

ANNUAL SUMMARY REPORT

P75 Transfer of Crumb Rubber Modified Gap-graded Asphalt Technology to Queensland and Western Australia (2018–19)

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Summary

The sustainable and environmentally friendly management of end-of-life tyres continues to present a challenge to governments and industry, both locally and internationally. In Australia alone, approximately 56 million equivalent passenger tyre units reached the end of their life in 2015–16. These end-of-life tyres do however contain valuable recoverable resources that can be re-used in a variety of different applications.

In the roads industry, crumb rubber obtained from end-of-life vehicle tyres can be used to enhance the performance of bituminous sprayed seals and asphalt layers. More specifically, international studies and experience have shown that crumb rubber modified gap-graded asphalt can provide improved resistance to crack reflection and fatigue cracking compared to conventional dense-graded asphalt. These mixes are therefore often used by some international road jurisdictions (and to a limited extent in Australia) to rehabilitate and/or overlay existing cracked pavements.

There are currently no local specifications available for the use of crumb rubber modified gap-graded asphalt in Queensland and Western Australia. As such, these states cannot readily make use of the performance and sustainability benefits provided by this technology.

A collaborative project was therefore established between the following organisations to facilitate the use of crumb rubber modified gap-graded asphalt in Queensland and Western Australia:

- Australian Asphalt Pavement Association
- Australian Road Research Board
- Tyre Stewardship Australia
- Queensland Department of Environment and Science
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia.

The key project objectives included the development of a new technical specification for the manufacture and placement of crumb rubber modified gap-graded asphalt, as well as undertaking two demonstration projects to assess industry's ability to produce and construct these mixes locally.

The technical specification developed was primarily based on the technical requirements adopted by the state road agencies in Arizona and California given that both these states have extensive experience in the successful use of these mixes.

The demonstration projects undertaken in Queensland and Western Australia demonstrated that industry has the capability to manufacture and place locally produced crumb rubber modified gap-graded asphalt in accordance with the specification requirements. Furthermore, the emissions monitoring undertaken during

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Acknowledgements

The project team would like to acknowledge the contributions from the City of Gold Coast, Fulton Hogan, and SAMI Bitumen Technologies.

the demonstration projects did not identify any concerns regarding the potential exposure of workers to harmful emissions during the placement and compaction of CRM GGA.

The laboratory testing undertaken on the CRM GGA placed in Queensland and Western Australia showed that the flexural fatigue resistance of these two mixes was superior to the performance of a DGA with C320 bitumen.

The following recommendations are made for consideration based on the project findings:

- The national specification should be updated based on the learnings from the demonstration projects, including a procedure to assess the equivalent binder viscosity required when warm mix additives are added during the manufacturing process.
- It is recommended that further implementation projects be undertaken to allow industry to gain experience in the manufacture and placement of CRM GGA.
- The ongoing performance of future implementation projects should be monitored to assess the in-service performance of these mix types. The learnings from these projects can be used to improve future specification updates.
- Given the potential differences in local materials, it is recommended that a future study benchmark the laboratory performance of locally manufactured CRM binders and GGA against the performance achieved internationally (more specifically in the USA).
- It is recommended that national harmonised specification criteria (based on local test methods) be developed for CRM binders used in asphalt.
- There is an opportunity to develop national best practice guidelines for the use of crumb rubber modified asphalt, including site evaluation, product selection, design, construction requirements, etc.

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1. Introduction

1.1 Background

The sustainable and environmentally friendly management of end-of-life vehicle tyres continues to present a challenge to governments and industry, both locally and internationally. In Australia alone, approximately 56 million equivalent passenger tyre units reached the end of their life in 2015–16. Between 60–65% of these end-of-life tyres were disposed of in landfill, dumped or illegally stockpiled (Genever et al. 2017). However, these end-of-life tyres contain valuable recoverable resources, including rubber, carbon black, nylon and steel. Fortunately, there are several markets ((including the roads industry) that can make use of these recoverable materials.

Crumb rubber (obtained from end-of-life tyres) can be used in bituminous sprayed seals, gap-graded asphalt (GGA), open-graded asphalt (OGA), stone mastic asphalt (SMA) and dense-graded asphalt (DGA) pavement surfacing layers (Denneman et al. 2015, Ghabchi et al. 2016). Previous National Asset Centre of Excellence (NACOE) research projects undertook development work to facilitate the increased use of crumb rubber modified (CRM) binders in sprayed seals and OGA throughout Queensland (Denneman et al. 2015, Grobler et al. 2017). Another research project as part of the Western Australian Road Research Innovation Program (WARRIP) introduced CRM OGA into Western Australia (van Aswegen 2019).

International studies and experience have shown that CRM GGA mixes can provide improved resistance to crack reflection and fatigue cracking compared to conventional DGA. These mixes are therefore often used by several international road jurisdictions (and to a limited extent in Australia) when rehabilitating and/or overlaying existing cracked pavements. Furthermore, the sustainability benefits of using crumb rubber obtained from recycled tyres are well documented (Denneman et al. 2015), and the introduction of CRM GGA in Queensland and Western Australia would therefore facilitate the increased use of an otherwise waste material.

However, there are currently no specifications for the manufacture and placement of CRM GGA in these two states. As such, the Queensland Department of Transport and Main Roads (TMR) and Main Roads Western Australia (Main Roads) cannot readily make use of the many benefits provided by this technology. It is therefore envisaged that the development of a local technical specification for CRM GGA would facilitate its wider use in both these states.

Project P75 *Transfer of Crumb Rubber Modified Gap-Graded Asphalt Technology to Queensland and Western Australia* is a collaboration between the Australian Asphalt Pavement Association (AAPA), Australian Road Research Board (ARRB), Main Roads, Queensland Department of Environment and Science (DES), TMR, and Tyre Stewardship Australia (TSA) aimed at developing technical specifications for the local manufacture and placement of CRM GGA.

1.2 Project Scope

The aim of the project was to develop a technical specification for CRM GGA and undertake construction projects in Queensland and Western Australia to demonstrate that these mixes can be manufactured and placed locally. The project scope comprised of the following main objectives:

- undertaking a literature review aimed at identifying local and international best practice specifications for the use of CRM GGA, including the benefits and potential applications of this mix type
- developing a new technical specification for the manufacture and placement of CRM GGA
- characterising the flexural stiffness and fatigue behaviour of locally produced CRM GGA mixes
- undertaking two construction projects to demonstrate that CRM GGA mixes can be manufactured and constructed locally in accordance with the technical specification developed as part of the project
- documenting the findings in a project report.

1.3 Purpose of this Report and Report Structure

The purpose of this report is to present the outcomes of the technology transfer activities undertaken to date to facilitate the use of CRM GGA in Queensland and Western Australia.

Section 2 of the report documents the findings of the literature review undertaken and summarises local and international best practice in the use of CRM GGA. Section 3 documents the technical specification developed for the manufacture and placement of CRM GGA, followed by the findings of the two demonstration projects in Section 4.

The results of the laboratory characterisation testing undertaken as part of the project are summarised in Section 5. Conclusions and recommendations for further work are provided in Section 6.

2. The use of Crumb Rubber in Asphalt

2.1 Background

The use of recycled rubber in pavements started in the 1840s (albeit with little benefit at the time), but it was not until the 1960s that a successful formulation was developed in the USA that could provide improved performance benefits. By the mid-1970s, recycled crumb rubber was successfully added to asphalt mixes (Widyatmoko & Elliot 2008).

There are several ways to produce crumb rubber from end-of-life tyres, but mechanical ambient grinding is the most common process used for road materials. The rubber obtained from tyres is mechanically ground into smaller particles (between 0.5 mm to 5.0 mm in size) at ambient temperatures using rotating blades. These rubber crumbs can then be added either to a bituminous binder or directly to an asphalt to improve the performance of these materials (Denneman et al. 2015).

This study focussed on the use of crumb rubber in GGA, and the sections below summarise current national and international best practice.

2.2 Using Crumb Rubber in Asphalt

2.2.1 The Benefits of using Crumb Rubber in Asphalt

Some of the main benefits reported internationally for using crumb rubber in asphalt include an increased resistance to reflective cracking, enhanced rutting and fatigue performance, lower road surface noise levels, reduced maintenance costs, longer pavement service life, as well as environmental benefits (Venudharan et al. 2017). Similar benefits have also been reported in Australia (Roads and Traffic Authority 1995). A literature review undertaken by researchers in the USA also found that crumb rubber modified asphalt (CRMA) performed equally as well or better compared to polymer modified asphalt (Ghabchi et al. 2016).

Ghabchi et al. (2016) reported that modifying bitumen with crumb rubber can improve both the low and high temperature susceptibility of the base bitumen. In addition, the high temperature viscosity of the base bitumen can be significantly increased (i.e. by a factor of 10 or more) when modified with at least 15% crumb rubber particles (Widyatmoko & Elliot 2008).

CRM GGA has successfully been used internationally (and to a limited extent in Australia) to overlay existing cracked pavements (including jointed concrete pavements) due to its improved resistance to crack reflection (Denneman et al. 2015).

Over 3,000 km of crumb rubber modified asphalt (CRMA) were constructed in Arizona between 1990 and 2000. Laboratory testing on cores extracted from these pavements indicated longer fatigue lives compared to conventional asphalt mixes (Ghabchi et al. 2016).

CRM GGA is also widely used in California to overlay existing cracked pavements or as a surfacing layer in new construction. It has been reported that CRM GGA can provide a durable, flexible surfacing layer with increased resistance to reflective cracking, oxidation and rutting. The gap-graded aggregate structure of the mixture also provides good surface friction, and it has been found to reduce traffic noise in some applications. CRM GGA can also be used in urban environments (such as signalised intersections and parking areas) where open-graded asphalt surfacings are not necessarily suitable (California Department of Transportation (Caltrans) 2003).

Studies (including accelerated pavement testing) in the USA also found that CRM GGA mixes can provide excellent resistance to reflective and fatigue cracking; and that overlay thickness reductions of up to 50%

compared to conventional DGA can be achieved in some applications to reduce the risk of reflective cracking occurring (Jones et al. 2007).

In addition to the reported performance benefits of CRMA, a life cycle cost analysis undertaken by Hicks and Epps (2000) suggested that CRMA mixes can be a cost-effective surfacing type in Arizona and California. The same study also found that these modified mixes are most cost effective when reflective cracking from the underlying pavement is expected.

International experience suggests that the material unit cost of CRMA is typically higher compared to conventional asphalt, however the whole-of-life costs are competitive due to lower ongoing maintenance costs. It was also found that the total construction cost using CRM GGA could be lower in some applications compared to more significant rehabilitation treatments using conventional asphalt (Widyatmoko & Elliot 2008).

Another study by the National Cooperative Highway Research Program (NCHRP) in 1994 also found that CRMA can be a cost-effective alternative to many highway pavement applications. The same study concluded that CRMA was the best choice in most of the applications considered when variability in the input parameters for a life-cycle assessment are considered. It should however be noted that CRMA was not necessarily the most cost-effective solution in all the applications considered, but a life-cycle cost analysis would allow users to determine whether this technology would be cost-effective for a particular application (Widyatmoko & Elliot 2008).

2.2.2 Local and International use of CRMA

As mentioned earlier, crumb rubber was first successfully incorporated into asphalt in mid-1970 and was subsequently introduced into California and Texas during the 1980s. The use of CRMA mixes significantly increased in the 1990s due to a mandate on its use imposed by the *Intermodal Surface Transportation Efficiency Act* in the USA, however this mandate has since been repealed which resulted in a significant drop in the use of crumb rubber in many parts of the USA (Hicks & Epps 2000).

A study in the 1990s by the Federal Highway Administration found that most CRMA being placed in the USA was in Arizona, California, Florida and Texas (Hicks & Epps 2000). It is estimated that the transportation departments in these states have used over 35 million end-of-life tyres between 1995 and 2001 (Willis et al. 2014).

Arizona primarily uses CRM binders in OGA and GGA, whereas California uses CRM binders in DGA, GGA and OGA. Florida also uses a fine-graded crumb rubber in DGA and OGA (Hicks et al. 1995). The Texas Department of Transportation (TDoT) has specifications for both CRM OGA and CRM SMA (TDoT 2004).

Europe has used CRM binders in asphalt to a limited extent since the early 1980s. The use of crumb rubber in asphalt appears to be far less common in Europe compared to the USA, partly due to the popularity of polymer modified binders (PMBs). However, Portugal and Spain have started to use this technology more widely in asphalt since 1999 (Widyatmoko & Elliot 2008).

CRMA technology was first introduced into South Africa in the mid-1980s and has a long history of good performance, including the use of GGA modified with crumb rubber (Renshaw et al. 2007).

Australia introduced CRM binders for use in asphalt and sprayed seals in the mid-1970s, but it is less commonly used in asphalt compared to PMBs (Widyatmoko & Elliot 2008). At the time of writing this report, the use of CRM GGA in Australia (manufactured using the 'dry' process) has been limited to certain regions in New South Wales and Victoria only.

2.2.3 Challenges with using CRMA

The construction of CRMA can be more challenging compared to conventional asphalt, primarily due to the higher viscosity and storage sensitivity of the CRM binder. Consequently, CRMA are typically compacted at higher temperatures compared to asphalt containing non-modified binders. CRM GGA mixes may also require a higher compactive effort to achieve the required field density due to the stone-on-stone aggregate structure (Widyatmoko & Elliot 2008).

Caltrans (2003) reported that CRM GGA may be prone to flushing at heavily trafficked intersections, which is also supported by anecdotal evidence in New South Wales.

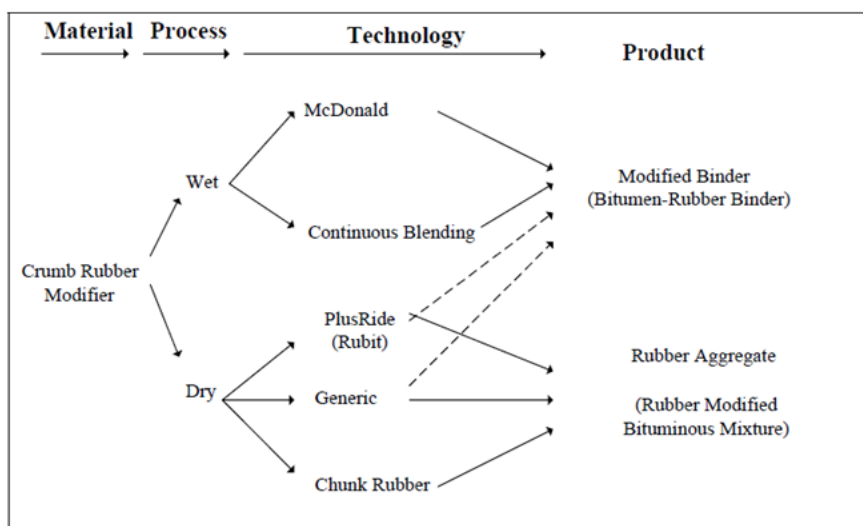
The Californian experience with the use of CRMA suggest that it should not be placed during rainy or cold weather conditions, over pavements with very severe cracks (i.e. > 12.5 mm wide), in areas where considerable handwork is required, or where long haul distances prevent the materials to be paved and compacted within the recommended temperature ranges (Caltrans 2003).

The risk associated with long haul distances can be mitigated with the use of warm mix technologies, such as the new crumb rubber technology (NCRT) developed in Germany. NCRT offers improved binder rheology, a longer shelf-life and enhanced storage stability compared to traditional CRM binders (Marais et al. 2017).

2.3 CRMA Manufacturing Methods

Crumb rubber can be added to asphalt using either a 'dry' or a 'wet' blending process (Figure 2.1). Each of these processes provide a different final products and performance characteristics and should be considered as distinctly different technologies (Denneman et al. 2015). It is therefore essential that road agencies are aware of the advantages and disadvantages of each technology, which in turn will allow them to select the appropriate technology to meet their specific requirements.

Figure 2.1: Different approaches for incorporating crumb rubber in asphalt pavements



Source: Widyatmoko and Elliot (2008).

The two different processing methods and their impact on the performance of CRMA are further discussed below.

2.3.1 The Dry Blending Process

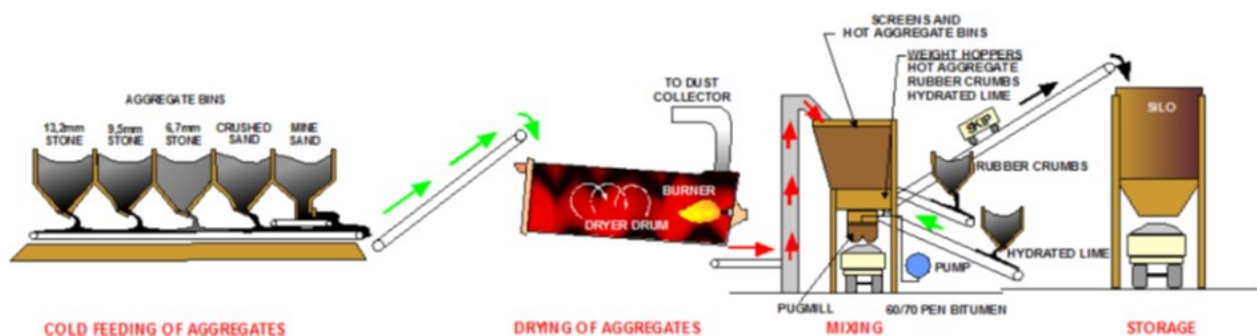
The dry blending process was originally developed in Sweden during the 1960s (Rahman 2004). With the dry blending process, crumb rubber is blended in with the aggregates (similar to adding recycled asphalt

pavement) prior to adding the bitumen (Figure 2.2). During the initial stage, the rubber forms part of the aggregate matrix and acts as a flexible aggregate, after which it becomes partially dissolved when the bitumen is added to the mix (Austroads Pavements Research Group 1999).

One of the main benefits of the dry blending process is that it provides a relatively straightforward and easy way for adding larger quantities of crumb rubber in asphalt without the need for specialised equipment or blending procedures (Rahman 2004).

However, a reported disadvantage of using the dry blending process is that the rubber-binder blend cannot be as well controlled as when the rubber is directly added to the bitumen. Furthermore, the full benefits of using crumb rubber in asphalt are not necessarily realised due to the partial binder modification that occurs (Denneman et al. 2015).

Figure 2.2: 'Dry' blending method



Source: Balmaceda and van Wijk (2013).

