TESTING** parameters included in Spec 201 (Text Methods, Minimum Testing Frequencies verified).	
7.	**ANNEXURES** completed (refer Specification Guidance Notes).	
8.	**HANDOVER** and **AS BUILT** requirements addressed.	
9.	Main Roads QS has approved changes to **SMM**.	
10.	Project Manager certifies completed Specification reflects intent of the design.	
11.	Completed Specification – independent verification arranged by Project Manager.	
12.	Project Manager's review completed.	
13.	**SPECIFICATION GUIDANCE NOTES** deleted.	
14.	**TABLE OF CONTENTS** updated.	
15.	**FOOTER** updated with Document No., Contract No. and Contract Name.	
16.	Supporting information prepared and submitted to Project Manager.	
Further action necessary:		

Signed: ________________________________ *(Project Manager)* Date: ____________

APPENDIX C WARM MIX ADDITIVES

C.1 Current Main Roads Specifications

Warm mix additives are included in current versions of Main Roads' specifications. These references are summarised in Table C 1.

Table C 1: References to warm mix additives in current Main Roads specifications

Specification	Relevant clause	Relevant extracts
Specification 504 Asphalt Wearing Course	504.01 Scope	1. The work under this specification consists of the supply and application of dense graded and open graded hot-mixed or warm mixed asphalt for pavement wearing courses.
	504.34 Use of organic wax compound	1. Sasobit may be used in the production of open or dense graded asphalt. 4. Where Sasobit is used in the production of hot mixed asphalt the temperature of the mixed asphalt at the discharge point of the asphalt manufacturing plant shall not exceed 170 °C for open or dense graded asphalt. Where produced as warm mix asphalt the mixed asphalt at the discharge point of the asphalt manufacturing plant shall not be less than 130 °C for dense graded asphalt.
	504.41 General	3. Asphalt shall be delivered to the work site at temperatures as follows: • warm mixed dense graded asphalt with Sasobit 135 °C to 155 °C.
Specification 510 Asphalt Intermediate Course	510.26.01 General	8. Asphalt mix designs shall not be designed including RAP, warm mix additives or other materials not specified.
	510.34	1. Sasobit may be used in the production of 14 mm or 20 mm dense graded asphalt. 4. Where Sasobit is used in the production of hot mixed asphalt the temperature of the mixed asphalt at the discharge point of the asphalt manufacturing plant shall not exceed 170 °C for open or dense graded asphalt. Where produced as warm mix asphalt the mixed asphalt at the discharge point of the asphalt manufacturing plant shall not be less than 130 °C for dense graded asphalt.
	510.41 General	3. Asphalt shall be delivered to the work site at temperatures as follows: • warm mixed dense graded asphalt with Sasobit 125 °C to 155 °C.

Sasobit is the only warm mix additive mentioned to be used as a warm mix technology. Specification 504 is silent on whether the warm mix technology may be included during the design process, with Specification 510 not allowing it.

C.2 Types of Warm Mix Technologies

There are various warm mix technologies marketed, which can be broadly grouped into one of the following four groups, namely:

1. Some type of organic additive or wax, such as Sasobit
2. A chemical additive or surfactant, emulsion systems, such as Evotherm®
3. Water for foaming, such as Astec Industries Double Barrel Green (Cheng, Hicks & Lane 2011)
4. Inorganic chemical additives, such as synthetic zeolite which creates a foaming effect in the binder when added e.g. Aspha-min (Wu, Herrington and Neaylon 2015).

The processes which use organic additives or waxes exhibit a decrease in the viscosity when heated above the melting point of the wax, allowing for mixing and coating. The processes using surfactants work via a variety of different chemical mechanisms. The processes that consume water utilise the volume expansion due to the conversion of liquid to gas/steam which causes an expansion of the asphalt binder resulting in a decrease in mix viscosity. The water can be introduced through a foaming operation or by using a material containing internal moisture, such as clay zeolite, or from moist aggregate (Cheng, Hicks & Lane, 2011).

The selection of the process depends on several factors such as how many tonnes of mix will be produced, initial cost, how much temperature reduction is required and if it affects the final binder grade (Cheng, Hicks & Lane, 2011).

Fulton Hogan opted to use Evotherm® as a warm mix additive.

C.3 Evotherm®

Evotherm® is a product developed by MeadWestvaco Asphalt Innovations (Charleston, South Carolina, USA). The earlier product version of Evotherm® was marketed in a package of additives which was used in the form of an emulsion. However, the third generation process of Evotherm (Evotherm 3G) is a water-free WMA. The Evotherm 3G additive is typically incorporated into asphalt binder before it is delivered to asphalt plants. Therefore, there are no equipment changes required either at the plant or job site when using the Evotherm® additive (Austroads 2007, Abdullah et al. 2014.).

The trial specification 516 allowed the use of a warm mix additive, but only at production stage and not during the design stage. Hurley and Prowell (2006) noted that results from the Superpave gyratory compactor indicated that Aspha-min , Sasobit , and Evotherm® may lower the optimum asphalt content, and recommended they should be added during the mix design process.

Kök, Yilmaz and Akpolat (2018) investigated the effects of Evotherm® on conventional and rheological properties of CRM binder. The researchers evaluated mixes with 6%, 8% and 10% crumb rubber and 0.7% Evotherm® by weight of neat bitumen. Penetration, softening point, rotational viscometer (RV), dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests were conducted on base and modified binders. Kök, Yilmaz and Akpolat (2018) concluded that:

- Crumb rubber modification is more effective on increasing softening points than the Evotherm® modification.
- Both the individual and common usage of Evotherm® with crumb rubber have very few effects on reducing the viscosity.
- The use of Evotherm® with 8% and 10% crumb rubber does not contribute to low temperature behaviour of crumb rubber modification but provides more flexible behaviour than the neat bitumen.
- The effects of Evotherm® cannot be evaluated by binder tests in terms of recognising it as a warm-mix additive.

APPENDIX D AGGREGATE PARTICLE DENSITY DISTRIBUTIONS OF INDIVIDUAL FRACTIONS

Table D 1 summarises the particle density distributions of the supplied material to ARRB's Vermont South laboratory.

Table D 1: Supplied aggregate's particle size distributions

Sieve size (mm)	Fraction size				
	10 mm	7 mm	5 mm	Dust	Hydrated lime
	Percentage passing (%)				
26.50	100.0	100.0	100.0	100.0	100.0
19.00	100.0	100.0	100.0	100.0	100.0
13.20	100.0	100.0	100.0	100.0	100.0
9.50	87.3	100.0	100.0	100.0	100.0
6.70	24.0	83.4	100.0	100.0	100.0
4.75	6.9	19.8	75.6	99.8	100.0
2.36	4.1	5.2	13.7	78.0	100.0
1.18	3.8	3.3	7.3	53.5	100.0
0.600	3.6	2.1	5.5	37.9	100.0
0.300	3.3	1.5	4.5	25.6	100.0
0.150	2.8	1.2	3.8	17.1	100.00
0.075	2.0	0.9	3.1	11.6	100.00
Bulk density (t/m^3)	2.714	2.723	2.628	2.554	2.750

APPENDIX E OGA MIX MATERIAL AND DESIGN PROPERTIES

E.1 Aggregate, Mineral Filler and Crumb Rubber Properties

Table E 1 summarises the aggregate and mineral filler properties used in the trial development.

Table E 1: Aggregate and mineral filler properties

Aggregate properties	14 mm	10 mm	7 mm	5 mm	Filler	Requirements
LA abrasion (%)		20				max 35%
Flakiness index (%)		21	15.8	18.7		max 35%
Water absorption – coarse (%)		0.4				max 2%
Water absorption – fine (%)						max 2%
Wet strength (kN)		182				min 100 kN
Dry strength (kN)		211				
Wet/dry strength ratio (%)		14				max 35%
Stripping test value (%)		2				max 10%
Degradation factor		88				min 50
Secondary mineral content (%)						max 25%
Petrographic examination	Suitable for use					Suitable
Voids in dry compacted filler (%)					36.5	≥ 28 and ≤ 45

Table E 2 summarises the aggregate and mineral filler properties used in the trial development.

Table E 2: Crumb rubber properties

Crumb rubber properties		
Bulk density (kg/m^3)	278 kg/m^3	max 350 kg/m^3
Iron or steel content (%)	0%	max 0.1%
Particle shape (mm)	Not reported	max 3 mm
Moisture content (%)	0.40%	max 1%
Sieve size (mm)	% Passing	
2.36	100	100
1.18	100	100
0.6	68.9	min 60
0.3	17.9	max 20
0.075		max 2

E.2 OGA Mix Design Properties

Table E 3 summarises the aggregate mix design of the conforming OGA mix used in the trial development.

Table E 3: Conforming OGA mix design

Sample no.	**Nominal size**		**Type & source**					
1	10 mm		Granite					
2	7 mm		Granite					
3	5 mm		Granite					
4	Dust		Granite					
5	Hydrated lime							
% in mix	**57.0**	**10.0**	**19.5**	**12.0**	**1.5**	**Proposed mix**	**Spec. 504.B4**	
Sieve size (mm)	**Percentage passing (%)**						Minimum	Maximum
26.5	100.0	100.0	100.0	100.0	100.0	100	100	100
19.0	100.0	100.0	100.0	100.0	100.0	100	100	100
13.2	100.0	100.0	100.0	100.0	100.0	100	100	100
9.5	87.3	100.0	100.0	100.0	100.0	93	90	100
6.7	24.0	83.4	100.0	100.0	100.0	55	–	–
4.75	6.9	19.8	75.6	99.8	100.0	34	30	40
2.36	–	5.2	13.7	78.0	100.0	14	10	16
1.18	–	3.3	7.3	53.5	100.0	10	8	14
0.600	–	2.1	5.5	37.9	100.0	7	–	–
0.300	–	1.5	4.5	25.6	100.0	6	4	10
0.150	–	1.2	3.8	17.1	100.0	4	–	–
0.075	–	0.9	3.1	11.6	100.0	3.6	2	4
Bulk density (t/m^3)	2.714	2.723	2.628	2.554	2.750	2.679		

APPENDIX F OGA TRIAL RESULTS

F.1 CRM OGA (Alternative PSD) Result Summary

Table F 1 contains the summarised results from the CRM OGA (Alternative PSD) with target binder content of 5.5% and 5.0%, paved on 17 and 18 March 2019 respectively.