Based on the literature reviewed, there appears to be three main types of dry blending technologies being used in the USA, i.e. 'PlusRide®', 'generic' and 'chunk rubber'.

PlusRide® was patented in the USA in 1978 and is a GGA mix with approximately 3% of the aggregate replaced with crumb rubber. The asphalt mix has a total binder content of between 7% and 9%. The PlusRide® dry blending process limits the reaction that occurs between the rubber and binder so that the rubber particles could maintain their elastic properties within the asphalt, typically referred to in literature as 'flexible aggregate'. Appropriate construction practices are important to ensure adequate performance of the PlusRide® system (Rahman 2004).

The generic dry blending technology (also known as the 'TAK' system) was developed in the late 1980s to incorporate crumb rubber into DGA and GGA. The technology uses both coarse and finely graded rubber to replace a proportion of the aggregate and improve the properties of the binder. Up to 3% of rubber by mass of the total mix (with a particle size of between 180 microns and 2 mm) is added to the asphalt. The advantage of this technology is that the use of smaller rubber particles allows for a greater degree of binder interaction and modification to occur. However, not all the asphalt plants can accommodate the modified grading that may be required to achieve the CRMA mix design requirements (Rahman 2004).

Chunk rubber technology was developed by the US Army Corps of Engineers to assist with ice-debonding of asphalt materials. The technology uses 4.75 mm to 9.5 mm rubber particles with a modified aggregate gradation to accommodate between 3%, 6% and 12% of rubber particles by mass of the asphalt mix. The optimum binder content of asphalt mixes using this technology varies between 6.5% and 9.5% (Rahman 2004).

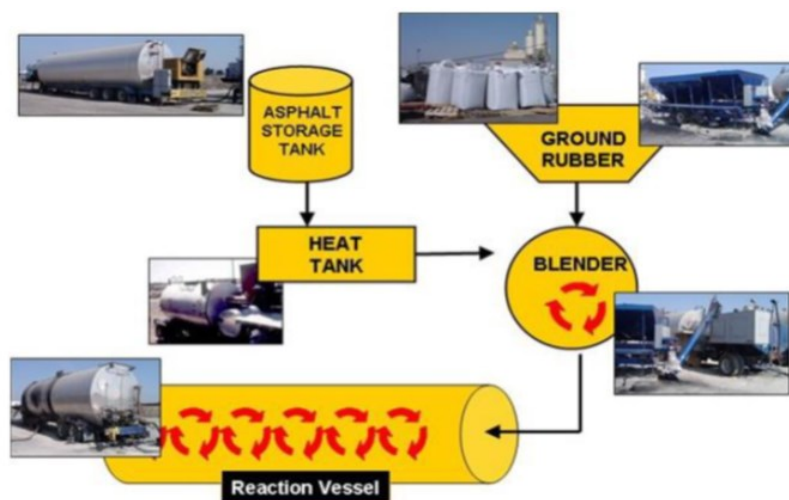
The generic dry blending process has mainly been used in Australia (and more specifically in New South Wales and Victoria) to modify asphalt with crumb rubber (Austroads Pavements Research Group 1999).

2.3.2 The High-viscosity Wet Blending Process

The wet blending process has largely replaced the dry blending process internationally as the preferred method for modifying asphalt with crumb rubber (Denneman et al. 2015). A comprehensive survey undertaken in the USA found that only 14% of all the states that allow the use of CRMA uses the dry blending process (Ghabchi et al. 2016).

The 'high-viscosity' wet blending process was originally developed in the USA with an aim to improve a binder's properties (e.g. elasticity and viscosity) at higher temperatures. The crumb rubber is blended directly with hot bitumen, allowing partial digestion of the rubber particles to occur (Figure 2.3). The blending can occur on site using a specialised field blending unit or alternatively the CRM binder can be manufactured at a bitumen terminal or refinery (Denneman et al. 2015).

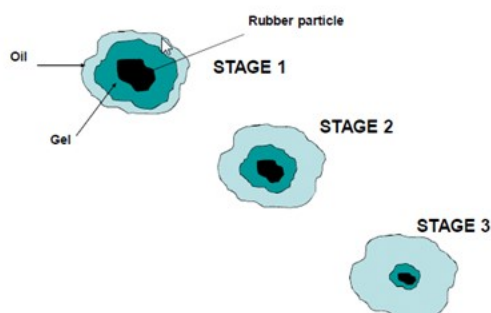
Figure 2.3: 'Wet' blending method



Source: <http://maxlinktyrerecycling.com>.

The literature suggests that the digestion of crumb rubber in bitumen occurs in three stages (Figure 2.4). In the initial stage, rubber particles swell as they start to absorb the lighter components of the bitumen, which increases the binder's resilience. In the next stage, the crumb rubber turns into a 'gel-like' phase that increases the binder's viscosity and softening point. The particles then turn into an oil after an extended digestion period which increases the durability and flexibility of the modified binder. Modified binders produced by means of the high-viscosity wet blending process require continuous agitation during storage and transportation to avoid phase separation (Denneman et al. 2015).

Figure 2.4: Digestion process of crumb rubber in bitumen



Source: South African Bitumen Association (Sabita) (2009).

At the time of writing this report, the high-viscosity wet blending process is mainly used in bituminous sprayed sealing applications in Australia, whereas internationally this process is used to modify binders for GGA, OGA and sprayed seals (Denneman et al. 2015).

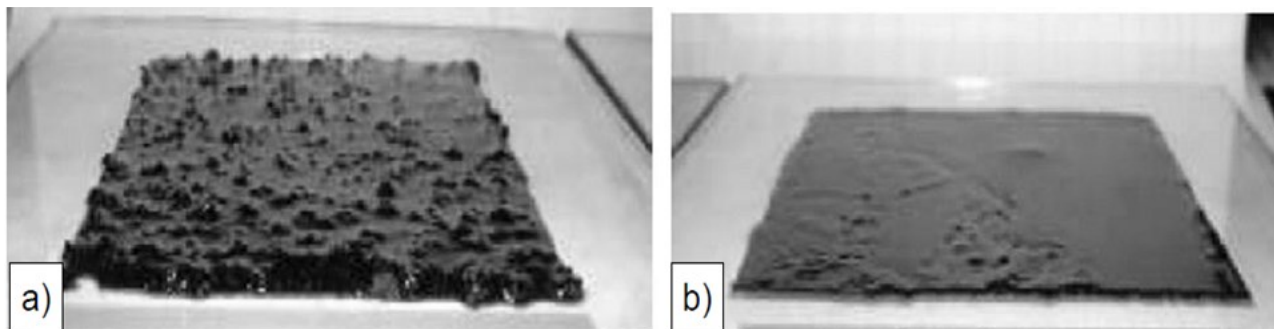
2.3.3 The No-agitation Wet Blending Process

The 'no-agitation' wet blending process blends the crumb rubber with hot bitumen by means of high shear stresses and pressure. The binders produced using this process are storage-stable (unlike the high-viscosity wet blending process) and do not require ongoing agitation. These modified binders are typically produced at refineries or bitumen terminals and are often referred to as 'terminal blends' (Denneman et al. 2015). Binders produced by the no-agitation wet blending process can be stored and handled in a manner similar to PMBs (Presti 2013).

The no-agitation wet blending process produces binders with a lower viscosity compared to the high-viscosity wet blending process, which somewhat reduces the binder's benefits in asphalt and sprayed seals. The viscosity of binders produced using the no-agitation wet blending process can typically range between 0.5 and 1.0 Pa.s at 135 °C, whereas the viscosity of binders produced by the high-viscosity wet blending process can range between 1.5 and 5.0 Pa.s at 177 °C (Presti 2013).

The contrasting appearance of binders produced by the high-viscosity and the no-agitation wet blending process are shown in Figure 2.5.

Figure 2.5: CRM binder produced using: a) High-viscosity wet process; b) No-agitation wet process



Source: Presti (2013).

The high-viscosity and no-agitation wet blending processes will result in binders with different properties that will perform differently in-service. The performance history of CRMA using the no-agitation wet blending process is not as well documented as the more widely used high-viscosity process (Denneman et al. 2015).

Internationally, binders prepared using the no-agitation wet blending process are mainly used in DGA, OGA and GGA. However, these binders do appear to be best suited for DGA (Hicks et al. 2013).

2.4 Performance of CRMA Manufactured using the Dry or Wet Blending Process

There is a large body of literature available that discusses the performance of CRMA manufactured using either the dry or wet blending process. It is however clear from the literature review that there is not currently a unified view amongst practitioners and researchers as to which technology provides the best outcome.

The performance of CRMA produced using either the dry or wet blending process, as reported in the literature, is presented in the following sections.

2.4.1 Dry Blending Process

Several international studies between 2004 and 2015 found that the dry blending process can successfully be used to manufacture CRMA with improved performance. However, (Ghabchi et al. 2016) found that the performance of CRMA using the dry blending process was not necessarily as good as asphalt manufactured using the wet blending process.

Some researchers found that the interaction between the rubber particles and the base bitumen was limited when the crumb rubber was added by means of the dry blending process (Shen et al. 2014). However, research at the University of Nottingham found that the interaction between the bitumen and rubber using the dry blending process can be sufficient to change the properties of the asphalt due to a stiffer and more elastic modified binder (Rahman 2004).

Rahman (2004) also reported that the field performance of CRMA manufactured with binders produced using the dry blending process was inconsistent, with in-service lives varying between two and 20 years. Several possible reasons were noted for this variable performance, including variable crumb rubber sources, poor construction practices, nature of the rubber particles, poor adhesion and varying interactions with the base bitumen.

Another study by Hunt (2002) found that road sections using the generic and PlusRide® systems in the USA did not perform as well in-service as the sections that were constructed with CRM binders manufactured using the wet blending process and conventional binders. The poorer performing sections exhibited premature crocodile cracking, block cracking and ravelling. The permanent deformation resistance of the mixes manufactured using the dry blending process in the study was also considered to be unacceptable.

However, contrary to the findings by Hunt (2002), Huang et al. (2002) reported that similar or better performance was observed on test sections constructed in Louisiana using the generic and PlusRide® technologies.

Shen et al. (2014) reported on the performance of CRMA manufactured using the dry blending process in the USA (Table 2.1).

Table 2.1: Performance of CRMA using the dry blending process

State	Method/type of mix	Observations
Alabama	CRM/AC-10	No significant difference from wet mixes in resilient modulus, indirect tension and dynamic creep.
Alaska	PlusRide gap-graded	Deeper ruts and faster rut accumulation rate than conventional HMA mixes.
Arkansas	AC-30 (1, 2, 3% by wt. of aggregate)	Slightly better if rubber was pre-treated with extender oil prior to mixing. Inferior to control and wet-processed mixes.
Caltrans	PlusRide/dense-graded	2 of 4 dry-process projects out-performed conventional mixes; one was comparable; one was not properly designed and required an overlay.
Georgia	PEM/SMA/Superpave 10% CRM with mesh -30/TOR	Performed as well as SBS mixes after 3–5 years' service based on visual inspection. Core samples did not differ significantly in density, permeability, and Marshall stability from SBS control. Cantabro loss was slightly greater.
Illinois	HMA	Lower performance than conventional asphalts.
Louisiana	PlusRide/gap-graded	Lower initial structural capacities (DYNAFLECT structural number) than the conventional dense-graded control.
Minnesota	PlusRide/dense-graded overlay	Performed well, with improved crack reflection. Benefits did not offset higher cost.
New York	Overlay project	After 3 years, no economic or structural benefit.
Oregon	PlusRide	Poor performance (premature degradation). Cost 50–100% more than conventional pavements.

State	Method/type of mix	Observations
South Carolina	PlusRide	Pelham Road has deteriorated in the 8 years since it was paved. Other asphalt rubber projects appear to be in satisfactory condition.
Texas	Generic dry process/dense-graded (0.5% by wt. of aggregate)	Less propensity for rutting but possibly more cracking. Remained in discrete particles.
Washington	PlusRide	The performance of 7 sections ranged from excellent to immediate failure. Overall, did not improve performance.

Source: Adapted from Shen et al. (2014).

The observations included in the table above and findings from previous research suggest that the performance of CRMA manufactured using the dry blending process has traditionally been variable in the USA.

CRMA has been used in South Africa since the early 1980s and the dry blending process was originally transferred from Australia (Bergh et al. 1989). Balmaceda and van Wijk (2013) assessed the performance of two projects in South Africa where CRM GGA was manufactured using the dry blending process. The study reported that the binder film thickness in CRM GGA was significantly higher than the film thickness in conventional asphalt. Laboratory fatigue testing undertaken on several asphalt specimens also indicated significantly improved fatigue resistance for the CRM GGA mixes (using both the dry and wet blending processes) compared to asphalt with conventional binders. The study concluded that both projects constructed with CRM GGA manufactured using the dry blending process still performed satisfactorily after 14 years in service. In conclusion, the authors suggested (based on their experience) that both the dry and wet blending processes have advantages and disadvantages that should be considered in design and during construction.

Denneman et al. (2015) previously reported that historically the dry blending process was the most widely used technology in Australia. Both Roads and Maritime Services (Roads and Maritime) in New South Wales and VicRoads have previously used CRM GGA manufactured using the dry blending process as a surfacing layer on pavements with a high risk of reflective cracking (including stabilised pavements, jointed concrete pavements and pavements with highly expansive subgrades). The performance of these pavements was however not well documented in the publicly available literature, but anecdotal evidence suggests that these pavements performed satisfactorily.

A limited study by Oliver (1998) in Australia did however find that an asphalt modified with crumb rubber using the dry blending process provided better fatigue and rutting resistance when tested in the laboratory compared to asphalt manufactured with a CRM binder using the wet blending process.

The body of literature reviewed suggests that the dry blending process has been used in many countries (including the USA, South Africa, and Australia) with varying degrees of success. Possible reasons for the variable performance appear to be:

- variations in the crumb rubber properties due to variable rubber sources
- variations in the interaction between the rubber and base bitumen
- difficulties in controlling and assessing the modified binder's properties during manufacturing.

2.4.2 Wet Blending Process

CRM binders manufactured using the high-viscosity wet blending process have been used in asphalt since at least the 1980s (Caltrans 2003). Some of the main reported benefits of using this technology in asphalt are (Presti 2013):

- the ability to achieve higher binder contents without the risk of increased bleeding or flushing occurring (due to a higher binder viscosity)
- increased binder resilience and elasticity at higher temperatures
- improved resistance to fatigue and reflective cracking
- improved durability

- enhanced rutting performance.

Shen et al. (2014) also reported on the benefits of using CRMA manufactured with the wet blending process across several states in the USA (Table 2.2).

Table 2.2: Performance of CRMA using the wet blending process

State	Applications	Conclusions
Alabama	PG 67-22 plus 11% CRM (#30–40 mesh)	After one year, rubberised and conventional mixes show no practical difference in field performance with regard to rutting and texture.
Arizona	Gap-graded hot mix asphalt with 20% CRM	Asphalt rubber reduced reflective cracking and improved rutting performance and smoothness. Less average maintenance cost.
Arkansas	5, 10, and 15% CRM	Increased rutting resistance. Resilience and tensile properties were not enhanced when tested at 25 °C. Performance-related properties did not differ significantly.
Caltrans	18±1% CRM (gap-graded and dense-graded asphalt)	Over 7 years in-service, asphalt mixes with 15% CRM outperformed all other mixes in crack reflection mitigation.
Florida	10% CRM	Routinely used in friction courses and SAMI layers since 1994. Better resistance to rutting and cracking than that of unmodified binders.
Illinois	No more than 5 pounds of CRM per ton of asphalt	No substantial difference in rut values between CRM and control sections.
Kansas	18% CRM MacDonald process	Rubber did not inhibit crack development in the higher density mixes. None of the rubber projects have rutted.
Louisiana	5% 'Neste Wright' Wet Process, 10% Rouse Wet Process, 17% Arizona Wet Process, 16-mesh CRM	The conventional mixes exhibited higher laboratory strength characteristics than the CRM mixes. Better performance indices (rut depth, fatigue cracks, IRI numbers) than the corresponding control sections after 5–7 years of traffic.
Minnesota	20% CRM	Wear courses exhibited less cracking than the control sections.
New Mexico	Open graded friction course	Better or comparable to conventional non-CRM materials. CRM OGFC pavements performed well in the short (2–4 years) and long term (5–9 years).
Oregon	Open graded asphalt	Varying results.
Pennsylvania	Thin overlays Chip seals and/or fog seals	Enhanced signs of wear and cracking. Performance unsatisfactory in comparison to the DOT standard ID-2 wearing course.
Texas	Chip seal SAM seal Terminal blends Open graded asphalt	The mix ravelled severely. SAMs exhibit improved resistance to alligator cracking and ravelling, but resistance to shrinkage cracking was not improved by chip seals. AC-20-5TR, a terminal blend, had excellent chip retention and resistance to flushing and tracking. Most open-graded mixes improved cracking resistance and prevented binder drain-down in permeable mixes.
Washington	SAM/SAMI seals Open graded friction course	Did not justify the added expense of their construction. OGFC exhibited good-to-very-good performance, except for one bridge deck overlay.

Source: Adapted from Shen et al. (2014).

The Arizona Department of Transportation (ADOT) uses the high-viscosity wet blending process to manufacture CRM GGA and has monitored several trial sections since 1988. It was found (after 10 years of performance monitoring) that the CRM GGA provided superior resistance to reflective cracking from underlying jointed concrete pavements compared to conventional DGA (Widyatmoko & Elliot 2008).

The California Department of Transportation (Caltrans) also uses the high-viscosity wet blending process to manufacture CRM GGA. Based on several studies (including accelerated pavement testing), Caltrans adopted an equivalency thickness factor of 2 when using CRM GGA compared to conventional DGA to overlay cracked pavements. This means that a 60 mm CRM GGA layer is considered to provide equivalent resistance to reflective cracking compared to a conventional 120 mm DGA layer (Widyatmoko & Elliot 2008).

As mentioned previously, laboratory fatigue testing undertaken on asphalt specimens in South Africa also indicated significantly improved fatigue resistance for CRM GGA mixes (using both the dry and wet blending processes) compared to asphalt with conventional binders (Balmaceda and van Wijk 2013).

There are, however, also several disadvantages reported in the literature regarding the use of CRM binders manufactured using the high-viscosity wet blending process. Some of the main disadvantages reported by Presti (2013) include:

- the need for special storage and transportation tanks with augers or paddles to keep the binder agitated
- limited shelf life of the binder
- higher compactive efforts required during construction due to the higher binder stiffness
- potentially higher initial costs due to plant modifications.

The no-agitation wet blending process has brought significant advantages for CRMA, including a longer shelf life, less concerns with fuming and odour at the point-of-use, lower initial costs compared to the high-viscosity wet blending process and lower mixing temperatures during asphalt manufacturing (Denneman et al. 2015).

However, the performance benefits of binders produced using the no-agitation wet blending process do not appear to be as well documented as for the high-viscosity binders, but it is widely believed that the lower viscosity of this storage stable binder will result in lower binder application rates and therefore reduced performance benefits (Denneman et al. 2015).

2.5 Comparison between the Performance of CRMA using the Wet or Dry Blending Process

The wet blending process was developed as a binder modification method, whereas the main objective of the dry blending process was to replace a portion of aggregate with crumb rubber, attaining 'flexible aggregate' properties (Buncher 1995). Consequently, each of these processes delivers different products with different expected performance outcomes.

Hassan et al. (2014) reported that the improved performance associated with the wet blending process (due to a better interaction between the bitumen and crumb rubber) has increased the popularity of this technology over the dry blending process. Generally, greater control of the CRM binder production process can also be achieved when using the wet blending process (Oliver 1999).

Several researchers found that CRMA manufactured using binders produced with the wet blending process showed better laboratory permanent deformation and fatigue resistance compared to conventional asphalt mixes (Shen et al. 2014).

A study by the Oregon Department of Transportation (Hunt 2002) found that CRMA manufactured using the dry blending process showed poorer performance in the field compared to asphalt manufactured with the wet blending process, particularly with regard to block cracking, fatigue cracking, ravelling and permanent deformation. Research undertaken by Kim et al. (2014) also found that CRMA manufactured using the wet blending process had higher rutting resistance at high temperatures, and higher tensile strengths at ambient temperatures compared to asphalt manufactured using the dry blending process.

However, contrary to the above, Losa et al. (2012) reported that CRM GGA manufactured using the dry blending process had greater fatigue resistance compared to CRMA GGA manufactured with the wet

blending process, whereas the resilient modulus was higher for the asphalt mixes prepared using the wet blending process. Both blending processes resulted in similar asphalt tensile strengths.

A study by Balmaceda and van Wijk (2013) also found that the Marshall Stability of CRM GGA manufactured using the dry blending process was higher than the stability measured for mixes manufactured with the wet blending process. In addition, the CRM GGA manufactured using the dry blending process had a higher resistance to permanent deformation compared to asphalt manufactured with the wet blending process.

Another study by Navarro et al. (2004) found that CRMA using the dry blending process had superior resistance to rutting at intermediate temperatures compared to CRMA manufactured using the wet blending process, however it could not prevent cracking at low temperatures. Similarly, a study by the Alaskan Department of Transportation reported that CRMA manufactured using the wet blending process had better resistance to thermal cracking compared to mixes using the dry blending process (Rahman 2004).

Earlier research by Oliver (1998) in Australia also found that the laboratory fatigue performance of CRMA mixes using the dry blending process was superior to the performance of an asphalt mix manufactured with a high-viscosity CRM binder. The author suggested that the reason for the better fatigue performance could be due to the larger amount of rubber that was used for the dry blending process in his study (i.e. 24% vs 15% crumb rubber by weight of the binder).

Newcomb et al. (1994) undertook a study to assess the influence of the wet and dry blending processes on the observed in-service performance of CRMA in the USA. A summary of their findings is presented in Table 2.3.

Table 2.3: CRMA field performance (wet and dry blending process)

Agency	Mixing method	Fatigue resistance	Rutting resistance	Thermal cracking resistance
Toronto	Wet	+	+	0
Alaska	Dry	+	0	+
California	Wet, Dry	+	+	+
Washington	Dry	0	0	0
Oregon	Dry	+	–	Not assessed
Florida	Wet	0	0	0
Minnesota	Wet	0	0	+
	Dry	Mixed outcomes	Mixed outcomes	Mixed outcomes

Note: + (improved performance), 0 (all test sections showed similar performance at time of reporting), – (control section performed better).

Source: Adapted from Newcomb et al. (1994).

As mentioned previously, in South Africa both the wet and dry blending process have been used to manufacture semi-open graded asphalt (similar to GGA) for several projects. Balmaceda and van Wijk (2013) reviewed a number of these projects and provided a comparison between the two blending processes, as presented in Table 2.4.

Table 2.4: CRMA produced using the wet and dry blending process

Criteria	Description	Preferred method	
		Wet	Dry
Constructability	The dry method requires less handling of raw materials, thus reducing cost, reducing safety hazards.		X
	For the wet method, the binder that must be pumped into the mixer is at least 10 times more viscous than conventional binders. This results in a reduction of the plant capacity, variability in the feeding of the blend into the mixer and possible pump blockages.		X
	If the dry method is followed, the mix cannot be discharged from the pugmill into the trucks as a period for reaction between the rubber and the bitumen is still needed.	X	

Criteria	Description	Preferred method	
		Wet	Dry
	The base bitumen must have special viscosity. Penetration of the base bitumen should not be too low (80/100 pen) resulting in an unstable mix nor too high (60/70 pen) resulting in pump blockages. This leads to extra care thus increased costs.	X	
Rubber content	More rubber can be accommodated if the dry method is used, as the pumps will only pump conventional binder (lower viscosity). This will result in a more durable and rut resistant mix (within certain ranges). More viscous binders can be used, thus more binder can be accommodated in the mix, resulting in improved durability, flexural strength and fatigue and rut resistance.		X
Binder quality control	The degree of reaction between the bitumen and the rubber of the bitumen-rubber blend can be properly controlled by measuring viscosity, flow and compression recovery if the wet method is used. If the dry method is used, quality control of the binder can only be controlled after extracting it from the premix.	X	
Risk of bleeding	The dry method does not require the pre-blending of the bitumen and the rubber crumbs, thus reducing storage times, lowering the risk of bitumen rubber degradation due to excessive storage times.		X
	Bleeding is less likely to occur if the dry method is followed since the viscosity of the binder, after reaction has taken place can be as high as 15,000 cP against the 2,000 or 3,000 cP of the binder of the BRASO wet method. This is only valid if mixes are produced and laid within the temperature time limits for bitumen rubber binders.	X	
Material pick-up during compaction and hand work behind the paver	Material pick-up during rolling was found to be lower if the dry method was applied due to the higher viscosity of the bitumen-rubber binder. Better compaction can be achieved as rolling can start earlier. However pneumatic tyred rollers should only be used when temperatures reach 130 °C.		X
	Handwork behind the paver or the rollers is more critical if the dry method is used. However, handwork for both asphalt types should be avoided.	X	

Source: Adapted from Balmaceda and van Wijk (2013).

It can be seen from the literature reviewed, both the wet and dry blending processes have advantages and disadvantages, as well as different performance outcomes. There also does not appear to be any consensus in the literature regarding a preferred blending process.

2.6 Local and International Specifications for CRM GGA

This section presents the findings of the review undertaken of selected local and international specifications and guidelines for the manufacture and placement of CRM GGA. The specifications included in the review were:

- American Society of Technical Methods (ASTM) *Standard Specification for Asphalt-Rubber Binder*, D6114/D6114M-09 (ASTM 2009)
- California Department of Transportation *Standard Specifications* (Caltrans 2015)
- ADoT *Standard Specifications for Road and Bridge Construction* (ADoT 2008)
- South African Bitumen Association (SABITA) *Guidelines for the Design, Manufacture and Construction of Bitumen-Rubber Asphalt Wearing Courses* (SABITA 2016)
- TMR Supplementary Specification PSTS112 *Crumb Rubber Modified Open Graded Asphalt Surfacing*, June 2016 Version 3 for Trial Purposes (TMR 2016)
- Roads and Maritime Services *QA Specification R118 Crumb Rubber Asphalt* (Roads and Maritime 2013)
- VicRoads *Section 421 – Bitumen Crumb Rubber Asphalt* (VicRoads 2006).

A summary of the key technical requirements in the documents listed above is presented in the following sections.

2.6.1 Crumb Rubber Requirements

The requirements for crumb rubber particles in the documents reviewed are summarised in Table 2.5.

The size of the crumb rubber used to modify asphalt is an important consideration, and it is reported that smaller rubber particles can increase the rate of reaction between the rubber and bitumen (Widyatmoko & Elliot 2008). The crumb rubber included in TMR's supplementary specification PSTS112 *Crumb Rubber Modified Open Graded Asphalt Surfacing* has a maximum particle size of 2.36 mm, which is similar to the maximum size in ASTM (2009), Caltrans (2015) and ADoT (2008). South Africa, Roads and Maritime and VicRoads allow for a smaller maximum rubber particle size compared to the other road jurisdictions included in the review.

The particle size distribution of the crumb rubber also differs significantly between the various jurisdictions. The impact of different particle size distributions on the modified binder properties is not clear at this stage and may have to be investigated in future.

Table 2.5: Crumb rubber specification requirements

Property		Requirement							
		ASTM (2009)	Caltrans (2015) ⁽¹⁾	ADoT Type A (2008)	ADoT Type B (2008)	SABITA (2016)	TMR (2016)	Roads and Maritime (2013)	VicRoads (2006)
Particle size distribution (% passing sieve)	2.36 mm sieve	100	100	100	–	–	100	–	–
	2.00 mm sieve	–	–	95–100	100	–	–	–	–
	1.18 mm sieve	–	–	0–10	65–100	–	–	100	100
	1.00 mm sieve	–	–	–	–	100	–	–	–
	0.600 mm sieve	–	–	–	20–100	40–70	–	60–100	80–100
	0.425 mm sieve	–	–	–	–	–	–	–	–
	0.300 mm sieve	–	–	–	0–45	–	–	0–20	–
	0.150 mm sieve	–	–	–	–	–	–	–	0–20
	0.075 mm sieve	–	–	–	0–5	0–5	–	–	–
	2.00 mm sieve ⁽²⁾	–	100	–	–	–	–	–	–
Wire content (max, %)		0.01	0.01	–	–	–	0.1	–	–
Fabric content (max, %)		0.5	0.05	0.1	0.5	–	–	–	–
Particle length (max, mm)		–	4.76	–	–	6	3	1	–
Foreign materials (max, %)		0.25	–	–	–	–	0.1	–	–
Moisture content (max, %)		0.75	–	–	–	–	1	–	–
Specific gravity		1.1–1.2	1.1–1.2	–	–	1.1–1.25	–	–	–
Bulk density (max, kg/m ³)		–	–	–	–	–	–	–	350
Natural rubber content in high natural crumb rubber (%)		–	40–48	–	–	–	–	–	–

1. Rubber must comprise of 75+/-2% scrap tyre crumb rubber and 25+/-2% high natural scrap tyre crumb rubber.

2. High natural crumb rubber.

2.6.2 CRM Binder Requirements

CRM binder specification requirements

Hicks and Epps (2000) reported that there are several important factors to consider when designing CRM binders. These factors are, in order of importance:

- temperature, time and stability of the binder-blend process
- source and grade of the base bitumen
- blending and agitation method/equipment
- rubber content
- rubber source and gradation
- additives used (such as extender oils).

The CRM binder requirements included in the specifications and guidelines reviewed are summarised in Table 2.6. Transport for New South Wales (previously known as Roads and Maritime Services) and the Victorian Department of Transport (previously known as VicRoads) use the dry process to manufacture CRM GGA and therefore do not have any CRM binder requirements.

Table 2.6: CRM binder specification requirements

Property	Requirement				
	ASTM (2009) ¹	Caltrans (2015)	ADoT (2008) ⁽¹⁾	SABITA (2016)	TMR (2016)
Penetration at 25 °C	25–75	25–70	Not specified	Not specified	Not specified
Penetration at 4 °C (min)	10 (Type 1) 15 (Type 2) 25 (Type 3)	Not specified	10 (Type 1) 15 (Type 2) 25 (Type 3)	Not specified	10 (CR1) 15 (CR2)
Penetration retention at 4 °C (min)	75	Not specified	Not specified	Not specified	Not specified
Resilience at 25 °C (min, %)	25 (Type 1) 20 (Type 2) 10 (Type 3)	18	25 (Type 1) 20 (Type 2) 15 (Type 3)	13–40	25 (CR1) 20 (CR2)
Compression/Recovery (%)	Not specified	Not specified	Not specified	> 80 (5 mins) > 70 (60 mins) > 40 (1,440 mins)	Not specified
Softening point (min, °C)	57 (Type 1) 54 (Type 2) 52 (Type 3)	52–74	57 (Type 1) 54 (Type 2) 52 (Type 3)	55–65	57 (CR1) 55 (CR2)
Viscosity at 190 °C (centipoises)	Not specified	1,500–4,000	Not specified	2,000–5,000	Not specified
Viscosity at 175 °C (Pa.s)	1.5–5.0	Not specified	1.5–4.0	Not specified	1.5–4.0
Flow (mm)	Not specified	Not specified	Not specified	10–50	Not specified
Flash point (min, °C)	Not specified	Not specified	Not specified	Not specified	250
Loss on heating (max, %)	Not specified	Not specified	Not specified	Not specified	0.6

Property	Requirement				
	ASTM (2009) ¹	Caltrans (2015)	ADoT (2008) ⁽⁴⁾	SABITA (2016)	TMR (2016)
Grade of base binder	Not specified	Not specified	PG 64-16 (Type 1) PG 58-22 (Type 2) PG 52-28 (Type 3)	Not specified ⁽³⁾	Not specified
Percentage extender oil (%)	Not specified	2–6 ⁽²⁾	Not specified	3 (max)	Not specified
Rubber content (%)	15 (min)	18–22	20 ⁽⁴⁾ (min)	18–24	18 (min)

1. Type 1 binders are typically used in hot climates, Type 2 binders in moderate climates and Type 3 binders in cold climates.

2. Defined as percentage by mass of the binder excluding the crumbed rubber component.

3. Base binder not specified but normally a 70/100 penetration grade binder is used (SABITA 2016).

4. Defined as a percentage of the base bitumen which equates to approximately 17% of the total binder content.

The CRM binder properties specified vary between the road jurisdictions reviewed, however, the most common properties specified are penetration, resilience, softening point, viscosity and rubber content of the modified binder. It is important to note that the test methods used to determine the various binder properties differ between the road jurisdictions and care should therefore be taken when comparing the binder requirements.

The penetration test is often used to assess the consistency (i.e. hardness) of a binder at typical pavement temperatures (Austroads 2008). Caltrans (2015) specifies that the penetration of the CRM binder must be determined at 25 °C, whereas ADoT (2008) and TMR (2016) specifies a 4 °C test temperature. ASTM (2009) specifies penetration limits for both 4 °C and 25 °C test temperatures.

Softening point is an empirical indication of a binder's consistency at elevated pavement temperatures and is often used to assess the level of modification that has occurred in a bitumen (Austroads 2008). The softening point specified for CRM binders is similar in all the specifications, with the lowest minimum value of 52 °C specified by ASTM (2009), Caltrans (2015) and ADoT (2008). ASTM (2009), ADoT (2008) and TMR (2016) only specify a minimum softening point requirement, whereas the other jurisdictions also specify a maximum value of between 65 °C and 74 °C.

The resilience test is commonly used to assess the elastic properties of CRM binders (Way, Kaloush & Biligiri 2011) and provides an indication of the expected field performance of these binders in terms of resistance to fatigue and reflective cracking (whereby increased resilience values indicated improved performance) (Caltrans 2003). The resilience test is also used as an indication of the amount of crumb rubber (i.e. level of modification) in the binder. The resilience values specified by TMR (2016) are similar to the values specified by ASTM (2009) and ADoT (2008) for moderate to hot climates. The minimum resilience values specified by Caltrans (18%) and SABITA (13%) are lower than the minimum value (20%) specified by the other jurisdictions for moderate to hot climates.

The viscosity of a binder at high temperatures is typically used to assess the handling characteristics of the binder during the manufacturing and construction process. The viscosity test is also used to determine the level of rubber digestion (i.e. binder-rubber interaction) that has occurred during the mixing and storage process. Caltrans (2015) and SABITA (2016) specify a viscosity range for CRM binders at 190 °C, whereas ASTM (2009), ADoT (2008) and TMR (2016) specify a test temperature of 175 °C. It is therefore likely that the binders with a viscosity requirement at 190 °C will be more viscous than the ASTM (2009), ADoT (2008) and TMR (2016) binders that have a lower temperature requirement for viscosity.

Extender (aromatic) oils can be used to promote the reaction between the base bitumen and rubber particles (Way, Kaloush & Biligiri 2011). Only Caltrans (2015) and SABITA (2016) include specific properties for extender oils. The addition of an extender oil is also a mandatory requirement in the Caltrans (2015) specification.

The rubber contents specified by the various jurisdictions vary between 15% and 24% by mass of the total binder. ASTM (2009) has the lowest minimum requirements of 15%.

ADoT (2008) is the only jurisdiction that specifies the grade of base bitumen to be used prior to modification, even though this has been identified by Hicks and Epps (2000) to be an important factor when designing CRM binders.

The binder requirements adopted by TMR in PSTS112 (2016) are similar to the requirements specified by ADoT (2008).

CRM binder handling requirements

As discussed in Section 2.4.2, the properties of high-viscosity CRM binders typically change over time and are a function of both temperature and blending/agitation methods. The handling of these binders during the manufacturing process is therefore critical to ensure consistency in the properties of these highly viscous binders.

The CRM binder handling requirements included in the documents reviewed as part of this project are summarised in Table 2.7. The CRM binder manufacturing temperatures specified by Caltrans (2015) and SABITA (2016) are similar, and higher compared to the temperature range specified by ADoT (2008) and TMR (2016).

It should however be noted that the minimum reaction time and allowable storage time (at elevated temperatures) of the binders manufactured in California and South Africa are lower compared to the binders specified by ADoT. The main reason for this is most likely the differences in the binder handling temperatures specified by the different jurisdictions.

TMR (2016) has adopted similar binder handling requirements to what is currently being specified by ADoT (2008).