Table F 2 contains the field core results from the CRM OGA (Alternative PSD).

Table F 1: Summary of results for CRM OGA (Alternative PSD)

Sample no.	H3096	H3103	H3104	H3106	H3107	H3108	Requirements
Lot no.	170310OGG/CRMB	170310OGG/CRMB	170310OGG/CRMB	180310OGG/CRMB	180310OGG/CRMB	180310OGG/CRMB	
Report no	PER19W0412	PER19W0412	PER19W0412	PER19W0419	PER19W0419	PER19W0419	
Date sampled	17/03/2019	17/03/2019	17/03/2019	18/03/2019	18/03/2019	18/03/2019	
Date tested	17/03/2019	18/03/2019	18/03/2019	18/03/2019	18/03/2019	18/03/2019	
Asphalt temperature	170	173	173	162	163	165	155–170
Compaction temp	145	144.5	145.3	143	145	145	–
Sieve size (mm)							
13.2	100.0	100.0	100.0	100.0	100.0	100.0	100
9.5	93.0	91.0	92.0	90.0	91.0	91.0	85–95
6.7	63.0	56.0	56.0	51.0	53.0	50.0	38–50
4.75	35.0	26.0	27.0	26.0	30.0	25.0	20–35
2.36	12.0	10.0	10.0	10.0	11.0	10.0	8–14
1.18	7.8	6.9	6.8	6.2	7.1	6.9	5–11
0.6	5.3	5.0	5.3	4.2	4.7	4.9	–
0.3	3.6	3.4	3.6	2.8	2.9	3.3	2–8
0.15	2.5	2.4	2.4	2.1	1.8	2.3	–
0.075	1.7	1.7	1.8	1.5	1.3	1.6	1–5
Target CRM BC	5.5	5.5	5.5	5.0	5.0	5.0	–
BC	4.2	4.1	4.2	4.3	4.4	4.1	–
CRM BC (0.8)	5.3	5.1	5.3	5.4	5.5	5.1	Target±0.3
BRD	2.046	2.040	2.040	2.063	2.083	2.076	–
MTRD	2.551	2.544	2.541	2.585	2.585	2.576	–
Voids	19.8	19.8	19.7	20.2	19.4	19.4	16.0–21.0

Sample no.	H3096	H3103	H3104	H3106	H3107	H3108	Requirements
Lot no.	170310OGG/CRMB	170310OGG/CRMB	170310OGG/CRMB	180310OGG/CRMB	180310OGG/CRMB	180310OGG/CRMB	
Report no	PER19W0412	PER19W0412	PER19W0412	PER19W0419	PER19W0419	PER19W0419	
Date sampled	17/03/2019	17/03/2019	17/03/2019	18/03/2019	18/03/2019	18/03/2019	
Date tested	17/03/2019	18/03/2019	18/03/2019	18/03/2019	18/03/2019	18/03/2019	
VMA	30.1	29.7	28.9	30.8	30.3	29.4	–
VFB	34.2	33.2	31.6	34.3	35.8	34.1	–
Stability	4.0	5.1	5.7	4.8	5.8	5.5	Min 4.0
Flow	3.9	3.7	3.8	3.8	3.2	3.4	2–4
Moisture content	0.01						–
Degree of particle coating	100						–

Table F 2: Summary of field core results for CRM OGA (Alternative PSD)

Sample no.		H3158				
Lot no.		170310OGG/CRMB				
Report no		PER19W0461				
Date sampled		17/03/2019				
Date tested		22/03/2019				
Location		NB L2 8074.06	Start SLK 22.88, length 427m			
Core	**Offset**	**Chainage**	**Thickness**	**In situ voids**	**Field density**	**Density ratio**
1	0.5	25 798.0	33	20.6	2.020	98.9%
2	1	25 782.6	34	18.6	2.073	101.5%
3	1.4	25 663.1	34	20.2	2.032	99.5%
4	2.1	25 587.0	30	17.8	2.091	102.4%
5	1.8	25 495.7	32	21.9	1.987	97.3%
6	4.8	25 863.8	33	22.4	1.976	96.8%
7	3.6	25 771.5	32	23.5	1.948	95.4%
8	4.5	25 638.3	31	21.6	1.996	97.7%
9	5.1	25 588.8	30	26.3	1.876	91.9%
10	4.8	25 494.8	34	20.9	2.013	98.6%
		Mean (R)	32.3	21.4	2.001	98.0%
		Stdev (s)	1.6	2.4	0.061	3.0%
		k				0.75
Mean Marshall		2.042			Rc = R – (k*s)	95.7%
Mean MTRD		2.545			Specification	93.0%
Average of		PER19W0412				

Sample no.		H3159				
Lot no.		180310OGG/CRMB				
Report no		PER19W0462				
Date sampled		18/03/2019				
Date tested		22/03/2019				
Location		NB L1 8074.06	Start SLK 22.54, length 425m			
Core	**Offset**	**Chainage**	**Thickness**	**In situ voids**	**Field density**	**Density ratio**
1	2	25 800.6	32	22.4	2.005	96.7%
2	2.1	25 759.6	31	19.3	2.084	100.5%
3	1.4	25 662.2	30	22.1	2.012	97.0%
4	2.4	25 610.1	34	20.5	2.052	98.9%
5	2.7	25 519.6	32	22.7	1.997	96.3%
6	4.1	25 840.7	30	19.5	2.079	100.2%
7	4.5	25 764.7	31	19.5	2.078	100.2%
8	4.9	25 669.9	32	22.6	1.999	96.4%
9	5.7	25 581.1	31	21.2	2.036	98.2%
10	4.1	25 469.2	32	21.2	2.034	98.1%
		Mean (R)	32	21.1	2.038	98.2%
		Stdev (s)	1.2	1.3	0.034	1.7%
		k				0.75
Mean Marshall		2.074			Rc = R – (k*s)	97.0%
Mean MTRD		2.582			Specification	93.0%
Average of		PER19W0419				

F.2 CRM OGA (Standard PSD) Result Summary

Table F 3 contains the summarised results from the CRM OGA (Standard PSD) with target binder content of 5.5%, paved on 20 and 21 March 2019.

Table F 4 contains the field core results from the CRM OGA (Standard PSD).

Table F 3: Summary of results for CRM OGA (Standard PSD)

Sample no.	H3127	H3128	H3146	H3147	H3148	Requirements
Lot no.	200310OGG/CRMB	200310OGG/CRMB	210310OGG/CRMB	210310OGG/CRMB	210310OGG/CRMB	
Report no	PER19W0595	PER19W0595	PER19W0596	PER19W0596	PER19W0596	
Date sampled	20/03/2019	20/03/2019	21/03/2019	21/03/2019	21/03/2019	
Date tested	21/03/2019	21/03/2019	22/03/2019	22/03/2019	22/03/2019	
Asphalt temperature	153	156	163	160	158	155–170
Compaction temp	145	142	144	144.5	145	–
Sieve size (mm)						
26.5	100.0	100.0	100.0	100.0	100.0	100
19	100.0	100.0	100.0	100.0	100.0	85—95
13.2	100.0	100.0	100.0	100.0	100.0	38—50
9.5	91.0	91.0	91.0	93.0	91.0	20—35
6.7	63.0	63.0	64.0	67.0	65.0	8—14
4.75	38.0	35.0	33.0	41.0	33.0	5—11
2.36	12.0	12.0	13.0	14.0	15.0	–
1.18	7.4	7.7	8.5	9.6	9.8	2—8
0.6	4.9	5.2	5.5	6.9	6.0	–
0.3	3.3	3.5	3.6	4.8	4.0	1—5
0.15	2.4	2.4	2.7	3.1	2.9	–
0.075	1.6	1.6	1.7	1.9	1.8	–
BC	4.4	4.3	4.5	4.5	4.4	Target±0.3
CRM BC (0.8)	5.5	5.4	5.6	5.6	5.5	–
BRD	2.036	2.053	2.05	2.039	2.05	–
MTRD	2.545	2.518	2.504	2.504	2.511	16.0—21.0
Voids	20	18.5	18.2	18.6	18.4	–
VMA	30.6	29	29	29.4	28.3	–
VFB	34.6	36.3	37.5	36.8	35	Min 4.0
Stability	5.0	4.3	6.3	6.1	5.8	2—4

Sample no.	**H3127**	**H3128**	**H3146**	**H3147**	**H3148**	**Requirements**
Lot no.	200310OGG/CRMB	200310OGG/CRMB	210310OGG/CRMB	210310OGG/CRMB	210310OGG/CRMB	
Report no	PER19W0595	PER19W0595	PER19W0596	PER19W0596	PER19W0596	
Date sampled	20/03/2019	20/03/2019	21/03/2019	21/03/2019	21/03/2019	
Date tested	21/03/2019	21/03/2019	22/03/2019	22/03/2019	22/03/2019	
Flow	2.9	3.2	2.8	2.2	3.4	–