Table 2.7: CRM binder handling requirements

Handling process	Requirement				
	ASTM (2009)	Caltrans (2015)	ADoT (2008)	SABITA (2016)	TMR (2016)
Bitumen temperature when rubber is added (°C)	No handling requirements specified	191–227	177–205	Not specified	175–205
Minimum reaction period (mins.)		45	60	45	60
Binder temperature during reaction period (°C)		191–218 ⁽¹⁾	163–191	170–210	165–190
Binder handling during storage		Maintain the binder temperature between 191–218 °C⁽¹⁾. Discontinue heating if binder is not used within 4 hours after the reaction period. If binder temperature drops below 191 °C, reheat binder to minimum 191 °C before use. The binder is not allowed to be reheated more than twice. Reheated binder must comply with the specified viscosity requirements. An additional 10% rubber can be added to bring binder back into specified limits.	Maintain the binder temperature between 163–191 °C. Discontinue heating if binder is not used within 10 hours after the reaction period. If binder temperature drops below 163 °C, reheat binder to 163–191 °C before use. The binder is not allowed to be reheated more than once.	Maintain the binder temperature between 190–210 °C for up to a max period of 6 hours. Short term storage: max. 165 °C up to 24 hrs. Long term storage: max. 150 hrs at 240 °C. Over-reacted binder can be classified as a homogenised modified binder. 25% of over-reacted binder can be blended with new CRM binder.	Maintain the binder temperature between 165–190 °C. Discontinue heating if binder is not used within 10 hours after the reaction period unless the binder design profile shows otherwise. If binder temperature drops below 165 °C, reheat to 165–190 °C before use. The binder is not allowed to be reheated more than once. An additional 10% rubber can be added to bring binder back into specified limits.
Maximum allowable storage time (days)		Not specified	4 days at a max. temperature of 121 °C	10 days	4 days at a max. temperature of 120 °C
Continuous binder agitation required		Not specified	Yes	Yes	Yes
Temperature of binder when added to aggregate (°C)		191–218	163–191	190–210	165–190
Maximum asphalt production temperature (°C)		Not specified	Not specified	Not specified	165 °C
Use of warm mix additives		Allowed	Not mentioned	Not mentioned	Mandatory

1. Maximum temperature limited to 4 °C below the flash point of the binder.

2.6.3 CRM GGA Mix Design Requirements

The particle size distribution for CRM GGA mixes nominated in the various documents reviewed are summarised in Table 2.8.

Table 2.8: CRM GGA particle size distribution specification requirements

Sieve size ⁽¹⁾	Requirement							
	Caltrans (2015)		ADoT (2008)	SABITA (2016)	Roads and Maritime (2013) ⁽²⁾		VicRoads (2006) ⁽²⁾	
	19 mm	12.5 mm	14 mm	14 mm	14 mm	10 mm	14 mm	10 mm
	Percentage passing by mass							
26.5 mm	100	–	–	–	–	–	–	–
19 mm	95–98	100	100	100	100	–	100	–
13.2 mm	83–87	90–98	80–100	84–100	83–100	100	90–100	100
12.5 mm	–	–	–	–	–	–	–	–
9.5 mm	65–70	83–87	65–80	68–83	58–82	83–100	65–75	90–100
6.7 mm	–	–	–	–	33–57	57–81	40–50	64–74
4.75 mm	28–42	28–42	29–43	29–43	23–47	29–53	30–40	36–46
2.36 mm	14–22	14–22	15–23	12–20	15–35	15–35	15–25	20–30
1.18 mm	–	–	–	–	9–28	9–28	10–19	12–22
0.600 mm	–	–	–	–	7–23	7–23	7–5	8–17
0.300 mm	–	–	–	–	0–12	0–12	5–10	6–11
0.150 mm	–	–	–	–	0–8.5	0–8.5	4–8	4–8
0.075 mm	0.0–6.0	0.0–6.0	0–3.5	1–4	0.5–5.5	0–5.5	3–5	3–5

1. Where sieve sizes are different in the parent specification, the closest Australian Standard sieve size is shown in the table.

2. Specification requirements apply to dry blending only.

Caltrans is the only jurisdiction that has a CRM GGA mix with a 19 mm maximum stone size. The particle size distribution requirements vary between the different road jurisdictions, but all are gap-graded as expected.

The mix design criteria for CRM GGA specified by the various road jurisdictions are summarised in Table 2.9.

Table 2.9: CRM GGA mix design requirements

Property	Requirement				
	Caltrans (2015)	ADoT (2008)	SABITA (2016)	Roads and Maritime (2013) ⁽¹⁾	VicRoads (2006) ⁽¹⁾
Method of compaction	Gyratory	Marshall	Marshall	Gyratory	Marshall
Binder content (%)	7.5 (min)	–	8 (min)	7.3–8.3	7.5–9.0
Air voids content (%)	4.0 (target)	4.5–6.5	3.0–6.0	3.0–6.0	5.0–6.5
Gyratory voids at 300 gyrations (min, %)	–	–	3	–	–

Property	Requirement				
	Caltrans (2015)	ADoT (2008)	SABITA (2016)	Roads and Maritime (2013) ⁽¹⁾	VicRoads (2006) ⁽¹⁾
Voids in mineral aggregate (%)	18.0–23.0	19 (min)	–	–	27 (min)
Active filler (min, %)	–	1	1	1.5 (lime)	–
Added filler (%)	–	–	–	–	1.0–2.0
Added crumb rubber (%) by mass of the total mix	–	–	–	2.0 (min)	2.5–3.0
Marshall stability (min, kN)	–	–	6	–	3.0 (14 mm mix) 2.5 (10 mm mix)
Marshall flow	–	–	2.0–5.0	–	3.0–5.5
Indirect tensile strength (min, kPa)	–	–	550	–	–
Immersion index (min, %)	–	–	75	–	–
Dynamic creep (min)	–	–	15	–	–
Binder film thickness (min, microns)	–	–	18	–	19–25
Drain-down (max, %)	–	–	–	–	–
Modified Lottman (min, %)	–	–	75	–	–
Hamburg wheel track (min, number of passes at 12 mm rut depth)	15,000 (PG 58) 20,000 (PG 64) 25,000 (PG 70)	–	–	–	–
Hamburg wheel track (min, number of passes at the inflection point)	10,000 (PG 58) 10,000 (PG 64) 12,500 (PG 70)	–	–	–	–
Moisture susceptibility, dry strength (min, kPa)	690	–	–	–	–
Moisture susceptibility, wet strength (min, kPa)	485	–	–	–	–

1. Mix design requirements apply to dry blending only.

Both gyratory and Marshall compaction methods are used by the different road jurisdictions for the design of CRM GGA mixes. The target binder content specified varies between 7.0% and 10%, which is significantly higher than the typical target binder content for DGA mixes.

The design air voids content varies between 3% and 6%. Only Caltrans (2008) and SABITA (2016) specify performance-related testing during the mix design, which mainly includes criteria for permanent deformation resistance and moisture susceptibility.

2.6.4 CRM GGA Construction Requirements

Some of the more important construction requirements for CRM GGA specified by the various road jurisdictions are summarised in Table 2.10.

Table 2.10: CRM GGA construction requirements

Handling process	Requirement				
	Caltrans (2015)	ADoT (2008)	SABITA (2016)	Roads and Maritime (2013)	VicRoads (2006)
Mix production temperatures (°C)	190–218 (binder temperature at time of mixing)	163–190 (binder temperature at time of mixing)	190–210 (binder temperature at time of mixing)	175 (max asphalt temperature)	195 (max asphalt discharge temperature)
Compaction temperatures (°C)	93–140	104 min	Not specified	Not specified	Not specified
Ambient/Pavement temperatures (°C)	13 min (ambient) 15 min (surface)	18 and rising (ambient and surface)	Not mentioned	13 and rising (0–5 km/h wind speed) 20 min (6–10 km/h wind speed) 25 min (11–15 km/h wind speed) 30 min (> 15 km/h wind speed)	15 min (surface)
In situ air voids (%)	3–9	4–9	Not specified	3–8 (30–50 mm thickness) 3–7 (> 50 mm thickness)	Not specified
Compaction density (min, %)	Not specified	Not specified	Not specified	Not specified	94 (< 50 mm thickness) 96 (> 50 mm thickness)

Again, the construction requirements vary between the different road jurisdictions included in this review, with the mix production temperatures typically higher in Caltrans (2015), SABITA (2016) and VicRoads (2006). The lower in situ air voids content ranges between 2.7% and 4%, with an upper range of between 7% and 9%.

2.7 Summary of Findings

The literature review found that CRM GGA has been used both locally and internationally over the past 30 years in environments where improved crack resistance, reduced temperature susceptibility and good permanent deformation resistance are required.

CRM GGA mixes can be manufactured by using either a dry or wet blending process, with advantages and disadvantages for both processes. The high-viscosity wet blending process appears to be the most widely used technology internationally and provides greater control over the binder and asphalt properties compared to the dry blending process.

The performance of CRMA manufactured using the dry blending process also appears to be more variable compared to the more widely used wet process. There are however several studies that showed the dry blending process can produce asphalt with good performance properties.

There are several specifications available, both locally and internationally, for the manufacture and placement of CRM GGA mixes. The basic specification properties are similar across the road jurisdictions, but the specification criteria vary for each property. It appears that only Caltrans and SABITA specify performance-related asphalt mix design criteria, including permanent deformation resistance and moisture susceptibility.

3. Technical Specification for CRM GGA

One of the key objectives of this project was to transfer the CRM GGA technology used in the USA (and more specifically from Arizona and California) to Australia. These two states have a proven history of successfully using CRM GGA (manufactured with high-viscosity wet blended binders) over cracked and jointed concrete pavements to reduce the risk of reflective cracking occurring.

The important technical criteria recommended for inclusion in a technical specification for the manufacture and placement of CRM GGA mixes include, but are not limited to:

- crumb rubber properties
- CRM binder properties
- CRM GGA mix design requirements
- CRM binder manufacturing, handling and storage requirements
- construction requirements.

A previous NACOE project developed technical specification PSTS112 for the manufacture and placement of CRM OGA (TMR 2016). Given that this specification has already been successfully used on construction projects in Queensland, it was agreed to keep the crumb rubber and CRM binder specification requirements of the new specification for CRM GGA consistent with the requirements in PSTS112.

It was also agreed that a national technical specification will be developed in collaboration with AAPA, which can be modified by road agencies to fit within their individual specification systems. A copy of the national specification developed as part of this project is included in Appendix A.

Some of the key specification requirements are discussed in more detail below.

3.1 Crumb Rubber Properties

The proposed properties specified for crumb rubber used to manufacture CRM binders are consistent with the requirements in AGPT/T190 *Specification framework for polymer modified binders*, except for the particle size distribution (grading) of the rubber particles. At the time of developing specification PSTS112, industry consultation suggested that there was currently limited control over the grading of the rubber particles supplied in Australia. It was therefore decided not to be prescriptive regarding the grading of the rubber particles given that the modified binder must still meet several other specification criteria (such as viscosity, softening point, resilience etc.). It is however understood that the grading of the crumb rubber can impact on the reaction time and binder properties. Further work is therefore recommended to better understand the impact of the grading of crumb rubber particles on binder performance.

The crumb rubber properties recommended for inclusion in the new specification for CRM GGA are summarised in Table 3.1.

Table 3.1: Proposed crumb rubber properties

Property		Test method	Requirement
Particle size distribution	Passing 2.36 mm	AGPT/T143	100
	Passing 1.18 mm		To be nominated by contractor
	Passing 0.600 mm		To be nominated by contractor
	Passing 0.300 mm		To be nominated by contractor
	Passing 0.150 mm		To be nominated by contractor
	Passing 0.075 mm		To be nominated by contractor
Particle length (mm), maximum		AGPT/T143	3
Bulk density (kg/m ³)		AGPT/T143	To be nominated by contractor

Property	Test method	Requirement
Water content (%), maximum	AGPT/T143	1
Foreign materials – other than iron (%), maximum	AGPT/T143	0.1
Foreign materials – metallic iron (%), maximum	AGPT/T143	0.1

3.2 CRM Binder Properties

The CRM binder properties recommended for inclusion in the pilot specification developed as part of this project were primarily based on the TMR (2016) and ADoT (2008) requirements for a Type 2 binder and are summarised in Table 3.2. The main reason for adopting the ADoT requirements is that binders in Arizona are manufactured at lower target temperatures compared to in California (i.e. 175 °C vs 190 °C), which has potential environmental and health benefits, as well as being more consistent with current binder handling temperatures in Australia.

Table 3.2: Proposed CRM binder properties

Property	Test method	Reaction time		
		60 mins	240 mins	To be nominated by the contractor
Penetration @ 4 °C, 200 g, 60 sec (0.10 mm), minimum	AS 2341.12	15	15	15
Penetration @ 25 °C, 100 g, 5 sec (0.10 mm)	AS 2341.12	To be reported	To be reported	To be reported
Resilience @ 25 °C (%), minimum	ASTM D5329	20	20	20
Torsional recovery @ 25 °C, 30 sec (%)	AGPT/T122	To be reported	To be reported	To be reported
Softening point (°C), minimum	AGPT/T131	55	55	55
Viscosity at 175 °C (Pa.s)	AGPT/T111	1.5–4.0	1.5–4.0	1.5–4.0

In addition to the requirements listed in Table 3.2, the CRM binder must also contain between 18% and 22% crumb rubber by total mass of the binder, as well as a warm mix additive to reduce the manufacturing temperature of the asphalt.

It is worth noting that even though the binder properties proposed in the new specification are similar to the properties adopted overseas, the performance of the locally manufactured binders could be different given differences in rubber particles, base bitumen, the use (or not) of combining oils, etc. It is therefore important that the performance of CRM binders manufactured in Australia be assessed over a period of implementation to ensure that the benefits observed overseas can be achieved locally.

3.3 CRM GGA Mix Design Requirements

In Australia, there is an increased desire to include performance-related specification requirements for asphalt mixes. Caltrans has extensive experience in the use of CRM GGA and their specification includes several performance criteria, including permanent deformation, moisture damage and tensile strength ratio (TSR). The CRM GGA mix design requirements included in the specification developed as part of this project are therefore based on the Caltrans mix design requirements.

The recommended grading and mix design requirements are summarised in Table 3.3 and Table 3.4.

Table 3.3: Proposed CRM GGA particle size distribution

Sieve size (mm)	Percentage by mass passing sieve size (%)	
	14 mm nominal size	19 mm nominal size
26.5		100
19.0	100	95–98
13.2	90–98	83–87
9.5	83–87	65–70
6.7	To be nominated by contractor	To be nominated by contractor
4.75	28–42	28–42
2.36	14–22	14–22
1.18	To be nominated by contractor	To be nominated by contractor
0.600	To be nominated by contractor	To be nominated by contractor
0.300	To be nominated by contractor	To be nominated by contractor
0.150	To be nominated by contractor	To be nominated by contractor
0.075	0–6	0–6

Table 3.4: Proposed CRM GGA mix design properties

Property	Test method	Requirement
Air voids content – gyratory compaction (%)	AS/NZS 2891.9.2	4
Gyratory compaction (no. of gyrations)	AS/NZS 2891.2.2 ^(1,2)	50–150
Voids in mineral aggregate	AS/NZS 2891.8	18–23
Filler/binder ratio	n/a	To be reported
Permanent deformation (minimum number of passes at 12 mm rut depth)	TMR Q325	20,000
Moisture damage (minimum number of passes at the inflection point)	TMR Q325	10,000
Tensile strength ratio (%)	AG:PT/T232 (with freeze-thaw cycle)	≥ 80
Air voids content – Marshall compaction (%)	AS/NZS 2891.5 or AS/NZS 2891.2.2	To be reported
Binder content (%)	AS/NZS 2891.3.1 or AG:PT/T234 ⁽³⁾	≥ 7.5%

1. The laboratory compaction temperature should be 145±5 °C if a warm mix additive is included, alternatively a temperature of 160±3 °C should be used.
2. The gyratory compaction settings should be adjusted to the Caltrans (2015) settings as per the paragraph below.
3. The binder content should be adjusted in accordance with SABITA (2016) when AS/NZS 2891.3.1 is used or Appendix A in AG:PT/T234 if AG:PT/T234 is used. This adjustment is made to allow for the undigested rubber particles in the binder.

The gyratory compaction settings recommended are consistent with the requirements in Caltrans (2015) and vary from the settings specified in AS/NZS 2891.2.2 *Methods of sampling and testing asphalt method 2.2: sample preparation – compaction of asphalt specimens using a gyratory compactor* as follows:

- The compaction pressure is increased from 240 kPa to 600–825 kPa. It is understood that the increased pressure allows for the higher viscosity of the CRM binder compared to more traditional binders.
- The gyratory angle is 1.16 degrees (consistent with the Superpave method) compared to 2 degrees used in Australia.
- A gyratory speed of 30 ± 0.5 revolutions per minute is used instead of 60 ± 5 revolutions per minute.

CRMA specimens are known to expand immediately after compaction when still hot due to the elasticity of the rubber particles in the binder. The Caltrans specification allows for laboratory compacted specimens to be cooled down in the compaction mould for a maximum period of 90 minutes under vertical pressure prior to determining the volumetric properties.

In Australia, the ‘Gyropac’ gyratory device is commonly used to compact asphalt specimens during production control. However, the ‘Gyropac’ cannot apply a compaction pressure of 600–825 kPa as per the recommended design criteria. To overcome this practical constraint initially in Australia, an additional air

voids requirement (for reporting purposes only) can be included by road agencies for specimens compacted during construction by either the Marshall or gyratory compaction method. This will allow the volumetric properties of CRM GGA mixes to be assessed during production using currently available equipment.

It is recommended that the design binder content (also known as the optimum binder content) of the CRM GGA mix be determined in accordance with the Caltrans procedure as follow:

- Select the number of gyratory cycles between 50 and 100 cycles.
- Select the gyratory compactor pressure between 600 kPa and 825 kPa.
- Compact three specimens at not less than four different binder contents, with the minimum binder content being 7.0%.
- Plot the average air voids content for each set of three specimens against the binder content and draw a best-fit curve through the data points.
- Plot the average voids in mineral aggregate (VMA) for each set of three specimens against binder content and draw a best-fit curve through the data points.
- The design binder content is determined so that the air voids content is 4% and the VMA is between 18.0% and 23.0%.
- The minimum design binder content must not be less than 7.5%.

The aggregate grading, number of gyratory cycles or compaction pressure can be adjusted to achieve the specified air voids, VMA and minimum binder content requirements.