Table F 4: Summary of field core results for CRM OGA (Standard PSD)

Sample no.	H3129					
Lot no.	200310OGG/CRMB					
Report no	PER19W0443					
Date sampled	20/03/2019					
Date tested	20/03/2019					
Location	SB L2 8074.01-2	Start SLK 22.54, length 425m				
Core	**Offset**	**Chainage**	**Thickness**	**In situ voids**	**Field density**	**Density ratio**
1	1.7	22 546.8	37	21.7	1.983	97.0%
2	2.6	22 600.8	34	21.2	1.995	97.6%
3	1	22 648.4	35	23.2	1.945	95.1%
4	1.2	22 696.0	33	22.2	1.970	96.4%
5	2.1	22 733.4	31	22.4	1.966	96.2%
6	0.6	22 770.8	30	22.4	1.964	96.1%
7	1.7	22 801.0	36	21.1	1.997	97.7%
8	1.2	22 849.4	34	22.8	1.956	95.7%
9	1.5	22 914.4	34	20.7	2.008	98.2%
10	1	22 942.1	34	23.1	1.946	95.2%
		Mean (R)	34	22.1	1.973	96.5%
		Stdev (s)	2.1	0.9	0.022	1.1%
		k				0.75
Mean Marshall	2.045				Rc = R – (k*s)	95.7%

EMISSION ASSESSMENTS

REPORT NUMBER: 1819-170

ARRB

Ambient Air and Occupational Hygiene Survey - Workplace Exposure Monitoring (Visit 1)

23 July 2019

ATTENTION: Elsabe van Aswegen

DOCUMENT REVIEW				
Version	**Date**	**Status**	**Prepared By**	**Authorised By**
1.0	23 July 2019	Final	Giacomo Collica (EAPL)	Giacomo Collica (EAPL)

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1 ISSUE STATUS OF REPORT

This report is the first issue of data pertaining to the Ambient Air and Occupational Hygiene Survey - Workplace Exposure Monitoring (Visit 1) program. It is considered to be the final issue and most current.

2 INTRODUCTION

Emission Assessments Pty Ltd was engaged by ARRB to undertake an Ambient Air and Occupational Hygiene Survey on pre-selected employees of Fulton Hogan. The survey was conducted on the 17 March and 18 March 2018, whilst bitumen paving at the Rowley Road exit.

3 AIMS AND OBJECTIVES

The objective of the survey was to determine the exposure of a representative cross-section of workers to **Inhalable dust, Volatile Organic Compounds (VOCs), Polyaromatic Hydrocarbons (PAHs)**, whilst the employees carry out their daily duties around site. Additionally, to identify high airborne contaminant (ambient air) work areas in order to apply adequate control.

Three Fulton Hogan employees were fitted with a personal sampler to monitor for inhalable dust, VOCs, PAHs, at their breathing zone over the course over a period of approximately 4.5 hours, of an eight (8) hour shift as detailed in **Table 1**.

Table 1: Worker details and measured analytes

Employee Name	Shift length	Work area / duties	Pollutants monitored
Jane	8 hours	Truck Controller	Inhalable dust, VOCs and PAHs
Ethan	8 hours	Paver Operator	Inhalable dust, VOCs and PAHs
Paul	8 hours	Leading Hand Screed	Inhalable dust, VOCs and PAHs

In addition one static sampler was installed at a location approximately 200 metres from the new road starting location. Although these do not relate to an individual's personal exposure the results can be used to identify areas of concern and aid with the implementation of mitigation measures.

Table 2: Static sampler details and measured analytes

Static sampler location	Pollutants monitored
Location 1: 200 metre from bitumen laying start point.	Ambient Inhalable dust, Ambient VOCs, Ambient PAHs

4 METHODOLOGY

Sampling was undertaken in accordance with:

- Australian Standard AS 3640-2009 *Workplace atmospheres – Method for sampling and gravimetric determination of inhalable dust*;
- NIOSH Method 2549 Issue 1: (1996) Volatile Organic Compounds Screening; and
- NIOSH Method 5506 Issue 3: (1998) Polynuclear Aromatic Hydrocarbons.

4.1 INHALABLE DUST

An SKC Airchek constant flow air sampling pump was used to extract a measured volume of ambient air at each location. Where **personal exposure monitoring** was undertaken the sampler was fitted to the worker and the sampling head was attached to the worker's shirt lapel, to measure from the breathing zone.

For the **static samplers**, the sampling head was positioned at a height that would best equate to the breathing zone of any workers in the area (a height of 1.5 to 2.0m above ground level) and oriented to face the main work activity / source of airborne contaminants.

The air was drawn through a PVC filter housed in an IOM sampler and cassette, at a constant flow rate of 2 litres/minute over a measured time period. Sampling was conducted over an approximate 4.5 hour period in order to obtain a representative sample over the course of a normal working day.

Upon completion of sampling the filters were then recovered and analysed by EAPL for inhalable dust in accordance with NATA accredited methods.

4.2 VOLATILE ORGANIC COMPUNDS (VOCS)

An SKC Airchek constant flow air sampling pump was used to extract a measured volume of ambient air at each location. Where **personal exposure monitoring** was undertaken the sampler was fitted to the worker and the sampling head was attached to the worker's shirt lapel, to measure from the breathing zone.

For the **static sampler (ambient)** the sampling head was positioned at a height that would best equate to the breathing zone of any workers in the area (a height of 1.5 to 2.0m above ground level) and oriented to face the main work activity / source of airborne contaminants. The Canister (which is under vacuum) is opened to the atmosphere and samples under its own vacuum for approximately 4 hours.

The air was drawn through a Charcoal Tube, at a constant flow rate of approximately 0.10 litres/minute over a measured time period. Sampling was conducted over an approximate 4.5 hour period in order to obtain a representative sample over the course of a normal working day.

Upon completion of sampling the tube was then recovered and analysed by MPL for volatile organic compounds in accordance with NATA accredited methods.

4.3 POLY AROMATIC HYDROCARBONS (PAHS)

An SKC Airchek constant flow air sampling pump was used to extract a measured volume of ambient air at each location. Where **personal exposure monitoring** was undertaken the sampler was fitted to the worker and the sampling head was attached to the worker's shirt lapel, to measure from the breathing zone.

For the **static samplers**, the sampling head was positioned at a height that would best equate to the breathing zone of any workers in the area (a height of 1.5 to 2.0m above ground level) and oriented to face the main work activity / source of airborne contaminants.

The air was drawn through a PVC filter and then onto a XAD Tube, at a constant flow rate of 2 litres/minute over a measured time period. Sampling was conducted over an approximate 4.5 hour period in order to obtain a representative sample over the course of a normal working day.

Upon completion of sampling the filters and tube were then recovered and analysed by MPL Laboratories for PAHs.

Raw sampling data is included as **Appendix A**, Chain of Custody documentation and laboratory certificates are included as **Appendix B** (inhalable dust and airborne fibres.

4.4 QUALITY ASSURANCE

Sampling pump calibrations and verifications were performed pre- and post-sampling using a calibrated SKC 320 series rotameter, in accordance with the required procedures. Calibration data is available upon request.

4.5 EXPOSURE STANDARDS

Results have been assessed according to *Occupational Safety and Health Regulations 1996* WA Regulation 3.37 (a) and (b) for atmospheric contaminants.

The regulations prescribe the exposure standards specified in the *Adopted National Exposure Standards for Atmospheric Contaminants in the Occupational Environment* [NOHSC:1003 (1995)]. The standards are described as a time weighted average (TWA), which is the average airborne concentration of a particular substance when calculated over a normal eight-hour working day, for a five-day working week, that should not cause adverse health effects nor cause undue discomfort to nearly all workers. The standards are listed in Error! Reference source not found..

The employees involved in this monitoring campaign however have longer shift lengths (9 hours) and therefore adjustments are made to the exposure standards to account for this, and are calculated using the 'Brief and Scala' model. There are several other mathematical models that

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can be applied but the 'Brief and Scala' model is chosen due to its simplicity, how it takes into account both increased hours of exposure and decreased exposure free time, and is more conservative than other formulas.

The following formula is used to calculate the adjusted TWA Exposure Standards that apply.

$$\textbf{Adjusted exposure standard } (TWA) = \frac{8 * (24 - h) * \textbf{Exposure standard } (8 \textbf{ Hour } TWA)}{16 * h}$$

*Where **h** = hours worked per day*

Table 3: TWA Exposure Standards for Atmospheric Contaminants

Analyte	Unit	TWA Exposure Standard mg/m³	
		8-hour shift	8-hour shift
Inhalable dust	mg/m^3	10	10
PAHs	mg/m^3	-	-
VOCs	mg/m^3	-	-

5 OBSERVATIONS

During the monitoring periods it was observed that none of the workers fitted with personal samplers were wearing respirators which would mitigate against exposure to the identified airborne contaminants.

During the monitoring period, site operations included haulage trucks entering the work zone to unload the hot-mix into the Paver.

Weather conditions experienced during the sampling period have been derived from the Bureau of Meteorology. Weather observations from the closest weather station, Garden Island (station 009256).

Table 4: Weather Observations

Date	Time	Temperature (°C)	Relative Humidity (%)	Wind speed (km/h)	Wind direction	Rain (mm)
18 March 2019	21:00	22	58	N/A	N/A	Nil

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6 RESULTS

The results of the Occupational Hygiene monitoring are summarised in **Table 5** to **Table 10**.

Table 5: Results of Personal Exposure Monitoring Inhalable Dust

Sampling Date dd/mm/yyyy	Worker Name and Position	Concentration mg/m³	Worker Shift Length hours	TWA Exposure limit mg/m³	% of TWA Limit %	Start Time (17/3/19) hh:mm	Finish Time (18/3/2019) hh:mm	Total Sampling Time Minutes	Total Sample Volume Litres
18/3/2019	**Jane** (Truck Controller)	**0.24**	8	10	2.4	23:00	03:30	270	540
18/3/2019	**Ethan** (Paver Operator)	**0.28**	8	10	2.8	23:00	03:30	270	540
18/3/2019	**Paul** (Leading Hand Screed)	**0.35**	8	10	3.5	23:00	03:30	270	540
18/3/2019	**Ambient** (Static Sampler)	**0.09**	8	10	0.9	23:00	03:30	270	540

**Full shift length.*

Table 6: Results of Personal Exposure Monitoring VOCs

Sampling Date dd/mm/yyyy	Compound	**Jane** (Truck Controller)	**Ethan** (Paver Operator)	**Paul** (Leading Hand Screed)
18/3/2019	m and p Xylenes (ug/m3)	167	104	93
18/3/2019	1,2,4 Trimethylbenzene (ug/m3)	48	119	41

**Reportable compounds only. Full list in Appendices*

Table 7: Results of Ambient VOCs

Sampling Date dd/mm/yyyy	Compound	Ambient (Static Sampler) ug/m3
18/3/2019	Dichlorodifluoromethane	5.8
18/3/2019	Acetone	5.8
18/3/2019	Ethanol	3.2
18/3/2019	Heptane	7.8
18/3/2019	Toluene	16
18/3/2019	Ethylbenzene	13
18/3/2019	m & p-Xylenes	66
18/3/2019	o-Xylene	27
18/3/2019	4-Ethyltoluene	8
18/3/2019	1,3,5-Trimethylbenzene	18
18/3/2019	1,2,4-Trimethylbenzene	43

**Reportable compounds only. Full list in Appendices*

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Table 8: Results of Ambient PAHs (Poly Aromatic Hydrocarbons)

Sampling Date dd/mm/yyyy	**Compound**	**Ambient** (Static Sampler) ug/m3
18/3/2019	TPH >C8-C10	150
18/3/2019	TPH >10-C12	55
18/3/2019	Toluene	16
18/3/2019	Ethylbenzene	13
18/3/2019	m&p Xylenes	66
18/3/2019	o-Xylenes	27
18/3/2019	TPH >10-C12 Less Naphthalene	55

**Detected compounds only. Full suite in Appendices.*

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Table 9: Results of Ambient TRSs (Total Reduced Sulphur)

Sampling Date dd/mm/yyyy	**Compound**	**Ambient** (Static Sampler) ug/m3
18/3/2019	Hydrogen Sulfide	<20
18/3/2019	Carbonyl Sulfide	<10
18/3/2019	Methyl Mercaptan	<9
18/3/2019	Ethyl Mercaptan	<10
18/3/2019	Dimethyl Sulfide	<10
18/3/2019	Isopropyl Mercaptan	<10
18/3/2019	n-Propyl Mercaptan	<10
18/3/2019	Ethyl methyl Sulfide	<10
18/3/2019	tert-Butyl Mercaptan	<20
18/3/2019	Dimethyl Disulfide	<20
18/3/2019	n-Butyl Mercaptan	<20

**All compounds*

Table 10: Results of Personal Exposure Monitoring PAHs

Sampling Date dd/mm/yyyy	**Compound**	**Jane** (Truck Controller**)**	**Ethan** (Paver Operator)	**Paul** (Leading Hand Screed)	**Ambient** (Static Monitor)
18/3/2019	Naphthalene (ug/m3)	**1.3**	**1.9**	**1.3**	**1.9**

**Reportable compounds only. Full list in Appendices*

EMISSION ASSESSMENTS
AIR QUALITY & NOISE

7 CONCLUSION

The results of the Ambient Air and Occupational Hygiene Monitoring conducted for ARRB during bitumen paving has indicated that all Inhalable Dust results were below the exposure standard of 10 mg/m^3. Polycyclic Aromatic Compounds (PAHs) were not detected and Volatile Organic Compounds (VOCs) detected were detected at low concentrations.

Ambient monitoring (static monitoring) has indicated a similar exposure with Inhalable Dust results were below the exposure standard of 10 mg/m^3. Polycyclic Aromatic Compounds (PAHs) were undetected and Volatile Organic Compounds (VOCs) were detected at low concentrations.

Further, and extended analytical suite for Ambient VOCs has indicated that Total Petroleum Hydrocarbons (TPHs) were detected at low levels and Reduced Sulfur Compounds were not detected at the static monitoring location.

The results of the Occupational Hygiene Survey would indicate the levels of airborne contaminants at the work site are being adequately controlled with regards to the impact on the workers' personal exposure.

APPENDIX A

Table of Results

Report Number	1819-170 (A)
Client	ARRB
Sampling Date	17 - 18 March 2019
Hygienest	Giacomo Collica
Test	Volatile Organic Compounds (Ambient)
Canister Method	(4 Hours)

Dichlorodifluoromethane	**5.8**	**ug/m3**
Acetone	**5.8**	**ug/m3**
Ethanol	**3.2**	**ug/m3**
Heptane	**7.8**	**ug/m3**
Toluene	**16**	**ug/m3**
Ethylbenzene	**13**	**ug/m3**
m & p-Xylenes	**66**	**ug/m3**
o-Xylene	**27**	**ug/m3**
4-Ethyltoluene	**8**	**ug/m3**
1,3,5-Trimethylbenzene	**18**	**ug/m3**
1,2,4-Trimethylbenzene	**43**	**ug/m3**
Propene	<0.9	ug/m3
Chloromethane	<3	ug/m3
1,2-Dichlorotetrafluoroethane	<3	ug/m3
Vinyl chloride	<1	ug/m3
1,3-Butadiene	<1	ug/m3
Bromomethane	<8	ug/m3
Chloroethane	<1	ug/m3
Acrolein	<1	ug/m3
2-Propanol	<1	ug/m3
Trichlorofluoromethane	<3	ug/m3
1,1-Dichloroethene	<2	ug/m3
Dichloromethane	<4	ug/m3
1,1,2-Trichloro-1,2,2 trifluoroethane	<4	ug/m3
Carbon disulfide	<2	ug/m3
trans-1,2-Dichloroethene	<2	ug/m3
1,1-Dichloroethane	<2	ug/m3
Methyl-tert-butylether (MTBE)	<2	ug/m3
Vinyl acetate	<2	ug/m3
2-Butanone (MEK)	<1	ug/m3
cis-1,2-Dichloroethene	<2	ug/m3
Hexane	<2	ug/m3
Chloroform	<2	ug/m3
Ethyl Acetate	<2	ug/m3
Tetrahydrofuran	<1	ug/m3
1,2-Dichloroethane	<2	ug/m3
1,1,1-Trichloroethane	<2	ug/m3
Benzene	<4	ug/m3
Carbon tetrachloride	<3	ug/m3
Cyclohexane	<2	ug/m3
1,2-Dichloropropane	<2	ug/m3
Bromodichloromethane	<3	ug/m3
Trichloroethene	<3	ug/m3
1,4-Dioxane	<2	ug/m3
Methyl methacrylate	<2	ug/m3
cis-1,3-Dichloropropene	<2	ug/m3
4-Methyl-2-pentanone (MIBK)	<2	ug/m3
trans-1,3-Dichloropropene	<2	ug/m3
1,1,2-Trichloroethane	<3	ug/m3
2-Hexanone (MBK)	<2	ug/m3
Dibromochloromethane	<4	ug/m3
1,2-Dibromoethane	<4	ug/m3
Tetrachloroethylene	<3	ug/m3
Chlorobenzene	<3	ug/m3
Bromoform	<5	ug/m3
Styrene	<2	ug/m3
1,1,2,2-Tetrachloroethane	<2	ug/m3
Benzyl Chloride	<3	ug/m3
1,3-Dichlorobenzene	<3	ug/m3
1,4-Dichlorobenzene	<3	ug/m3
1,2-Dichlorobenzene	<3	ug/m3
1,2,4-Trichlorobenzene	<4	ug/m3
Hexachlorobutadiene	<5	ug/m3
Naphthalene	<7	ug/m3

Report Number	1819-170 (A)
Client	ARRB
Sampling Date	17 - 18 March 2019
Hygienest	Giacomo Collica
Test	Total Petroleum Hydrocarbons (Ambient)
Canister Method	(4 Hours)

Alphatic		
TPH C5-C6	<20	ug/m3
TPH >C6-C8	<20	ug/m3
TPH >C*-C10	<30	ug/m3
TPH >C10-C12	<100	ug/m3
Aromatic		**ug/m3**
TPH C6-C8	<20	ug/m3
TPH >C8-C10	**150**	**ug/m3**
TPH >10-C12	**55**	
BTEX		**ug/m3**
Benzene	**<4**	**ug/m3**
Toluene	**16**	**ug/m3**
Ethylbenzene	**13**	**ug/m3**
m&p Xylenes	**66**	**ug/m3**
o-Xylenes	**27**	**ug/m3**
Naphthalene	<7	ug/m3
NEPM F1		ug/m3
TPH C6-C10 less BTEX	<30	ug/m3
NEPM F2		ug/m3
TPH >10-C12 less Napthalene	**55**	**ug/m3**

Report Number	1819-170 (A)
Client	ARRB
Sampling Date	17 - 18 March 2019
Hygienest	Giacomo Collica
Test	Sulfide (Ambient)
Canister Method	(4 Hours)