3.4 CRM Binder Manufacturing, Handling and Storage Requirements

As mentioned previously, the properties of CRM binders change over time when exposed to elevated temperatures. It is therefore essential to manufacture, handle and store CRM binders in an appropriate manner to reduce the risk of over-digestion occurring. The technical specification developed as part of this project includes the following manufacturing, handling and storage requirements:

- The temperature of the CRM binder immediately after the initial dispersion of the crumb rubber into the bitumen must be between 165 °C and 200 °C.
- The producer must ensure that the crumb rubber and bitumen are thoroughly mixed prior to the beginning of the reaction period. The reaction period must be a minimum of 60 minutes, during which time the CRM binder continues to be mixed while the temperature is maintained between 165 °C and 200 °C.
- Once the CRM binder has been blended, the binder must be kept thoroughly agitated to prevent settling of the crumb rubber particles. The temperature of the CRM binder must be maintained between 165 °C and 190 °C prior to using the binder.
- If in the first 10 hours after completion of the reaction period, the temperature of CRM binder falls below 165 °C, it may be reheated to a temperature between 165 °C and 190 °C.
- In no case must the CRM binder be held at a temperature between 165 °C to 190 °C for more than 10 hours after the completion of the reaction period. CRM binders that are to be held for more than 10 hours must be allowed to cool and gradually reheated to a temperature between 165 °C and 190 °C prior to use.
- The reheating of CRM binders that have cooled to below 165 °C will not be allowed more than once, unless otherwise approved by the Administrator.
- CRM binders must not be held at a temperature above 120 °C for more than four days after completion of the reaction period, unless otherwise approved by the Administrator.
- The temperature of the CRM delivered into the asphalt plant must not exceed 190 °C.

The requirements included in the specification are primarily based on the ADoT requirements and are consistent with the requirements specified by TMR for CRM OGA (TMR 2016).

3.5 Construction Requirements

Some of the key construction requirements included in the specification are:

- asphalt manufacturing temperatures
- compaction requirements
- finishing requirements.

It is proposed that the temperature of the CRM binder delivered to the asphalt mixer be limited to a maximum value of 190 °C, consistent with the proposed binder handling requirements. The temperature of the asphalt mix should also not exceed 165 °C when exiting the asphalt mixer. The lower asphalt temperature recommended is to reduce the amount of fuming during production and asphalt placement, which means that a warm mix additive will likely be required.

The in situ air voids contents nominated in the specifications reviewed as part of this project range between 2.7% and 9.0%. Local experience indicates that asphalt mixes with an in situ air voids content of greater than 8% can be highly permeable and prone to moisture damage. It is therefore proposed to limit the maximum allowable characteristic air voids content to 8.0% in the field, with a minimum characteristic value of 3.0%.

Due to the higher binder content of CRM GGA mixes and the behaviour of the binder when hot, it is proposed that pneumatic-tyred rollers should not be used during construction due to the risk of binder pick-up (similar to construction practices in California).

The high binder content of CRM GGA mixes also results in higher binder film thicknesses around the aggregates, which in turn could cause a reduction in the early skid resistance of the asphalt layer (similar to SMA). It is therefore recommended to grit the CRM GGA surface prior to opening the works to traffic until such time it is confirmed that the thicker binder film will not adversely affect early life skid resistance. The grit will also minimise the potential for binder pickup during early trafficking.

4. Demonstration Projects

Demonstration projects were undertaken in Queensland and Western Australia as part of the technology transfer process. These projects were aimed at assessing if CRM GGA can be manufactured and placed locally in accordance with the technical requirements developed as part of this project. The findings from the demonstration projects are presented below.

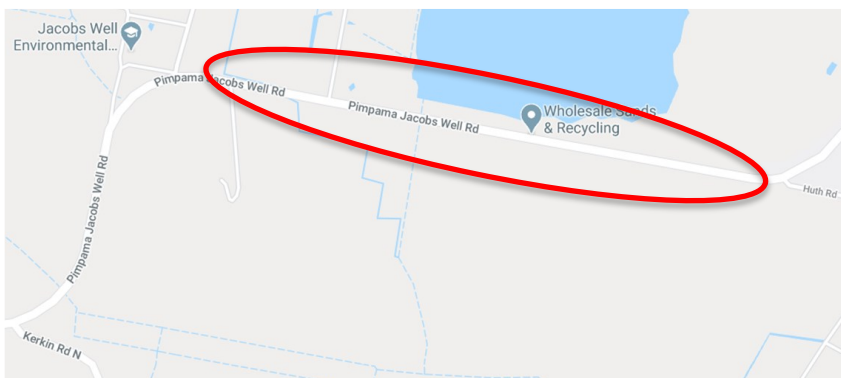
4.1 Queensland Demonstration Project

The City of Gold Coast undertook the first demonstration project along a section of Pimpama Jacobs Well Road on 29 June 2018. The CRM GGA was manufactured and placed by Fulton Hogan in accordance with the specification presented in Section 3 of this report.

4.1.1 Site Description

The demonstration project was undertaken along both lanes of a section of Pimpama Jacobs Well Road between project chainage 3046 m and chainage 3256 m (Figure 4.1). Was it both lanes?

Figure 4.1: Project location



Source: Google Maps (2020), 'Queensland', map data, Google, California, USA.

The project site is located along flat and low-lying terrain surrounded by sugar cane fields (Figure 4.2).

Figure 4.2: Road alignment and environment



The existing pavement comprised of a cement stabilised basecourse with a sprayed seal surface and was showing severe signs of block cracking (5–10 mm wide) due to the underlying cement treated base (Figure 4.3). Pumping of the fine material through the cracks was also observed, as well as deformation around some of the larger cracks (Figure 4.4).

Figure 4.3: Large stabilisation crack



Figure 4.4: Block cracking with pumping of the fines



The pavement repair works comprised of the placement of a 10 mm C170 sprayed seal prior to constructing a 50 mm nominal thick CRM GGA overlay. A control section with a 50 mm nominal thickness DGA modified with an A5S PMB was also constructed between project chainage 2846 m and chainage 3046 m.

4.1.2 Weather Conditions

The works were undertaken during favourable weather conditions on the day with clear skies and an ambient temperature of between 18 °C and 25 °C during paving operations.

4.1.3 Manufacture of CRM Binder

The CRM binder was manufactured for Fulton Hogan by SAMI Bitumen Technologies (SAMI) at their plant in Pinkenba. The binder properties, as provided by SAMI, are summarised in Table 4.1.

It is important to note that the binder properties are commercial in confidence information and should not be distributed to anyone outside of the project team. A redacted version of this report will be made available for publication.

Table 4.1: CRM binder properties – Queensland demonstration project

Property	Test method	Value	Requirement
Penetration @ 4 °C, 200 g, 60 sec (0.10 mm)	AS 2341.12	19	10 (min)
Penetration @ 25 °C, 100 g, 5 sec (0.10 mm)	AS 2341.12	Not tested	Report only
Resilience @ 25 °C (%)	ASTM D5329	60	25 (min)
Torsional recovery @ 25 °C, 30 sec (%)	AG:PT/T122	37	Report only
Softening point (°C)	AG:PT/T131	67	57 (min)
Viscosity at 175 °C (Pa.s)	AG:PT/T111	0.99	1.5–4.0

The viscosity at 175 °C of the binder is below the minimum specified value for a CRM binder in accordance with AAPA's (2018) model specification. However, the testing was undertaken on the binder after a warm mix additive was added and a reduction in binder viscosity is therefore expected.

It is also worth noting that the resilience value of 60% is significantly higher than the minimum specified value of 25%. A value of 60% is highly unlikely given a minimum percentage rubber content of 18%. It is believed that this test result may be erroneous and should be treated with caution.

In addition to the testing undertaken by the binder supplier, TMR also undertook on-site viscosity testing at different temperatures using a hand-held viscometer (Figure 4.5).

The testing was undertaken on a binder sample taken at the start of production (sample 1) and a binder sample after 160 tonnes of asphalt produced (Sample 2). The test results are summarised in Table 4.2.

It is important to note that the viscosity testing at the plant was again undertaken on the binder after the warm mix additive has been added.

Figure 4.5: Hand-held viscometer used for testing

Source: TMR (2018).

Table 4.2: On-site viscosity test results

Temperature (°C)	Viscosity (Pa.s)	
	Sample 1	Sample 2
180	0.4	0.7
175	1.0	1.0
170	1.2	1.2
165	1.5	1.5
160	1.6	1.7
155	1.7	2.1
150	Not tested	2.4
145	Not tested	2.7
140	Not tested	3.2
135	Not tested	4.0

A key learning from the demonstration project was that the binder should either be tested for compliance without the warm mix additive, or alternatively, a temperature versus viscosity relationship (with and without the warm mix additive) should be established for the specific binder used on a project to assess the viscosity of the binder at 175 °C.

It is therefore proposed that the following procedure be included in future updates to the specification to evaluate the effect of the warm mix additive on the viscosity of the binder:

- Split a sample of CRM binder into two sub-samples.
- Add the warm mix asphalt additive that will be used on the project to one of the sub-samples and determine the viscosity of the other sub-sample at 175 °C.
- Determine the viscosity of the sub-sample with the warm mix additive at 175 °C, 165 °C and every 10 °C reduction thereafter until the viscosity of the binder with the additive is higher than the viscosity of the sub-sample without any additive.
- Plot the viscosity of the binder without warm mix asphalt additive against temperature and draw a best-fit curve through the data points.
- The appropriate test temperature of the binder with warm mix asphalt additive will then be the temperature on the graph corresponding to the viscosity of the binder without warm mix asphalt additive at 175 °C.

It is also worth noting that testing undertaken as part of a separate WARRIP study found that there are differences between the viscosity measured with the Brookfield device and the hand-held viscometer (van Aswegen 2019). It is therefore recommended that the effect of different test methods on the viscosity of CRM binders be further assessed in future studies.

4.1.4 Manufacture of CRM GGA

The CRM GGA mix was designed by Fulton Hogan to meet the asphalt requirements in the technical specification developed as part of this project. The asphalt mix was manufactured by Fulton Hogan at their asphalt plant in Ormeau, Queensland.

A summary of the mix design information is provided in Table 4.3. Some mix design and quality control information was omitted from this report for proprietary reasons.

Table 4.3: Mix design information – Queensland demonstration project

Property	Test method	Value	Requirement
Binder content (%)	Q308A	7.8	7.5 min.
Gyratory compaction (no. of gyrations)	AS/NZS 2891.2.2	As nominated by contractor	50–150

Property		Test method	Value	Requirement
Air voids content (%)		AS/NZS 2891.9.2	4.0	4.0
Voids in mineral aggregate (%)		AS/NZS 2891.8	21.9	18–23
Filler/binder ratio		n/a	0.6	Report only
Permanent deformation (min. number of passes at 12 mm rut depth)		TMR Q325	49,400	20,000
Moisture damage (min. number of passes at the inflection point)		TMR Q325	30,000	10,000
Moisture sensitivity (%)		AG:PT/T232	89	≥ 80
Particle size distribution	Passing 19.0 mm sieve (%)	Q308A	100	100
	Passing 13.2 mm sieve (%)		99	90–98
	Passing 9.50 mm sieve (%)		83	83–87
	Passing 6.70 mm sieve (%)		61	No requirement
	Passing 4.75 mm sieve (%)		31	28–42
	Passing 2.36 mm sieve (%)		20	14–22
	Passing 1.18 mm sieve (%)		14	No requirement
	Passing 0.600 mm sieve (%)		9	No requirement
	Passing 0.300 mm sieve (%)		6.5	No requirement
	Passing 0.150 mm sieve (%)		5.5	No requirement
	Passing 0.075 mm sieve (%)		4.5	0–6.0
Fibre content (%)			0.3	

The test results provided by the contractor indicate that the mix design met the specification requirements.

The contractor also undertook quality control testing as part of their contractual obligations for the project and this information is summarised in Table 4.4.

Table 4.4: Quality control test results – Queensland demonstration project

Property		Test method	Value			Requirement ⁽¹⁾
			Sample A	Sample B	Sample C	
Mix temperature (°C)		n/a	158	158	158	165 (max)
Air voids content – Marshall (50 blows per face) (%)		Q311	6.5	6.5	5.5	Report only
Filler binder ratio		n/a	0.8	0.6	0.6	1.6 (max)
Binder content (%)		Q308A	7.7 ⁽²⁾	7.4 ⁽²⁾	7.8 ⁽²⁾	7.2–8.3
Particle size distribution	Passing 37.5 mm sieve (%)	Q308A	100	100	100	100–100
	Passing 26.5 mm sieve (%)		100	100	100	100
	Passing 19.0 mm sieve (%)		100	100	100	100–100
	Passing 13.2 mm sieve (%)		99	99	100	92–100
	Passing 9.50 mm sieve (%)		85	81	85	76–90
	Passing 6.70 mm sieve (%)		66	64	64	54–68
	Passing 4.75 mm sieve (%)		37	33	36	24–38
	Passing 2.36 mm sieve (%)		20	18	19	15–25
	Passing 1.18 mm sieve (%)		14	13	13	9.0–19
	Passing 0.600 mm sieve (%)		10	8.6	9.2	5.0–13
	Passing 0.300 mm sieve (%)		7.6	5.8	6.8	2.5–10.5
	Passing 0.150 mm sieve (%)		5.9	4.5	5.3	3.0–8.0
	Passing 0.075 mm sieve (%)		4.8	3.8	4.4	3.0–8.0

1. Specification requirements include allowable production tolerances.

2. Based on a correction factor of 0.87 to allow for undigested rubber particles.

Again, it can be seen from the test results provided by the contractor that the asphalt manufactured for the demonstration project complied with the specification requirements.

4.1.5 Surface Preparation

Limited pavement repairs (i.e. shallow patching) were undertaken prior to the asphalt overlay. Most of the cracks due to the cement treated base were however left untreated prior to the overlay to test the effectiveness of CRM GGA to resist these cracks from migrating through to the surface.

The road was treated with a 10 mm C170 sprayed seal prior to constructing a nominal 50 mm thick CRM GGA overlay.

4.1.6 Placement and Compaction

The contractor started paving the CRM GGA mix at 09:45 am and paving ended at 01:30 pm. The asphalt was placed and compacted using the following conventional construction equipment (Figure 4.6):

- 1 x self-propelled asphalt paver
- 1 x material transfer vehicle
- 2 x vibratory steel wheeled rollers (8.5 tonnes each)
- 1x vibratory steel wheeled roller (12 tonnes).

The material was discharged from the asphalt plant at an approximate temperature of 165 °C and delivered to the paver at a temperature of between 140 °C and 165 °C.

Figure 4.6: Conventional construction equipment



Source: AAPA (2018).

The asphalt was compacted using steel wheeled rollers. Breakdown rolling was done with one pass of the steel wheeled roller in static mode, followed by three passes in vibratory mode. This was followed by at least two roller passes (1 in static mode and 1 in vibratory mode) after the sand grit was applied to the asphalt surface (Figure 4.7).

Figure 4.7: Sand grit applied to the surface to improve early-life skid resistance



Source: ARRB (2018).

The compaction process was also monitored using a pavement quality indicator (PQI). The PQI is a device that instantaneously measures the in situ density of a material through electro-magnetism. The PQI was used to adjust the number of passes for each area based on the density readings to assist with determining appropriate compaction sequences (Figure 4.8).

Figure 4.8: PQI taking density measurements



Source: AAPA (2018).

It is important to note that pneumatic tyred rollers were not allowed during the compaction process to reduce the risk of binder pick-up occurring.

Some visible movement was observed underneath the rollers during initial compaction, most probably due to the higher binder content in the GGA mix.

At one stage during the paving process, excess binder was observed in the material transfer vehicle which highlights the potential risk of binder drain-off with this mix type due to the higher binder content and gap-graded aggregate structure. Fibres can be added to the mix to reduce the risk of binder drain-off occurring.

The contractor also undertook density measurements of cores extracted from the compacted layer as part of quality control processes and the test results are summarised in Table 4.5.

Table 4.5: Compaction test results – Gold Coast demonstration project

Chainage (m)	Core thickness (mm)	Compacted density (t/m ³)	Air voids content (%)
29	57	2.356	7.5
79	54	2.339	8.2
129	57	2.354	7.6
179	48	2.315	9.1
54	45	2.329	8.6
104	55	2.336	8.3
154	45	2.347	7.9
204	56	2.355	7.6

The air voids of the compacted asphalt varied between 7.5% and 9.1%, with lower and upper characteristic values of 7.7% and 8.5% respectively. The upper characteristic air voids value is 0.5% higher than the maximum value nominated in the specification. The contractor confirmed that the CRM GGA did require more compactive effort compared to conventional asphalt to achieve the required density.

The overlay works were opened to traffic once the surface temperature was below 45 °C.

4.1.7 Finished Surface

The finished surface (after the rolling was completed) visually appeared to be uniform and well textured (Figure 4.9).

Figure 4.9: Finished surface



Source: ARRB (2018).

TMR undertook texture depth (using the sand patch method) and skid resistance (using the British Pendulum device) testing on the finished asphalt surface. The texture depth and skid resistance testing were undertaken after the surface has been gritted. The test results are summarised in Table 4.6.

Table 4.6: Surface texture depth soon after opening to traffic

Lane	Chainage (m)	Location	Surface temperature (°C)	Texture depth (mm)	SRV (dry)	SRV (wet)	SRV30
Westbound	62	OWP	24.0	0.7	99	61	59
Westbound	112	BWP	23.9	0.7	100	70	68
Westbound	164	OWP	24.9	0.7	98	63	62
Westbound	164	BWP	25.0	0.7	99	67	65
Westbound	211	IWP	25.5	0.8	94	57	56
Eastbound	120	OWP	26.5	0.7	95	60	59
Eastbound	70	BWP	27.1	0.6	93	61	60
Eastbound	50	IWP	27.0	0.6	97	68	67
Eastbound	50	BWP	27.7	0.6	95	65	64
Eastbound	50	OWP	28.0	0.6	97	64	63

The texture depth of the finished surface varied between 0.6 mm and 0.8 mm within one week after construction.

The Skid Resistance Value (SRV) at a reference surface temperature of 30 °C (SRV30) varied between 59 and 68, with an average value of 62.

4.2 Western Australian Demonstration Project

4.2.1 Site Description

The demonstration project in Western Australia was arranged by MRWA and constructed on the southbound carriageway of Marmion Avenue, North Beach Western Australia.

The works comprised of placing both a 10 mm and 14 mm nominal aggregate size CRM GGA over an existing pavement that showed signs of fatigue cracking. The profiled surface was sealed with a strain alleviating membrane interlayer (SAMI) prior to placing the CRM GGA.

The demonstration project (including construction details and laboratory testing) is comprehensively documented in a separate WARRIP report (Middleton 2020). In summary, the project demonstrated that CRM GGA can be successfully manufactured and placed in Western Australia using local materials.