Hydrogen Sulfide	<20	ug/m3
Carbonyl Sulfide	<10	ug/m3
Methyl Mercaptan	<9	ug/m3
Ethyl Mercaptan	<10	ug/m3
Demethyl Sulfide	<10	ug/m3
Isopropyl Mercaptan	<10	ug/m3
n-Propyl Mercptan	<10	ug/m3
Ethylmethyl Sufide	<10	ug/m3
tert-Butyl Mercaptan	<20	ug/m3
Demethyl Disufide	<20	ug/m3
n-Butyl Mercaptan	<20	ug/m3

Report Number	1819-170 (A)
Client	ARRB
Sampling Date	17 - 18 March 2019
Hygienest	Giacomo Collica
Test	Inhalable Dust

	1819170-001	1819170-002	1819170-003	1819170-004
Sample Volume (L) **540**	Jane	Ethan	Paul	Ambient
Inhalable Dust (Total mg)	**0.13**	**0.15**	**0.19**	**0.05**
Inhalable Dust (mg/m3)	**0.24**	**0.28**	**0.35**	**0.09**
Inhalable Dust (MDL)	0.0019			

Report Number	1819-170 (A)
Client	ARRB
Sampling Date	17 - 18 March 2019
Hygienest	Giacomo Collica
Test	PAHs

	1819170-010	1819170-011	1819170-012	1819170-013	1819170-014
Sample Volume (L) **540**	Jane	Ethan	Paul	Ambient	Blank
Naphthalene (Total ug)	**0.7**	**1.0**	**0.7**	**1.0**	**<0.5**
Naphthalene (ug/m3)	**1.3**	**1.9**	**1.3**	**1.9**	**Nil**
Acenaphthylene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Acenaphthene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Fluorene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Phenanthrene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Anthracene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Fluoranthene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Pyrene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Benzo(a)anthracene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Chrysene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Benzo(b,j+k)fluoranthene	<0.0019	<0.0019	<0.0019	<0.0019	<0.0019
Benzo(a)pyrene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Indeno(1,2,3-c,d)pyrene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Dibenzo(a,h)anthracene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093
Benzo(g,h,i)perylene	<0.00093	<0.00093	<0.00093	<0.00093	<0.00093

Report Number	1819-170 (A)
Client	ARRB
Sampling Date	17 - 18 March 2019
Hygienest	Giacomo Collica
Test	Volatile Organic Compounds

	1819170-005	1819170-006	1819170-007	1819170-008
Sample Volume (L)	Jane	Ethan	Paul	Blank
27.0				
Benzene	<1	<1	<1	<1
Toluene	<1	<1	<1	<1
Ethylbenzene	<1	<1	<1	<1
m & p-Xylenes (total ug)	**4.5**	**2.8**	**2.5**	**<2**
m & p-Xylenes (ug/m3)	**167**	**104**	**93**	**Nil**
o-Xylene	<1	<1	<1	<1
Styrene	<1	<1	<1	<1
Isopropylbenzene	<1	<1	<1	<1
n-Propylbenzene	<1	<1	<1	<1
1,3,5-Trimethylbenzene	<1	<1	<1	<1
tert-Butylbenzene	<1	<1	<1	<1
1,2,4-Trimethylbenzene (Toal ug)	**1.3**	**3.2**	**1.1**	**<1**
1,2,4-Trimethylbenzene (ug/m3)	**48**	**119**	**41**	**Nil**
sec-Butylbenzene	<1	<1	<1	<1
4-Isopropyltoluene	<1	<1	<1	<1
n-Butylbenzene	<1	<1	<1	<1
Dichlorodifluoromethane	<1	<1	<1	<1
Chloromethane	<1	<1	<1	<1
Vinyl chloride	<1	<1	<1	<1
Bromomethane	<1	<1	<1	<1
Chloroethane	<1	<1	<1	<1
Trichlorofluoromethane	<1	<1	<1	<1
1,1-Dichloroethane	<1	<1	<1	<1
Dichloromethane	<1	<1	<1	<1
trans-1,2-Dichloroethene	<1	<1	<1	<1
1,1-Dichloroethene	<1	<1	<1	<1
2,2-Dichloropropane	<1	<1	<1	<1
cis-1,2-Dichloroethene	<1	<1	<1	<1
Bromochloromethane	<1	<1	<1	<1
1,1,1-Trichloroethane	<1	<1	<1	<1
Carbon tetrachloride	<1	<1	<1	<1
1,1-Dichloropropene	<1	<1	<1	<1
1,2-Dichloroethane	<1	<1	<1	<1
Trichloroethene	<1	<1	<1	<1
1,2-Dichloropropane	<1	<1	<1	<1
Dibromomethane	<1	<1	<1	<1
cis-1,3-Dichloropropene	<1	<1	<1	<1
trans-1,3-Dichloropropene	<1	<1	<1	<1
1,1,2-Trichloroethane	<1	<1	<1	<1
Tetrachloroethene	<1	<1	<1	<1
1,3-Dichloropropane	<1	<1	<1	<1
1,2-Dibromoethane	<1	<1	<1	<1
1,1,1,2-Tetrachloroethane	<1	<1	<1	<1
1,1,2,2-Tetrachloroethane	<1	<1	<1	<1
1,2,3-Trichloropropane	<1	<1	<1	<1
1,2-Dibromo-3-chloropropane	<1	<1	<1	<1
Hexachlorobutadiene	<1	<1	<1	<1
Chlorobenzene	<1	<1	<1	<1
Bromobenzene	<1	<1	<1	<1
2-Chlorotoluene	<1	<1	<1	<1
4-Chlorotoluene	<1	<1	<1	<1
1,3-Dichlorobenzene	<1	<1	<1	<1
1,4-Dichlorobenzene	<1	<1	<1	<1
1,2-Dichlorobenzene	<1	<1	<1	<1
1,2,4-Trichlorobenzene	<1	<1	<1	<1
1,2,3-Trichlorobenzene	<1	<1	<1	<1
Chloroform	<1	<1	<1	<1
Bromodichloromethane	<1	<1	<1	<1
Dibromochloromethane	<1	<1	<1	<1
Bromoform	<1	<1	<1	<1
Naphthalene	<1	<1	<1	<1

APPENDIX B

Analytical Reports and Chain of Custody

Envirolab Services (WA) Pty Ltd trading as MPL Laboratories
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16-18 Hayden Court Myaree WA 6154
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CERTIFICATE OF ANALYSIS 223977

Client Details

Client	Emission Assessments Pty ltd
Attention	Giacomo Collica
Address	Unit 6, 35 Sustainable Ave, Bibra Lake, WA, 6163

Sample Details

Your Reference	**1819-170**
Number of Samples	5 filter and 5 tube
Date samples received	19/03/2019
Date completed instructions received	19/03/2019
Sampler Name	Not applicable for this job

Analysis Details

Please refer to the following pages for results, methodology summary and quality control data.

Samples were analysed as received from the client. Results relate specifically to the samples as received.

Report Details

Date results requested by	26/03/2019
Date of Issue	26/03/2019

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Results Approved By
Michael Kubiak, Laboratory Manager

Authorised By

Michael Kubiak, Laboratory Manager

PAH in Tube							
Our Reference			223977-1	223977-2	223977-3	223977-4	223977-5
Your Reference	UNITS	PQL	1819170-010	1819170-011	1819170-012	1819170-013	1819170-014
Date Sampled			18/03/2019	18/03/2019	18/03/2019	18/03/2019	18/03/2019
Type of sample			Filter and Tube	Filter and Tube	Filter and Tube	Filter and Tube	Filter and Tube
Date extracted	-		20/03/2019	20/03/2019	20/03/2019	20/03/2019	20/03/2019
Date analysed	-		21/03/2019	21/03/2019	21/03/2019	21/03/2019	21/03/2019
Naphthalene	µg/tube	0.5	0.7	1	0.7	1	<0.5
Acenaphthylene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Acenaphthene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluorene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Phenanthrene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Anthracene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluoranthene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Pyrene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(a)anthracene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chrysene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(b,j+k)fluoranthene	µg/tube	1	<1	<1	<1	<1	<1
Benzo(a)pyrene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1,2,3-c,d)pyrene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dibenzo(a,h)anthracene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(g,h,i)perylene	µg/tube	0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Surrogate p-Terphenyl-D_{14}	%		96	102	94	96	96

PAH in filters							
Our Reference			223977-1	223977-2	223977-3	223977-4	223977-5
Your Reference	UNITS	PQL	1819170-010	1819170-011	1819170-012	1819170-013	1819170-014
Date Sampled			18/03/2019	18/03/2019	18/03/2019	18/03/2019	18/03/2019
Type of sample			Filter and Tube	Filter and Tube	Filter and Tube	Filter and Tube	Filter and Tube
Date extracted	-		20/03/2019	20/03/2019	20/03/2019	20/03/2019	20/03/2019
Date analysed	-		21/03/2019	21/03/2019	21/03/2019	21/03/2019	21/03/2019
Naphthalene	µg/filter	1	<1	<1	<1	<1	<1
Acenaphthylene	µg/filter	1	<1	<1	<1	<1	<1
Acenaphthene	µg/filter	1	<1	<1	<1	<1	<1
Fluorene	µg/filter	1	<1	<1	<1	<1	<1
Phenanthrene	µg/filter	1	<1	<1	<1	<1	<1
Anthracene	µg/filter	1	<1	<1	<1	<1	<1
Fluoranthene	µg/filter	1	<1	<1	<1	<1	<1
Pyrene	µg/filter	1	<1	<1	<1	<1	<1
Benzo(a)anthracene	µg/filter	1	<1	<1	<1	<1	<1
Chrysene	µg/filter	1	<1	<1	<1	<1	<1
Benzo(b,j+k)fluoranthene	µg/filter	2	<2	<2	<2	<2	<2
Benzo(a)pyrene	µg/filter	1	<1	<1	<1	<1	<1
Indeno(1,2,3-c,d)pyrene	µg/filter	1	<1	<1	<1	<1	<1
Dibenzo(a,h)anthracene	µg/filter	1	<1	<1	<1	<1	<1
Benzo(g,h,i)perylene	µg/filter	1	<1	<1	<1	<1	<1
Surrogate p-Terphenyl-D_{14}	%		90	94	96	102	114

Method ID	Methodology Summary
ORG-012	Soil samples are extracted with Dichloromethane/Acetone and waters with Dichloromethane and analysed by GC-MS. Benzo(a)pyrene TEQ as per NEPM draft B1 Guideline on Investigation Levels for Soil and Groundwater.
ORG-012/017/033	SVOC on Sorbents extracted with various solvents and analysed by GC-MS and/or GC-MS/MS.

QUALITY CONTROL: PAH in Tube					Duplicate					Spike Recovery %	
Test Description	Units	PQL	Method	Blank	#	Base	Dup.	RPD	LCS-1	[NT]
Date extracted	-			20/03/2019	[NT]	[NT]	[NT]	[NT]	20/03/2019	[NT]
Date analysed	-			21/03/2019	[NT]	[NT]	[NT]	[NT]	21/03/2019	[NT]
Naphthalene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	78	[NT]
Acenaphthylene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Acenaphthene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Fluorene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	84	[NT]
Phenanthrene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	86	[NT]
Anthracene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Fluoranthene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	82	[NT]
Pyrene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	84	[NT]
Benzo(a)anthracene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Chrysene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	83	[NT]
Benzo(b,j+k)fluoranthene	µg/tube	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Benzo(a)pyrene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	82	[NT]
Indeno(1,2,3-c,d)pyrene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Dibenzo(a,h)anthracene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Benzo(g,h,i)perylene	µg/tube	0.5	ORG-012/017/033	<0.5	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Surrogate p-Terphenyl-D_{14}	%		ORG-012/017/033	110	[NT]	[NT]	[NT]	[NT]	96	[NT]

QUALITY CONTROL: PAH in filters					Duplicate				Spike Recovery %	
Test Description	Units	PQL	Method	Blank	#	Base	Dup.	RPD	LCS-1	[NT]
Date extracted	-			20/03/2019	[NT]	[NT]	[NT]	[NT]	20/03/2019	[NT]
Date analysed	-			21/03/2019	[NT]	[NT]	[NT]	[NT]	21/03/2019	[NT]
Naphthalene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	95	[NT]
Acenaphthylene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Acenaphthene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Fluorene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	96	[NT]
Phenanthrene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	100	[NT]
Anthracene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Fluoranthene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	93	[NT]
Pyrene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	96	[NT]
Benzo(a)anthracene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Chrysene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	96	[NT]
Benzo(b,j+k)fluoranthene	µg/filter	2	ORG-012/017/033	<2	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Benzo(a)pyrene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	91	[NT]
Indeno(1,2,3-c,d)pyrene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Dibenzo(a,h)anthracene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Benzo(g,h,i)perylene	µg/filter	1	ORG-012/017/033	<1	[NT]	[NT]	[NT]	[NT]	[NT]	[NT]
Surrogate p-Terphenyl-D_{14}	%		ORG-012	100	[NT]	[NT]	[NT]	[NT]	106	[NT]

Result Definitions

DOL	Samples rejected due to particulate overload
RPF	Sample rejected due to pump failure
RFD	Sample rejected due to filter damage
RUD	Sample rejected due to uneven deposition
PQL	Practical quantitation limit

Quality Control Definitions

Blank	This is the component of the analytical signal which is not derived from the sample but from reagents, glassware etc, can be determined by processing solvents and reagents in exactly the same manner as for samples.
Duplicate	This is the complete duplicate analysis of a sample from the process batch. If possible, the sample selected should be one where the analyte concentration is easily measurable.
Matrix Spike	A portion of the sample is spiked with a known concentration of target analyte. The purpose of the matrix spike is to monitor the performance of the analytical method used and to determine whether matrix interferences exist.
LCS (Laboratory Control Sample)	This comprises either a standard reference material or a control matrix (such as a blank sand or water) fortified with analytes representative of the analyte class. It is simply a check sample.
Surrogate Spike	Surrogates are known additions to each sample, blank, matrix spike and LCS in a batch, of compounds which are similar to the analyte of interest, however are not expected to be found in real samples.
Australian Drinking Water Guidelines recommend that Thermotolerant Coliform, Faecal Enterococci, & E.Coli levels are less than 1cfu/100mL. The recommended maximums are taken from "Australian Drinking Water Guidelines", published by NHMRC & ARMC 2011.	
The recommended maximums for analytes in urine are taken from “2018 TLVs and BEIs”, as published by ACGIH (where available).	

Laboratory Acceptance Criteria

Duplicate sample and matrix spike recoveries may not be reported on smaller jobs, however, were analysed at a frequency to meet or exceed NEPM requirements. All samples are tested in batches of 20. The duplicate sample RPD and matrix spike recoveries for the batch were within the laboratory acceptance criteria.

Filters, swabs, wipes, tubes and badges will not have duplicate data as the whole sample is generally extracted during sample extraction.

Spikes for Physical and Aggregate Tests are not applicable.

For VOCs in water samples, three vials are required for duplicate or spike analysis.

Duplicates: >10xPQL - RPD acceptance criteria will vary depending on the analytes and the analytical techniques but is typically in the range 20%-50% – see ELN-P05 QA/QC tables for details; <10xPQL - RPD are higher as the results approach PQL and the estimated measurement uncertainty will statistically increase.

Matrix Spikes, LCS and Surrogate recoveries: Generally 70-130% for inorganics/metals; 60-140% for organics (+/-50% surrogates) a

In circumstances where no duplicate and/or sample spike has been reported at 1 in 10 and/or 1 in 20 samples respectively, the sample volume submitted was insufficient in order to satisfy laboratory QA/QC protocols.

When samples are received where certain analytes are outside of recommended technical holding times (THTs), the analysis has proceeded. Where analytes are on the verge of breaching THTs, every effort will be made to analyse within the THT or as soon as practicable.

Where sampling dates are not provided, Envirolab are not in a position to comment on the validity of the analysis where recommended technical holding times may have been breached.

Measurement Uncertainty estimates are available for most tests upon request.

EMISSION ASSESSMENTS

TO BE COMPLETED BY SUB-CONTRACTED LABORATORY:

Date Received: 19/3/19

Time Received: 1455

Expected Date of Completion:

Sample Condition on Arrival:

Name and Signature: C. Tadena

EAPL Job Number: 1819-170

CHAIN OF CUSTODY – SAMPLE DETAILS

EAPL Contact Person: **Giacomo Collica**

Phone: 9494 2958

Requested Completion Date: **10 days**

PLEASE RETURN THIS COMPLETED PAGE TO EMISSION ASSESSMENTS ON FAX NO. (08) 9494 2959

EAPL Sample Number	Sample Details	Date Collected	Media/Matrix	Filter / Tube Number	Analysis/Suite
1 1819170-010	Poly Aromatic Hydrocarbons (Jane)	18/03/2019	Filter and Tube	F074 + 3074	PAHs
2 1819170-011	Poly Aromatic Hydrocarbons (Ethan)	18/03/2019	Filter and Tube	F071 + 3071	PAHs
3 1819170-012	Poly Aromatic Hydrocarbons (Paul)	18/03/2019	Filter and Tube	F073 + 3073	PAHs
4 1819170-013	Poly Aromatic Hydrocarbons (Ambient)	18/03/2019	Filter and Tube	F072 + 3072	PAHs
5 1819170-014	Poly Aromatic Hydrocarbons (Blank)	18/03/2019	Filter and Tube	F075 + 3075	PAHs

mpl Laboratories Envirolab Group

Job No.- 223977

Date Rec - 19/3

Time Rec - 1455

Rec By - CT

TAT Req - SAME 1 / 2 / 3 / STD

Temp - cool / ambient

Cooling - Ice / Ice pack / None

Security Seal - Yes / No

T +61 8 9494 2958
F +61 8 9494 2959
E science@emissionassessments.com.au
A Unit 6, 35 Sustainable Avenue, Bibra Lake 6163
PO Box 1272, Bibra Lake DC 6965
www.emissionassessments.com.au

Emission Assessments Pty Ltd ABN 88 133 000 049

EMISSION ASSESSMENTS

MPL
16-18 Hayden Court
Myaree WA 6154

ATTENTION: SAMPLE RECEIVABLE
Ms Kiara Lockerbie

Please find enclosed a total of **4** samples. A detailed outline of the samples sent and the analyses required is given in the attached Chain of Custody.

EAPL Job Number:	1819-170
Laboratory Quote Number:	**Email 11 March K.Lockerbie**
EAPL PO Number:	**PO1819215**
Date of Sample Submission:	19/03/2019

QUALITY CONTROL REQUESTS:
Please report all internal quality control results including recoveries of certified reference materials, duplicate and laboratory blank analysis, surrogates/spikes etc for all samples provided.

REPORTING OF RESULTS:
- Please issue a soft copy via email to: **data@eapl.net.au**
- To reduce paper use **please do not issue a hardcopy.**

Please do not hesitate to contact the undersigned should there be any query with this request.