4.3 Emissions Monitoring

There are concerns that the introduction of crumbed rubber to asphalt at high temperatures could potentially result in harmful emissions (Grobler et al. 2017). Emissions monitoring was undertaken during an earlier demonstration project on the Sunshine Coast using CRM binder in OGA (Grobler et al. 2017). The study by Grobler et al. (2017) found that mix temperature was a dominant factor in determining the relative risk of worker exposure to potentially harmful emissions. The study also found that producing asphalt at lower temperatures could reduce the risk of exposure to these potentially harmful emissions. However, the concentration of benzene (a known harmful substance) was higher for the mixes containing CRM binder and further studies were recommended.

Following on from this recommendation, personal exposure monitoring was undertaken as part of the demonstration projects in Queensland and Western Australia.

The emissions monitoring of the Queensland project was undertaken and documented by Assured Environmental (2018), and a copy of the emissions monitoring report is also included in Appendix B. Personal exposure samples were collected from four construction workers (i.e. truck spotter, level hand, shuttle buggy operator and paver operator) over the course of the paving shift (Figure 4.10).

Figure 4.10: Emissions monitoring – note blue backpack on construction worker



Source: ARRB (2018).

The emissions monitoring of the Western Australian project was undertaken by Emissions Assessments and the findings are documented in Middleton (2020).

In both cases, the emissions monitoring undertaken during the demonstration projects did not identify any concerns regarding the potential exposure of workers to harmful emissions during the placement and compaction of CRM GGA.

5. Laboratory Assessment CRM GGA

The following asphalt testing was undertaken as part of this study prepared from materials provided by the asphalt supplier:

- gyratory compacted density of loose asphalt sampled during production for the Queensland demonstration project
- testing of the binder used for the Queensland demonstration project
- resilient modulus of asphalt specimens manufactured in the laboratory from samples obtained during the Queensland demonstration project
- flexural modulus and fatigue resistance testing of asphalt beams from samples manufactured in the laboratory using materials sourced from the Queensland and Western Australian demonstration projects.

Additional laboratory testing was undertaken on the CRM GGA produced for the Western Australian demonstration project as part of a separate WARRIP project. The results of these tests are documented in Middleton (2020).

5.1 CRM Binder Testing

The binder sampled by the contractor for the demonstration project in Queensland was not representative of the binder used in the asphalt during construction. It was therefore agreed to use a similar binder previously sampled during the CRM OGA trial in 2018 to manufacture laboratory prepared specimens for further testing. This binder was tested by ARRB to ensure that it met the specification requirements prior to preparing the asphalt specimens.

The results of the binder testing are summarised in Table 5.1.

Table 5.1: CRM binder properties – Queensland project

Property	Test method	Test result	Requirement
Penetration @ 4 °C, 200 g, 60 sec, 0.10 mm	AS 2341.12	23	10 (min)
Resilience @ 25 °C (%)	ASTM D5329	39.8	25 (min)
Softening point (°C)	AG:PT/T131	67.2	57 (min)
Viscosity at 175 °C (Pa.s)	AG:PT/T111	1.75	1.5–4.0

The binder used for the demonstration project in Western Australia was tested by the contractor's national laboratory and the results are summarised in Table 5.2.

Table 5.2: CRM binder properties – Western Australian project

Property	Test method	Test result	Requirement
Penetration @ 4 °C, 200 g, 60 sec, 0.10 mm	AS 2341.12	24 & 25	10 (min)
Resilience @ 25 °C (%)	ASTM D5329	34 & 35	25 (min)
Softening point (°C)	AG:PT/T131	69 & 70	57 (min)
Viscosity at 175 °C (Pa.s)	AG:PT/T111	1.6 & 1.6	1.5–4.0
Torsional recovery at 25 °C (%)	AGPT/T122	42.8 & 45.8	Report only
Consistency 6% at 60 °C (Pa.s)	AGPT/T121	2355 & 2582	Report only

5.2 Gyratory Compacted Density of Asphalt Specimens

The Caltrans (2015) specification allows for a gyratory compaction pressure of between 600 kPa and 825 kPa to be used during the mix design process. This pressure increase may enable the mix to satisfy the minimum optimum binder content of 7.5%. A similar requirement was included in AAPA's technical

specification and the impact of increasing the compaction pressure was assessed on the asphalt mix used for the demonstration project in Queensland.

Asphalt specimens were compacted in the laboratory from production samples obtained from the asphalt plant using the following gyratory compaction settings:

- compaction pressure: 600 and 825 kPa
- gyratory angle: 1.16°
- rate of gyrations: 30 rev/min
- number of gyratory cycles: 150
- temperature: 145 ± 3 °C.

The density results are summarised in Table 5.3 and Table 5.4.

Table 5.3: Density of laboratory asphalt specimens – 600 kPa compaction pressure

Specimen number	Specimen thickness (mm)	Compacted density (t/m ³)	Air voids content (%)
CR13	117.53	2.405	5.2
CR24	116.31	2.399	5.4
CR35	115.42	2.398	5.5
CR46	114.63	2.400	5.4

Table 5.4: Density of laboratory asphalt specimens – 825 kPa compaction pressure

Specimen number	Specimen thickness (mm)	Compacted density (t/m ³)	Air voids content (%)
CR57	114.51	2.414	4.8
CR68	115.11	2.424	4.5
CR79	115.44	2.422	4.5
CR810	115.25	2.420	4.6

The results indicate that an increase in compaction pressure from 600 kPa to 825 kPa reduced the air voids content of the asphalt specimens by an average value of 0.8%. Furthermore, the specimens compacted with either a 600 kPa or 825 kPa compaction pressure had an air voids content greater than 4% at 150 gyratory cycles which suggests that this particular mix may be difficult to compact in the field, which is consistent with the observation made during the demonstration project in Queensland.

The Caltrans (2015) specification for CRM GGA recommends that asphalt specimens compacted in the laboratory should be allowed to cool under pressure for a period of up to 90 minutes prior to removing the specimens from the compaction mould. This is to compensate for any relaxation that may occur within the specimens as a result of the elastic rubber particles whilst the material is still hot. However, it is understood that cooling asphalt specimens while maintaining a constant compaction pressure is not possible without making modifications to the locally available gyratory compaction equipment.

The impact of specimen relaxation on the air voids content was therefore determined in the laboratory and the results are summarised in Table 5.5.

Table 5.5: Changes in density due to specimen relaxation

Specimen number	Compaction pressure (kPa)	Specimen thickness (mm)	Specimen thickness – after cooling (mm)	Change in thickness (mm)	Air voids content before cooling (%)	Air voids content after cooling (%)	Difference in air voids content (%)
CR13	600	117.53	118.63	+1.11	5.2	6.1	+0.9
CR24	600	116.31	116.82	+0.51	5.4	5.9	+0.5
CR35	600	115.42	115.37	-0.05	5.5	5.4	-0.1
CR46	600	114.63	115.62	+0.99	5.4	6.2	+0.8
CR57	825	114.51	114.59	+0.08	4.8	4.9	+0.1

Specimen number	Compaction pressure (kPa)	Specimen thickness (mm)	Specimen thickness – after cooling (mm)	Change in thickness (mm)	Air voids content before cooling (%)	Air voids content after cooling (%)	Difference in air voids content (%)
CR68	825	115.11	114.96	-0.15	4.5	4.3	-0.2
CR79	825	115.44	116.11	+0.67	4.5	5.1	+0.6
CR810	825	115.25	116.91	+1.66	4.6	6.0	+1.4

Note: Back-calculated from specimen thickness measurements.

The difference in air voids contents before and after cooling ranged between -0.1% and 0.9% for the specimens compacted at 600 kPa pressure and between -0.2% and 1.4% for the specimens compacted at 825 kPa, with an average difference of 0.5% for both compaction pressures. Given that the typical tolerance allowed for air voids during production is 1.5%, the change in air voids as a result of mix relaxation can potentially be an issue and should be further investigated.

5.3 Flexural Modulus

NACOE previously developed a mix-specific procedure to characterise the flexural (dynamic) modulus and fatigue resistance of asphalt for pavement design purposes. This procedure, as documented in Technical Note 167 *A New Approach to Asphalt Pavement Design* (TMR 2017), was used to characterise the flexural modulus of four beam specimens using Austroads test method AGPT/T274 *Characterisation of Flexural Stiffness and Fatigue Performance of Bituminous Mixes*. The beams were manufactured from asphalt samples prepared in the laboratory using raw materials provided by the asphalt supplier.

The flexural moduli of the CRM GGA mixes used for the two demonstration projects were determined over a range of temperatures and load frequencies. The individual test results are summarised in Appendix C. These modulus results were then used to develop flexural modulus master curves in accordance with the procedure recommended in Technical Note 167 (TMR 2017). It should be noted that the technical note recommends that the temperature range for modulus testing should extend to 40 °C, however testing at 40 °C was abandoned due to the highly elastic nature of the CRM binder at high temperatures resulting in erroneous results.

Flexural modulus master curves can be used to determine an asphalt's modulus at any selected temperature and load frequency for pavement design purposes. The master curve of the CRM GGA mixes used in the Queensland and Western Australian demonstration projects are shown in Figure 5.1 and Figure 5.2, respectively. The model parameters used to develop the master curves were omitted from this report for proprietary reasons.

Figure 5.1: Flexural modulus test results and master curve – Queensland mix

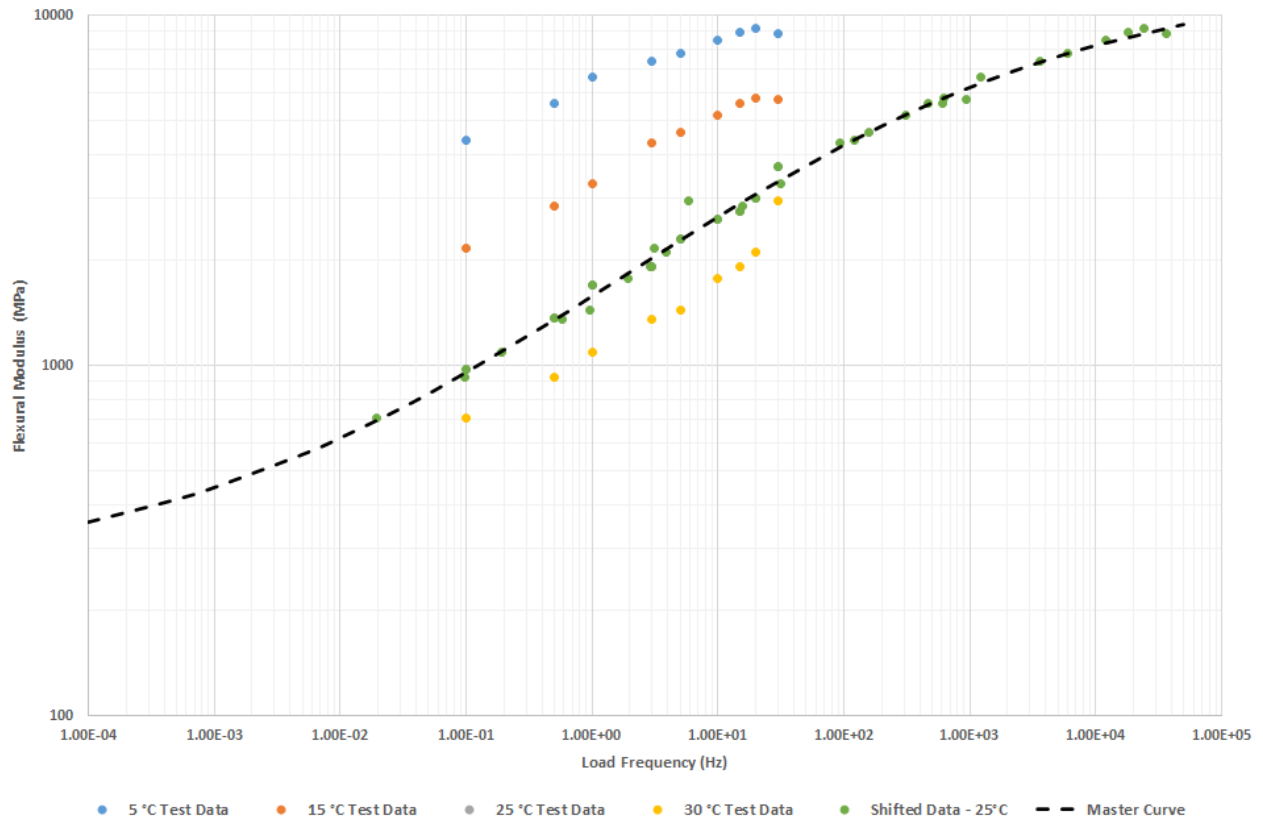
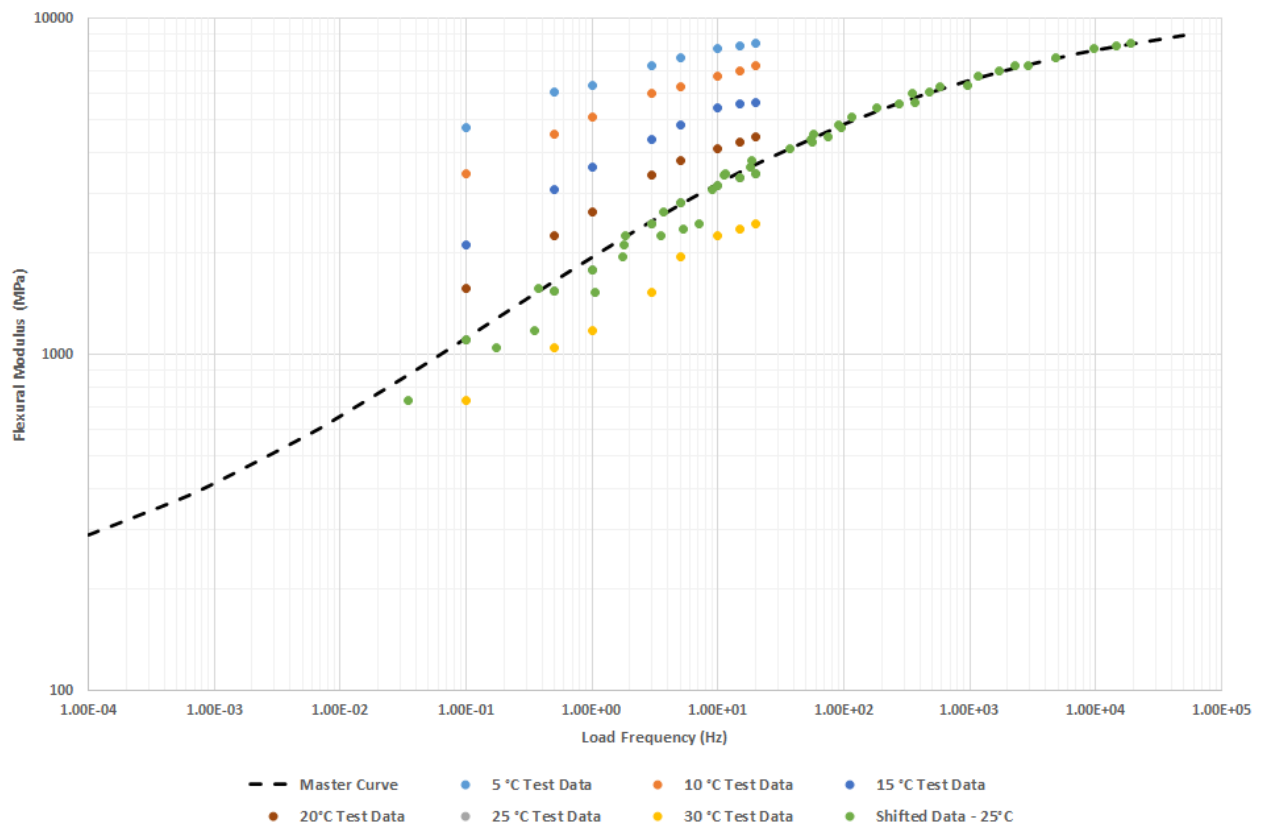


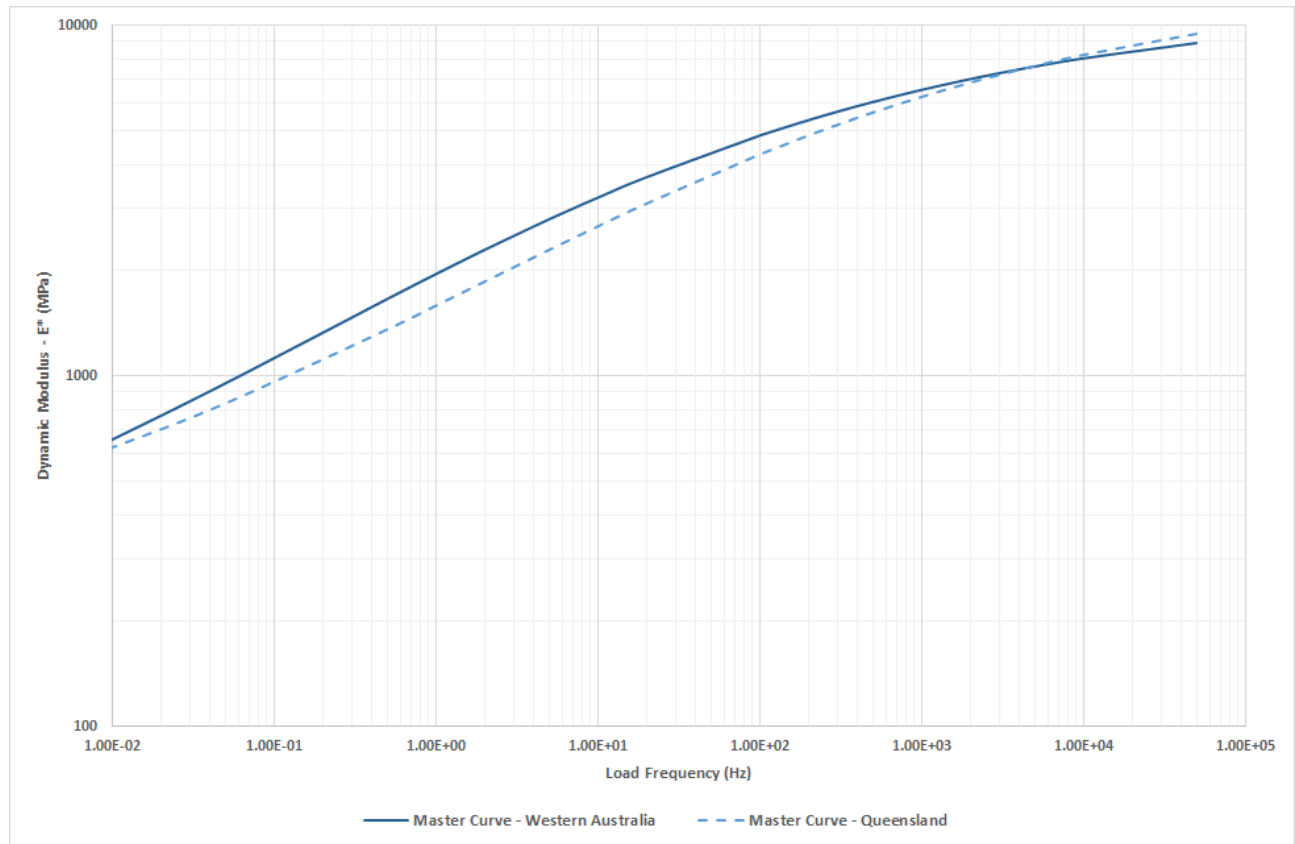
Figure 5.2: Flexural modulus test results and master curve – Western Australian mix