Yours sincerely,

For Emission Assessments Pty Ltd.

Giacomo Collica

REPORT OF ANALYSIS

Client	: EMISSION ASSESSMENTS PTY LTD UNIT 6 / 35 SUSTAINABLE AVENUE BIBRA LAKE WA 6163	**Job No.**	: EMIS02/190320
		Quote No.	: QT-01541
		Order No.	: PO1819-206
		Date Received	: 20-MAR-2019
Attention	: GIACOMO COLLICA	**Sampled By**	: CLIENT
Project Name	:		
Your Client Services Manager	: Richard Coghlan	**Phone**	: 02 9449 0161

Lab Reg No.	Sample Ref	Sample Description
N19/007213	1819170-005	VOC TUBE 226-16 18/03/2019 JOB: 1819-170
N19/007214	1819170-006	VOC TUBE 226-16 18/03/2019 JOB: 1819-170
N19/007215	1819170-007	VOC TUBE 226-16 18/03/2019 JOB: 1819-170
N19/007216	1819170-008	VOC TUBE 226-16 18/03/2019 JOB: 1819-170

Lab Reg No.		**N19/007213**	**N19/007214**	**N19/007215**	**N19/007216**	
Date Sampled		**18-MAR-2019**	**18-MAR-2019**	**18-MAR-2019**	**18-MAR-2019**	
Sample Reference	**Units**	**1819170-005**	**1819170-006**	**1819170-007**	**1819170-008**	**Method**
Monocyclic Aromatic Hydrocarbons NMI 1120 Screen						
Benzene	ug	<1	<1	<1	<1	NGCMS_1120
Toluene	ug	<1	<1	<1	<1	NGCMS_1120
Ethylbenzene	ug	<1	<1	<1	<1	NGCMS_1120
m & p-Xylenes	ug	4.5	2.8	2.5	<2	NGCMS_1120
o-Xylene	ug	<1	<1	<1	<1	NGCMS_1120
Styrene	ug	<1	<1	<1	<1	NGCMS_1120
Isopropylbenzene	ug	<1	<1	<1	<1	NGCMS_1120
n-Propylbenzene	ug	<1	<1	<1	<1	NGCMS_1120
1,3,5-Trimethylbenzene	ug	<1	<1	<1	<1	NGCMS_1120
tert-Butylbenzene	ug	<1	<1	<1	<1	NGCMS_1120
1,2,4-Trimethylbenzene	ug	1.3	3.2	1.1	<1	NGCMS_1120
sec-Butylbenzene	ug	<1	<1	<1	<1	NGCMS_1120
4-Isopropyltoluene	ug	<1	<1	<1	<1	NGCMS_1120
n-Butylbenzene	ug	<1	<1	<1	<1	NGCMS_1120
Halogenated Aliphatic Hydrocarbons NMI 1120 Screen						
Dichlorodifluoromethane	ug	<1	<1	<1	<1	NGCMS_1120
Chloromethane	ug	<1	<1	<1	<1	NGCMS_1120
Vinyl chloride	ug	<1	<1	<1	<1	NGCMS_1120
Bromomethane	ug	<1	<1	<1	<1	NGCMS_1120
Chloroethane	ug	<1	<1	<1	<1	NGCMS_1120
Trichlorofluoromethane	ug	<1	<1	<1	<1	NGCMS_1120
1,1-Dichloroethane	ug	<1	<1	<1	<1	NGCMS_1120
Dichloromethane	ug	<1	<1	<1	<1	NGCMS_1120
trans-1,2-Dichloroethene	ug	<1	<1	<1	<1	NGCMS_1120
1,1-Dichloroethene	ug	<1	<1	<1	<1	NGCMS_1120
2,2-Dichloropropane	ug	<1	<1	<1	<1	NGCMS_1120

REPORT OF ANALYSIS

Report No. RN1226788

Lab Reg No.		N19/007213	N19/007214	N19/007215	N19/007216	
Date Sampled		18-MAR-2019	18-MAR-2019	18-MAR-2019	18-MAR-2019	
Sample Reference	Units	1819170-005	1819170-006	1819170-007	1819170-008	Method
Halogenated Aliphatic Hydrocarbons NMI 1120 Screen						
cis-1,2-Dichloroethene	ug	<1	<1	<1	<1	NGCMS_1120
Bromochloromethane	ug	<1	<1	<1	<1	NGCMS_1120
1,1,1-Trichloroethane	ug	<1	<1	<1	<1	NGCMS_1120
Carbon tetrachloride	ug	<1	<1	<1	<1	NGCMS_1120
1,1-Dichloropropene	ug	<1	<1	<1	<1	NGCMS_1120
1,2-Dichloroethane	ug	<1	<1	<1	<1	NGCMS_1120
Trichloroethene	ug	<1	<1	<1	<1	NGCMS_1120
1,2-Dichloropropane	ug	<1	<1	<1	<1	NGCMS_1120
Dibromomethane	ug	<1	<1	<1	<1	NGCMS_1120
cis-1,3-Dichloropropene	ug	<1	<1	<1	<1	NGCMS_1120
trans-1,3-Dichloropropene	ug	<1	<1	<1	<1	NGCMS_1120
1,1,2-Trichloroethane	ug	<1	<1	<1	<1	NGCMS_1120
Tetrachloroethene	ug	<1	<1	<1	<1	NGCMS_1120
1,3-Dichloropropane	ug	<1	<1	<1	<1	NGCMS_1120
1,2-Dibromoethane	ug	<1	<1	<1	<1	NGCMS_1120
1,1,1,2-Tetrachloroethane	ug	<1	<1	<1	<1	NGCMS_1120
1,1,2,2-Tetrachloroethane	ug	<1	<1	<1	<1	NGCMS_1120
1,2,3-Trichloropropane	ug	<1	<1	<1	<1	NGCMS_1120
1,2-Dibromo-3-chloropropane	ug	<1	<1	<1	<1	NGCMS_1120
Hexachlorobutadiene	ug	<1	<1	<1	<1	NGCMS_1120
Halogenated Aromatic Hydrocarbons NMI 1120 Screen						
Chlorobenzene	ug	<1	<1	<1	<1	NGCMS_1120
Bromobenzene	ug	<1	<1	<1	<1	NGCMS_1120
2-Chlorotoluene	ug	<1	<1	<1	<1	NGCMS_1120
4-Chlorotoluene	ug	<1	<1	<1	<1	NGCMS_1120
1,3-Dichlorobenzene	ug	<1	<1	<1	<1	NGCMS_1120
1,4-Dichlorobenzene	ug	<1	<1	<1	<1	NGCMS_1120
1,2-Dichlorobenzene	ug	<1	<1	<1	<1	NGCMS_1120
1,2,4-Trichlorobenzene	ug	<1	<1	<1	<1	NGCMS_1120
1,2,3-Trichlorobenzene	ug	<1	<1	<1	<1	NGCMS_1120
Trihalomethanes NMI 1120 Screen						
Chloroform	ug	<1	<1	<1	<1	NGCMS_1120
Bromodichloromethane	ug	<1	<1	<1	<1	NGCMS_1120
Dibromochloromethane	ug	<1	<1	<1	<1	NGCMS_1120
Bromoform	ug	<1	<1	<1	<1	NGCMS_1120
Polycyclic Aromatic Hydrocarbons(volatile) NMI 1120 Screen						
Naphthalene	ug	<1	<1	<1	<1	NGCMS_1120
Dates						
Date extracted		25-MAR-2019	25-MAR-2019	25-MAR-2019	25-MAR-2019	
Date analysed		26-MAR-2019	26-MAR-2019	26-MAR-2019	26-MAR-2019	

REPORT OF ANALYSIS

Report No. RN1226788

N19/007213
To
N19/007216

VOCs were not detected in the back portion of carbon tube samples where detection limit is 1 ug.

Danny Slee, Section Manager
Organic - NSW
Accreditation No. 198

27-MAR-2019

This Report supersedes reports: *RN1226783*

Measurement Uncertainty is available upon request.
Chemical Accreditation 198: 105 Delhi Road, North Ryde, NSW, 2113

EMISQ2/190320/1
Due 27/3/19 mw

Chain of custody form for the analysis of volatile organic compounds in air collected in canisters

National Measurement Institute, Australia/1

105 Delhi Road, Riverside Corporate Park, North Ryde NSW 2113, ph +61 2 9449 0111, fax +61 2 9449 0153
www.measurement.gov.au ABN: 74 599 608 295

Australian Government
National Measurement Institute

Client Contact Information

Company: Emission Assessments Pty Ltd
Client Contact: Giacomo Collica
Client email: giacomo@eapl.net.au
Address: 6/35 Sustainable Ave State WA
Bibra Lake Postcode 6163
Client Phone: 61 8 9494 2958 Fax

Project Information

Project: 1819-170
Site: AREA TRIALS
Contact: GIACOMO COLLICA
Phone: 0409882059
Signature: [signature]

Analysis Turnaround Time

Standard:
Priority:

Invoice Information

Purchase Order:
Reference:

Additional Info

Canister(s) dispatched at -30"Hg. Canister Gauge reads -30 ± 5"Hg.