A comparison between the two master curves at 25 °C is shown in Figure 5.3. The modulus of the Western

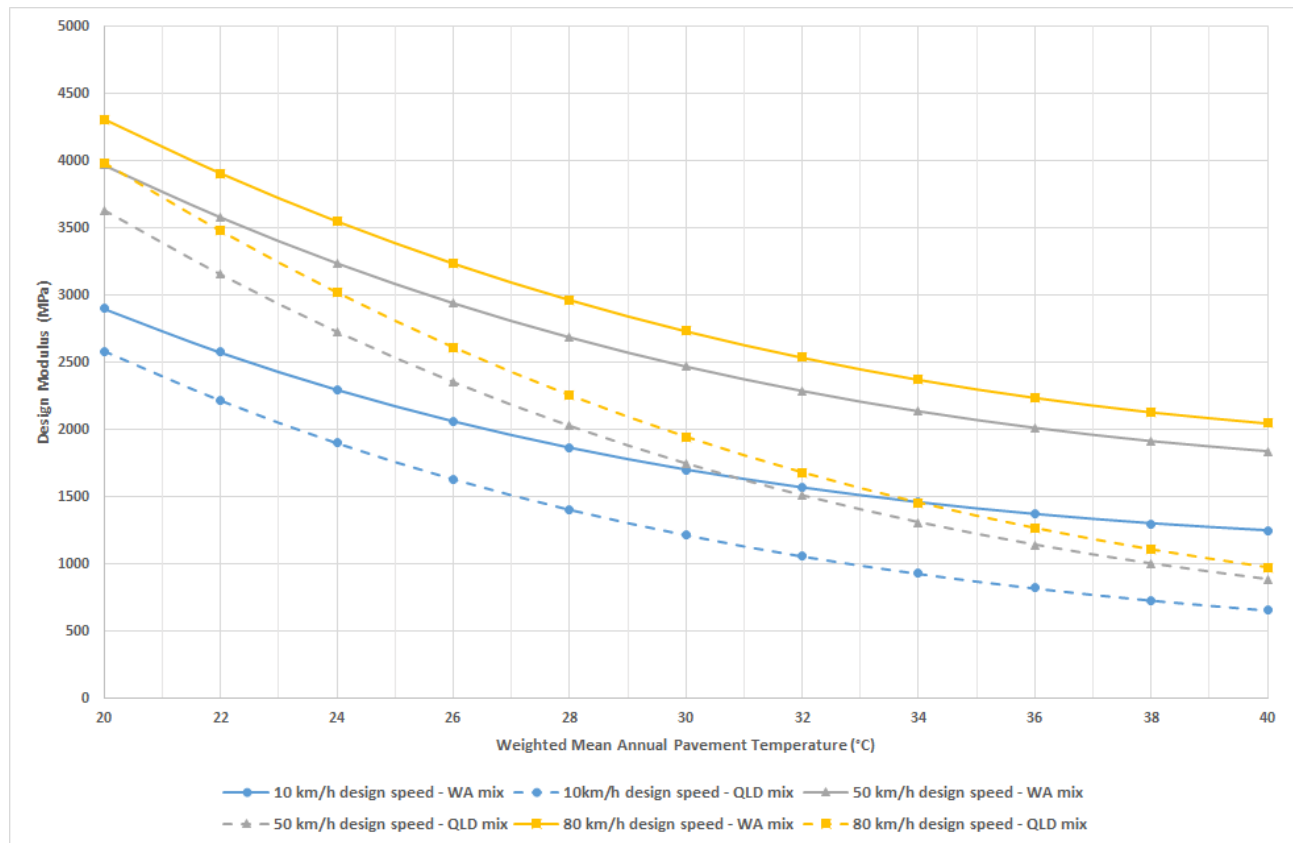
Australian mix is higher than the modulus of the mix used in Queensland over a reduced frequency range of between 0.02 Hz and 16 Hz (the typical operating range for pavements in these states).

Figure 5.3: Comparison between flexural modulus master curves



The pavement design modulus at various heavy vehicle speeds and weighted mean annual pavement temperatures (WMAPT) for the two CRM GGA mixes are also shown in Figure 5.4. Again, the design modulus (at 5% air voids) of the Western Australian mix is higher than the modulus of the Queensland mix for the typical operating pavement temperatures and heavy vehicle speeds in these states.

Figure 5.4: CRM GGA design modulus at 5% air voids



5.4 Fatigue Resistance

The fatigue resistance of the CRM GGA mixes used in the Queensland and Western Australian demonstration projects were determined in accordance with Technical Note 167 (TMR 2017). This included testing a minimum of 27 beam specimens per mix, comprising of nine specimens at each test temperature (i.e. 10 °C, 20 °C and 30 °C). The testing was equally divided over three different strain levels (low, medium, and high) per test temperature.

The fatigue results of the mixes tested at different temperatures are summarised in Appendix C and shown in Figure 5.5, Figure 5.6 and Figure 5.7.

Figure 5.5 Fatigue results at 10 °C

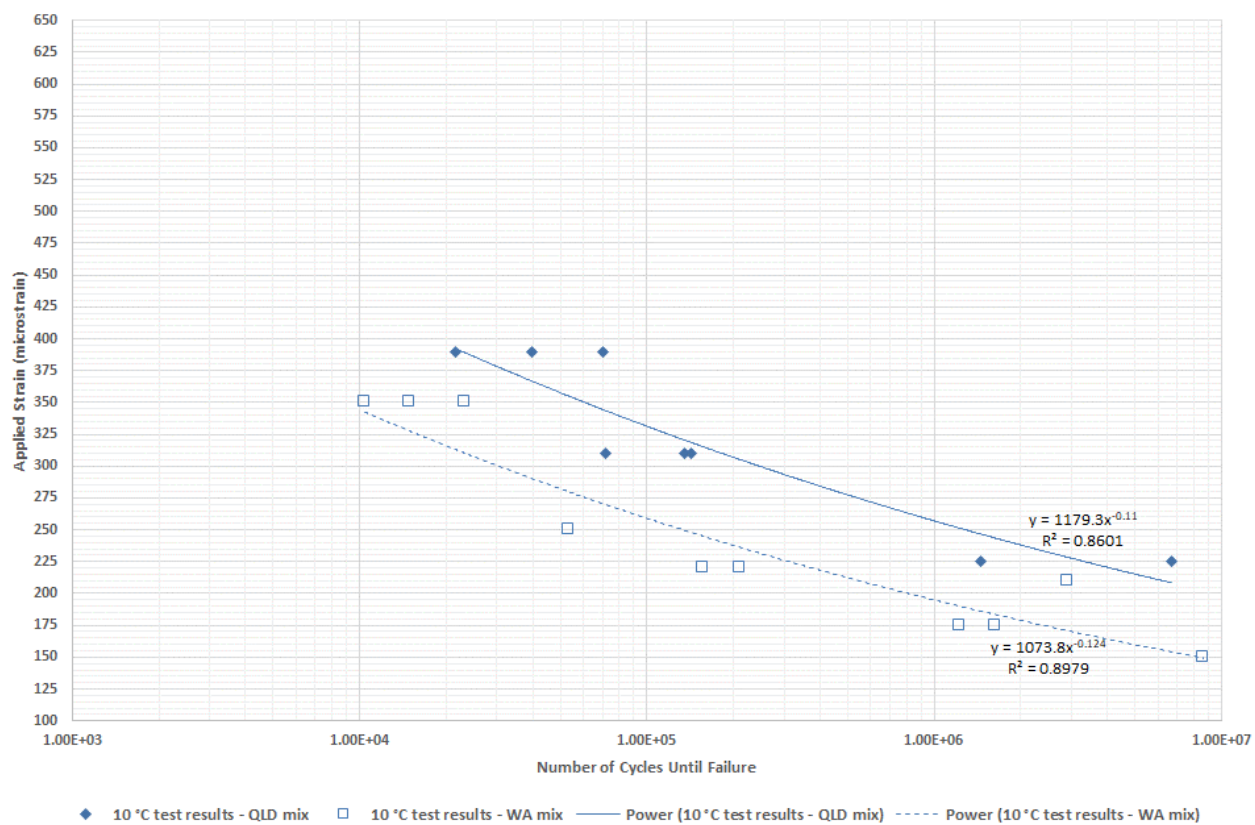


Figure 5.6 Fatigue results at 20 °C

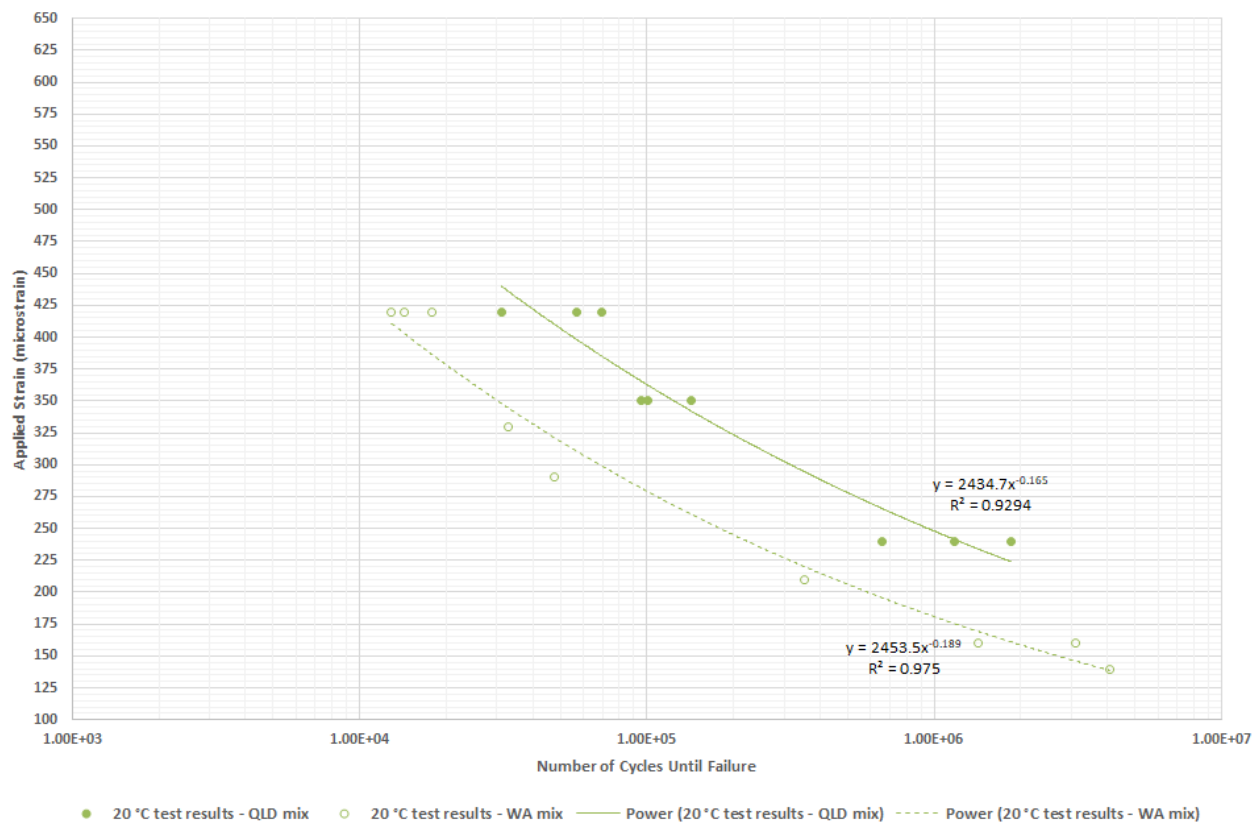
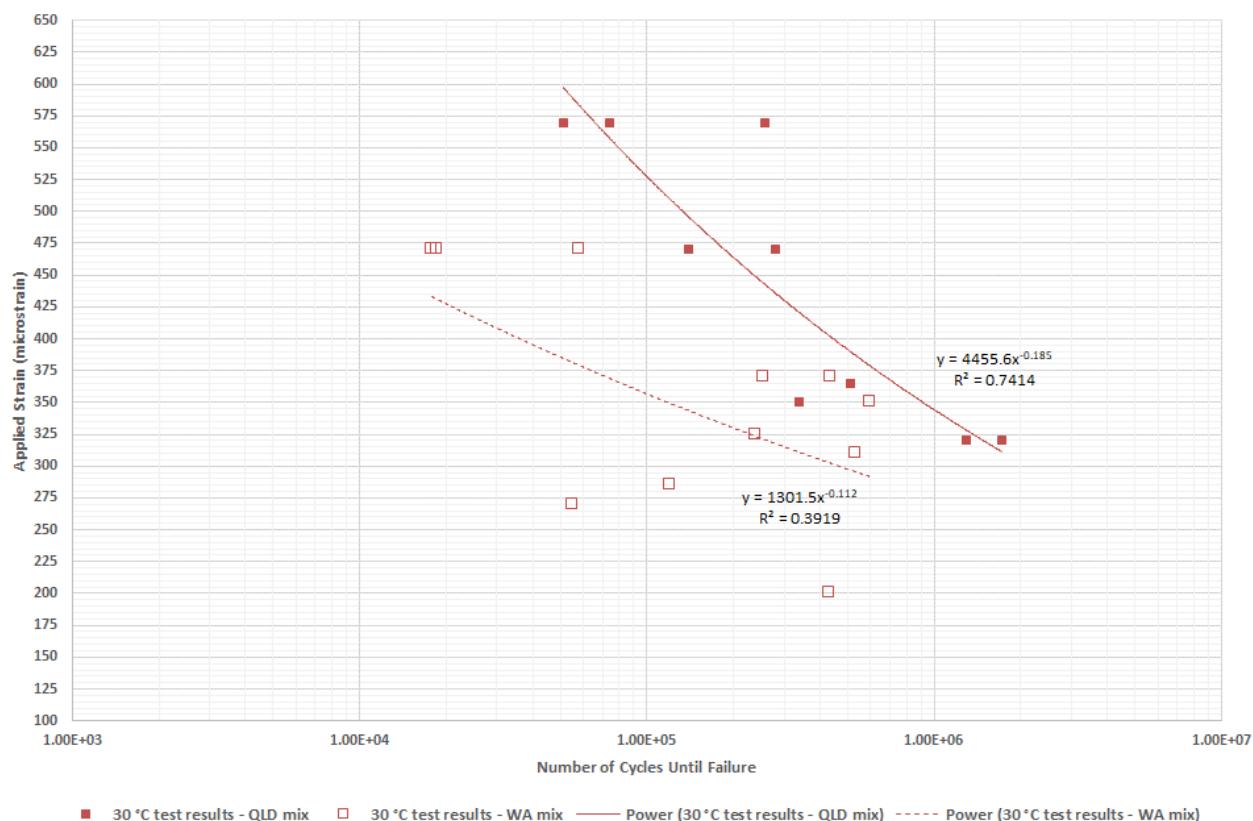


Figure 5.7 Fatigue results at 30 °C



A strong correlation was observed between the applied strain and number of cycles until failure (where failure was defined as the number of load cycles required to reach 50% of the specimen's initial stiffness), except for the Western Australian mix when tested at 30 °C. The reason for the poor correlation observed between the applied strain and fatigue resistance for the WA mix at 30 °C is unclear at the time of writing this report.

The strain level required to achieve 1 million load cycles is often used to assess the fatigue resistance of an asphalt mix in the laboratory. The estimated strain levels at 1 million cycles for each of the test temperatures are summarised in Table 5.6.

Table 5.6: Strain at 1 million cycles

Temperature (°C)	Tolerable strain at 1 million cycles (µε)	
	Queensland mix	Western Australian mix
10	258	194
20	249	180
30	346	277

The Queensland mix had a higher laboratory fatigue resistance at all three test temperatures compared to the WA mix. It is generally expected that the laboratory fatigue performance of asphalt mixes increases with an increase in test temperatures. Interestingly, the testing undertaken as part of this study showed a minor decrease in fatigue resistance of both mixes when the test temperature was increased from 10 °C to 20 °C. The reason for this anomaly was not further investigated. However, the fatigue resistance of both mixes increased significantly with an increase in test temperature from 20 °C to 30 °C which is consistent with expectations.

The difference in fatigue results of the two mixes tested suggest that there could be a significant difference in the fatigue performance of CRM GGA mixes manufactured to the same specification but using different materials.

Mix-specific fatigue relationships were also developed in accordance with Technical Note 167 (TMR 2017), which allows the fatigue resistance of a particular asphalt mix to be determined at any combination of pavement temperature and loading speed. The relationships for a loading speed of 63 km/h (consistent with the frequency used for the fatigue testing) and WMAPT typical for Brisbane (32 °C) and Perth (27 °C) are shown in Figure 5.8: and Figure 5.9. The model parameters used to develop the fatigue relationships were omitted from this for proprietary reasons.

In addition, the fatigue results of an asphalt surfacing mix (i.e. 14 mm dense graded asphalt with a conventional C320 bitumen) previously tested as part of an earlier NACOE study are also shown in the figures below.

It can be seen from the comparative fatigue results that the CRM GGA manufactured in Queensland and Western Australia had a higher fatigue resistance at both WMAPTs assessed compared to the DGA with a conventional bitumen.