NMI LRN (NMI use only)	Sample ID (max.10 characters)	Sample Description (eg. Soil vapour, ambient)	Canister Number	NMI Clean can LRN	Flow device Number	Requested Sampling time	Canister Volume (L)	Starting canister pressure "Hg	Sampling start date	Sampling start time (hh:mm)	Sampling finish date	Sampling finish time (hh:mm)	End sampling pressure "Hg	Receipt pressure "Hg	VOC - TO15 (NMI Test Codes: NOABTVO15 & DIOXTVO15)	VOCs - Library Search (NMI Test Code: NCONSULT22, NCONSULT23)	VOC - Hydrocarbons (NEPM F1, F2 fractions +BTEXN) (NMI Test Code: NOA_TOTHYD, DIOXTOTHYD)	VOC - Sulfur Gases (NMI Test Code: NOA_SULF, DIOXSULF)	VOC - Fixed Gases (NMI Test Code: NOA_GASES, DIOXGASES)
			~~CAN042~~	~~NV19/00034~~	~~SG-18~~	~~2hr~~	~~3~~												
NV19/00178	1819170-	AREA MON.	CAN041	NV19/00033	SG-15	2hr	3	-40	18/3	11:15pm	19/3	0240	-5		✓		✓	✓	

Special Analysis Instructions / QC Requirements

NMI Stamp Receipt

Care warning

Please use appropriate care with NMI sampling equipment when sampling and packing for shipment. The client is responsible for all damage incurred to NMI equipment. Please notify NMI (02 9449 0114) if equipment is damaged upon receipt.

Relinquished by:
Print name:
Date & time: / / : hrs
Signature:

Laboratory use only - Received by NMI NSW by:
Print name:
Date & time: / / : hrs
Signature:

PAGE No 1 of 1 PAGES
If multiple pages, ensure ALL pages are stapled together.

RECEIVED
20 MAR 2019
BY: AO 14:30 A

Australian Government
Department of Industry, Innovation and Science

National Measurement Institute

SAMPLE RECEIPT NOTIFICATION

CUSTOMER DETAILS

Attention: GIACOMO COLLICA

Customer: EMISSION ASSESSMENTS PTY LTD

Address: UNIT 6 / 35 SUSTAINABLE AVENUE
BIBRA LAKE WA 6163

Email: data@eapl.net.au

Telephone: 61 8 9494 2958

Fax: 61 8 9494 2959

LABORATORY DETAILS

Lab: National Measurement Institute

Contact: Susanne Neuman

Address: 105 Delhi Road, North Ryde, NSW
NSW 2113

Email: Susanne.Neuman@measurement.gov.au

Telephone: 02 9449 0181

Fax:

SAMPLE DETAILS

NMI Job Name: **EMIS02/190320/1**

Total No. of Samples: **4**

LRNs	Customer Sample ID	Lab Sample Description
NV19/00033	.	CLEANLINESS CERTIFICATION
NV19/00178	1819170-009	18/3/19 11:15 19/3/19 02:40
NV19/00178/1	1819170-009	18/3/19 11:15 19/3/19 02:40
NV19/00178/2	1819170-009	18/3/19 11:15 19/3/19 02:40

SAMPLE RECEIVED CONDITION

Date samples received:	20-MAR-2019
Sample received in good order:	Yes
NMI Quotation no. provided:	
Client purchase order number:	PO1819-206
Temperature of samples:	Room Temprature
Comments:	ALL OK
Estimated report date:	27-MAR-2019
Mode of Delivery:	Courier

Additional Terms and Conditions

Incomplete / unclear information about samples or required testing will delay the start of the analysis work

If you require your Purchase Order (PO) number to be included on our invoice, please provide the number during sample submission and before the completion of work to avoid unnecessary delays and/or additional processing/handling fees.

The lodgement of an order or receipt of samples for NMI services referenced in this Sample Receipt Notification constitutes an acceptence of the current version of NMI Terms and Conditions or other applicable Terms referenced in the NMI Quotation. NMI Terms and Conditions are available on the web at http://www.measurement.gov.au/Services/EnvironmentalTesting/Pages/Terms-and-Conditions.aspx

Mean MTRD	2.532		Specification	93.0%
Average of	PER19W0439			

F.3 OGA (Standard PSD, A20E) Result Summary

Table F 5 contains the summarised results from the OGA (Standard PSD, A20E) with target binder content of 4.5%, paved on 24 and 25 March 2019.

Table F 6 contains the field core results from the OGA (Standard PSD, A20E).

Table F 5: Summary of results for OGA (Standard PSD, A20E)

Sample no.	H3166	H3167	H3168	H3179	H3180	H3183	Requirements
Lot no.	240310OGG/A20E	240310OGG/A20E	240310OGG/A20E	250310OGG/A20E	250310OGG/A20E	250310OGG/A20E	
Report no	PER19W0466	PER19W0466	PER19W0466	PER19W0480	PER19W0480	PER19W0480	
Date sampled	24/03/2019	24/03/2019	24/03/2019	25/03/2019	25/03/2019	25/03/2019	
Date tested	25/03/2019	25/03/2019	25/03/2019	25/03/2019	25/03/2019	26/03/2019	
Asphalt temperature	163	165	161	164	162	165	155–170
Compaction temp	122.6	122.4	121.9	138	138	136.8	–
Sieve size (mm)							
26.5	100.0	100.0	100.0	100.0	100.0	100.0	100
19	100.0	100.0	100.0	100.0	100.0	100.0	85–95
13.2	100.0	100.0	100.0	100.0	100.0	100.0	38–50
9.5	92.0	92.0	92.0	93.0	91.0	90.0	20–35
6.7	61.0	67.0	64.0	65.0	64.0	61.0	8–14
4.75	36.0	37.0	34.0	40.0	35.0	33.0	5–11
2.36	12.0	11.0	11.0	13.0	12.0	13.0	–
1.18	7.6	7.6	7.5	8.1	8.6	9.5	2–8
0.6	5.7	5.9	5.7	5.9	6.9	7.6	–
0.3	4.7	5.0	4.7	4.5	5.6	6.2	1–5
0.15	3.9	4.0	3.7	3.5	4.6	5.0	–
0.075	3.1	3.2	2.7	2.4	3.5	3.8	–
BC	4.3	4.2	4.3	4.2	4.2	4.4	Target±0.3
BRD	1.996	2.015	2.002	1.984	2.018	2.012	–
MTRD	2.507	2.525	2.504	2.503	2.512	2.512	–
Voids	20.4	20.2	20.7	20.7	19.7	19.9	16.0–21.0
VMA	28.7	28.4	29.1	28.9	27.9	28.4	–
VFB	29.1	28.8	28.9	28.2	29.5	29.9	–
Stability	6.4	6.9	6.1	5.0	5.0	5.6	Min 4.0
Flow	3.7	2.9	3.5	2.7	3	3	2–4
Moisture content				0.01			–

Sample no.	H3166	H3167	H3168	H3179	H3180	H3183	Requirements
Lot no.	240310OGG/A20E	240310OGG/A20E	240310OGG/A20E	250310OGG/A20E	250310OGG/A20E	250310OGG/A20E	
Report no	PER19W0466	PER19W0466	PER19W0466	PER19W0480	PER19W0480	PER19W0480	
Date sampled	24/03/2019	24/03/2019	24/03/2019	25/03/2019	25/03/2019	25/03/2019	
Date tested	25/03/2019	25/03/2019	25/03/2019	25/03/2019	25/03/2019	26/03/2019	
Degree of particle coating				100			–

Table F 6: Summary of field core results for CRM OGA (Standard PSD)

Lot no.		240310OGG/A20E					Lot no.		250310OGG/A20E				
Report no		PER19W0474					Report no		PER19W0487				
Date sampled		24/03/2019					Date sampled		25/03/2019				
Date tested		25/03/2019					Date tested		26/03/2019				
Location		SB 8074.02-04					Location		SB L1 8074.05				
Core	**Offset**	**Chainage**	**Thickness**	**In situ voids**	**Field density**	**Density ratio**	**Core**	**Offset**	**Chainage**	**Thickness**	**In situ voids**	**Field density**	**Density ratio**
1	2.5	23 137.6	26	21.2	1.980	98.8%	1	2.7	23 691.2	27	20.5	1.994	99.5%
2	1.4	23 175.6	27	21.4	1.975	98.5%	2	2.9	23 782.7	27	20.9	1.985	99.0%
3	0.6	23 241.6	30	21.3	1.976	98.6%	3	3.6	23 875.7	28	21.8	1.963	97.9%
4	0.8	23 309.0	27	21.2	1.980	98.8%	4	0.8	23 965.5	27	23.6	1.916	95.6%
5	2.1	23 346.9	30	21.8	1.965	98.0%	5	1	24 065.0	28	23.9	1.911	95.3%
6	2.4	23 417.1	28	20.2	2.004	100.0%	6	1.2	24 095.4	27	20.2	2.003	99.9%
7	2.7	23 487.2	25	20.5	1.996	99.6%	7	1.9	24 175.6	28	22.3	1.950	97.3%
8	3.2	23 557.4	26	21	1.985	99.0%	8	1.8	24 263.8	30	22.8	1.938	96.7%
9	3.5	23 576.9	27	20.1	2.006	100.1%	9	1.4	24 348.1	31	24.9	1.883	93.9%
10	0.8	23 659.7	27	23.9	1.910	95.3%	10	1.8	24 413.0	26	19.9	2.011	100.3%
		Mean (R)	27	21.3	1.978	98.7%			Mean (R)	28	22.1	1.955	97.5%
		Stdev (s)	1.6	1.1	0.027	1.4%			Stdev (s)	1.5	1.7	0.043	2.2%
		k				0.75			k				0.75
Mean Marshall		2.004		Rc = R – (k*s)		97.7%	Mean Marshall		2.005		Rc = R – (k*s)		95.9%

Mean MTRD	2.512	Specification	93.0%	Mean MTRD	2.509	Specification	93.0%
Average of	PER19W0466			Average of	PER19W0480		

APPENDIX G EMISSION ASSESSMENTS REPORT