Figure 5.8: CRM GGA fatigue model (27 °C WMAPT)

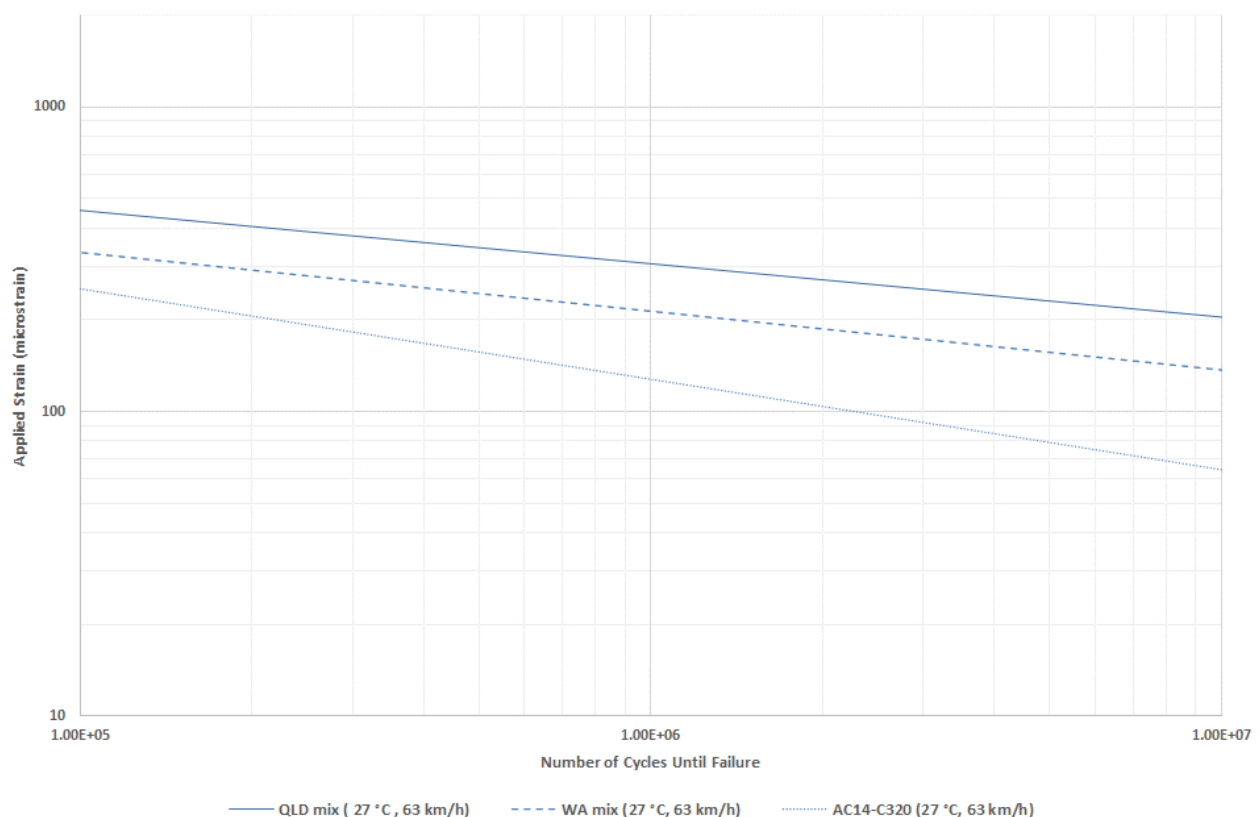
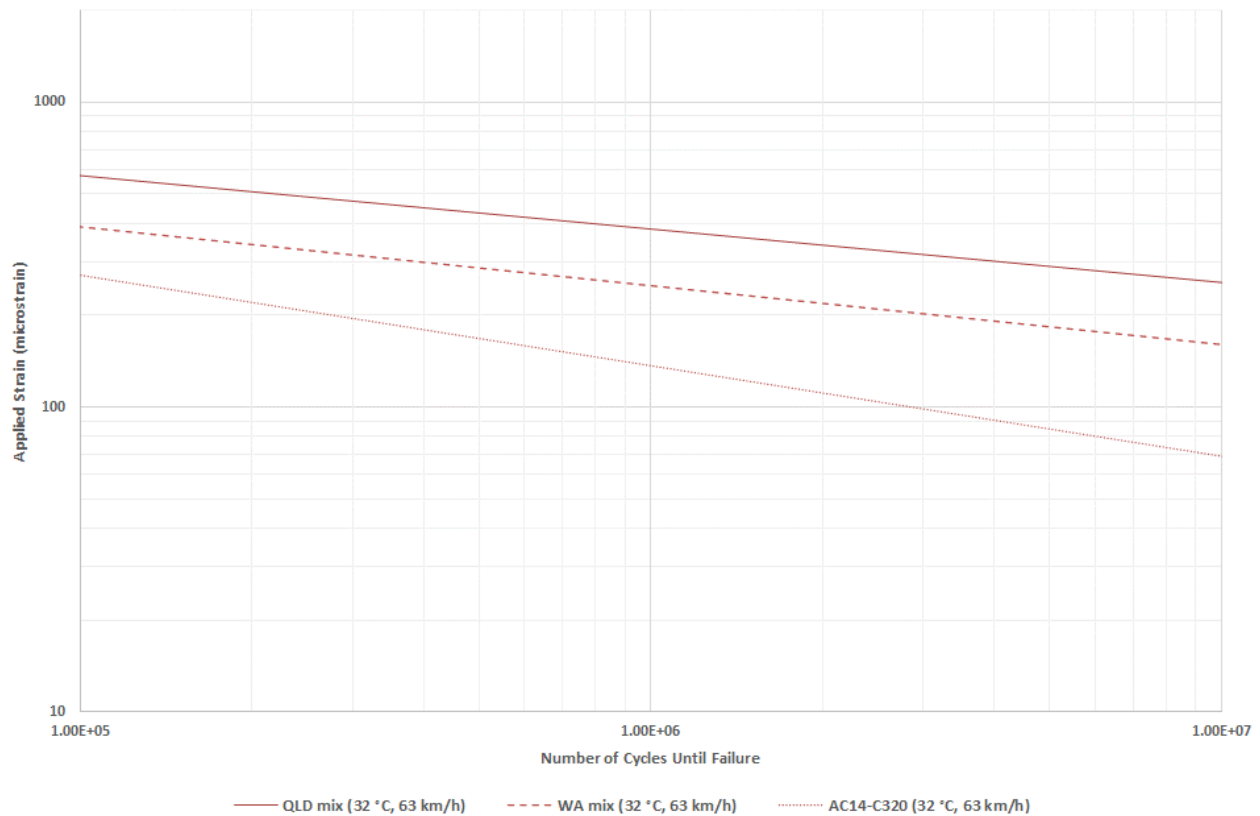


Figure 5.9: CRM GGA fatigue model (32 °C WMAPT)



5.5 Resilient Modulus

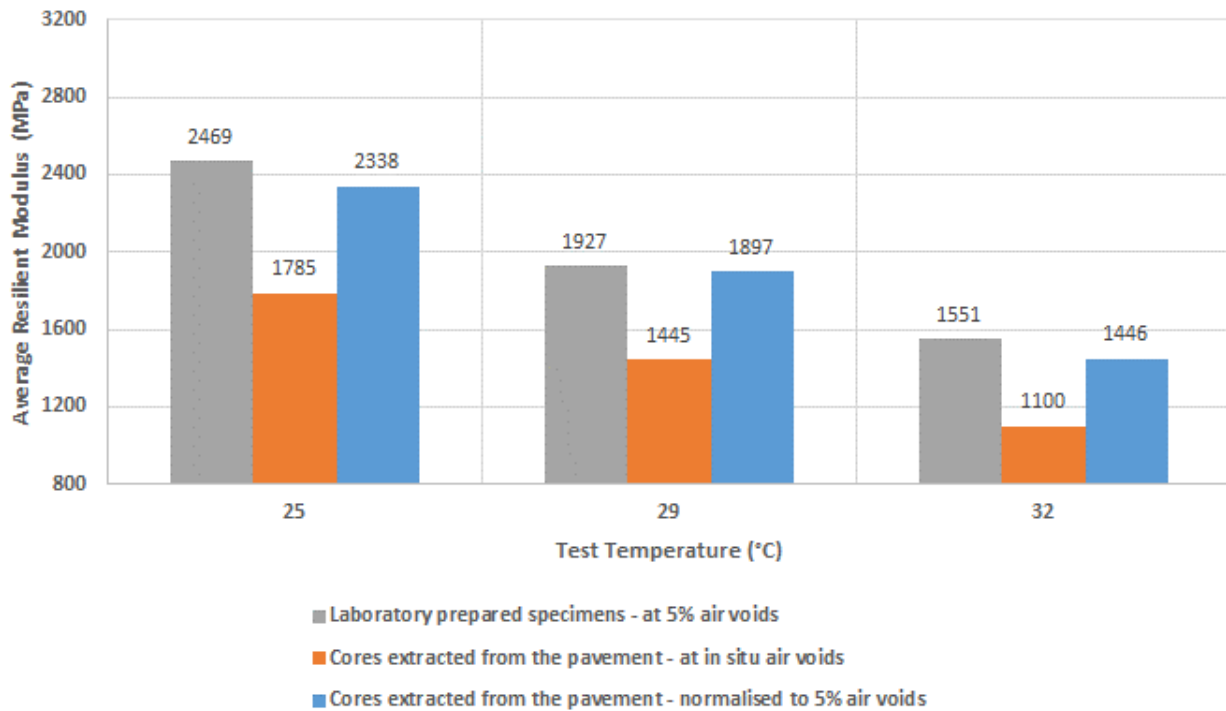
In addition to the flexural modulus testing undertaken, the indirect tensile resilient modulus of the CRMA GGA manufactured for the Queensland demonstration project was also determined as part of this study in accordance with AS/NZS 2891.13.1 *Methods of Sampling and Testing Asphalt, Method 13.1: Determination of the Resilient Modulus of Asphalt – Indirect Tensile Method*. The indirect tensile resilient modulus test is currently widely used throughout Australia. Modulus testing was carried out at temperatures of 25 °C, 29 °C and 32 °C and 40 ms rise time on specimens prepared in the laboratory and cores extracted from the finished asphalt layer. The modulus results are summarised in Table 5.7 and shown in Figure 5.10.

Table 5.7: Resilient modulus results

Test temperature(°C)	Resilient modulus (MPa)		
	Laboratory prepared specimens (at 5% air voids)	Cores extracted from the pavement (in situ air voids)	Cores extracted from the pavement (normalised to 5% air voids)
25	1,994	1,749	2,136
	2,955	1,460	2,031
	2,237	1,834	2,348
	2,633	1,707	2,553
	2,528	1,577	2,213
		1,862	2,568
		1,790	2,170
		2,299	2,685
Minimum:	1,994	1,460	2,031

Test temperature(°C)	Resilient modulus (MPa)		
	Laboratory prepared specimens (at 5% air voids)	Cores extracted from the pavement (in situ air voids)	Cores extracted from the pavement (normalised to 5% air voids)
Maximum:	2,955	2,299	2,685
Average:	2,469	1,785	2,338
Standard deviation:	369	248	239
29	1,446	1,458	1,781
	2,242	1,251	1,741
	1,990	1,457	1,865
	1,904	1,368	2,046
	2,051	1,346	1,889
		1,539	2,123
		1,490	1,806
		1,647	1,924
Minimum:	1,446	1,251	1,741
Maximum:	2,242	1,649	2,123
Average:	1,927	1,445	1,897
Standard deviation:	296	123	132
32	1,250	901	1,100
	1,724	900	1,252
	1,602	1,025	1,312
	1,584	1,093	1,634
	1,594	1,094	1,535
		1,231	1,698
		1,105	1,341
		1,448	1,691
Minimum:	1,250	900	1,100
Maximum:	1,724	1,448	1,698
Average:	1,551	1,100	1,446
Standard deviation:	177	179	225

Figure 5.10: Resilient modulus results



The results shown in Figure 5.10 indicate that the resilient modulus of the cores extracted from the pavement correlate reasonably well with the modulus of the laboratory prepared specimens when the air voids content is normalised to 5%.

However, the cores extracted from the pavement had air voids contents ranging between 7.3–10.3%, with an average value of 8.8%. The resilient modulus of the cores at these higher air voids contents was significantly lower than the modulus at 5% air voids. This is consistent with current literature, in so far that higher air voids contents reduce the modulus of compacted asphalt mixes (Austroads 2017). It is therefore essential that the air voids content adopted to determine the pavement design modulus are representative of the air voids expected in-service.

The air voids contents achieved in the field during the two demonstration projects (based on the density testing undertaken by the contractors) ranged between 3.4% and 9.1%, with an average value of 6.6%. It is therefore recommended that initially the design modulus for CRM GGA be based on an in-service air voids content of 7%. This recommendation can be reconsidered once more project compaction data from future construction projects becomes available.

6. Conclusions and Recommendations

The sustainable and environmentally friendly management of end-of-life tyres continues to present a challenge, both locally and internationally. There are several markets that can make use of these recoverable materials, and one such market is in bituminous pavement surfacings.

More specifically, crumb rubber (obtained from end-of-life vehicle tyres) can be used in bituminous sprayed seals and several different asphalt mix types, including in GGA. International experience has shown that CRM GGA can provide improved resistance to crack reflection and fatigue cracking compared to DGA with conventional binders. These mix types are therefore often used by many road jurisdictions internationally (and to a limited extent in Australia) when rehabilitating and/or overlaying existing cracked pavements. Furthermore, the sustainability benefits of using crumb rubber obtained from recycled tyres are well documented.

This project was primarily aimed at developing a technical specification for CRM GGA to facilitate its use in both Queensland and Western Australia.

6.1 Conclusions

The literature review undertaken as part of the study found that CRM GGA has been successfully used internationally over the past 30 years. The main benefits of using CRM GGA include improvements in the asphalt's resistance to reflective and fatigue cracking, deformation resistance and durability.

There are several methods currently available (and in use) to modify GGA with crumb rubber, including adding the rubber as an aggregate substitute (dry method) or blending the rubber with a base binder (wet method). Both these methods have their respective advantages and disadvantages; however, the wet method is predominantly used internationally due to its ability to produce a controlled product that provides more consistent performance improvements.

Internationally, CRM GGAs are commonly used in Arizona, California, Texas, and South Africa. A review of the technical specifications adopted by these jurisdictions found that even though the binder and asphalt properties being specified are reasonably similar, the actual criteria specified vary between the jurisdictions.

A key objective of this project was to transfer the CRM GGA technology used in the USA (and more specifically in Arizona and California) to Australia. These two states have a proven history of successfully using CRM GGA (manufactured with high-viscosity wet blended binders) over cracked and jointed concrete pavements to reduce the risk of reflective cracking occurring. A national specification, in collaboration with AAPA, Main Roads WA and TMR was therefore developed based on the requirements in the ADoT and Caltrans specifications.

Importantly, the CRM binder properties recommended for inclusion in the pilot specification developed as part of this project were primarily based on ADoT requirements for a Type 2 binder. The main reason for adopting the ADoT requirements is that binders in Arizona are manufactured at lower target temperatures compared to in California (i.e. 175 °C vs 190 °C), which has potential environmental and health benefits, as well as being more consistent with current binder handling temperatures in Australia.

In Australia, there is an increased focus on including performance-related specification requirements for asphalt mixes. Caltrans has extensive experience in the use of CRM GGA and their specification includes several performance criteria, including permanent deformation, moisture damage and TSR. It was therefore agreed to adopt the Caltrans CRM GGA mix design requirements in the national specification developed as part of this project.

Two demonstration projects were undertaken (one in Queensland and one in Western Australia) to assess whether CRM GGA mixes can be manufactured and placed locally in accordance with the specification

developed as part of this project. Both these projects were delivered successfully and the in-service performance of the asphalt will be monitored over time.

The emissions monitoring undertaken during both the demonstration projects did not identify any concerns regarding exposure of workers to harmful emissions during the asphalt placement and compaction processes.

The laboratory testing undertaken on the CRM GGA placed in Queensland and Western Australia showed that the flexural fatigue resistance of these two mixes were superior to the performance of a DGA with C320 bitumen.

6.2 Recommendations

The following recommendations are made for consideration (based on the findings of the literature review, the laboratory testing undertaken as part of this study, and the outcomes from the demonstration projects):

- The national specification should be updated based on the learnings from the demonstration projects, including a procedure to assess the equivalent binder viscosity required when warm mix additives are added during the manufacturing process.
- It is recommended that further implementation projects be undertaken to allow industry to gain experience in the manufacture and placement of CRM GGA.
- The ongoing performance of future implementation projects should be monitored to assess the in-service performance of these mix types. The learnings from these projects can be used to improve future specification updates.
- Given the potential differences in local materials, it is recommended that a future study benchmark the laboratory performance of locally manufactured CRM binders and GGA against the performance achieved internationally (more specifically in the USA).
- It is recommended that national harmonised specification criteria (based on local test methods) be developed for CRM binders used in asphalt.
- There is an opportunity to develop national best practice guidelines for the use of CRMA, including site evaluation, product selection, design, construction requirements, etc.

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Austroads Test Methods

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AGPT/T131-2006 *Softening point of polymer modified binders.*

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Q308A-2018 *Binder content and aggregate grading of asphalt – reflux method.*

Q311-2018 *Voids properties for compacted asphalt.*

Q325-2018 *Stability of asphalt – Hamburg wheel tracking device (HWTD).*

Standards Australia and New Zealand

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AS/NZS 2891.3.1:2013 *Methods of sampling and testing asphalt, binder content and aggregate grading – reflux method.*

AS/NZS 2891.5:2015 *Methods of sampling and testing asphalt, compaction of asphalt by Marshall method and determination of stability and flow – Marshall procedure.*

AS/NZS 2891.8:2014 *Methods of sampling and testing asphalt – voids and volumetric properties of compacted asphalt mixes.*

AS/NZS 2891.9.2:2014 *Methods of sampling and testing asphalt – determination of bulk density of compacted asphalt – presaturation method.*

AS/NZS 2891.13.1:2013 *Methods of sampling and testing asphalt, method 13.1: determination of the resilient modulus of asphalt – indirect tensile method.*

Appendix A Crumb Rubber Modified Open Graded and Gap-graded Asphalt Pilot Specification

Australian Asphalt Pavement Association

Crumb Rubber Modified Open Graded and Gap Graded Asphalt Pilot Specification

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Preface

This pilot specification is intended as a guide for asset owners in the creation of technical specifications for the supply of crumb rubber modified (CRM) open graded asphalt (OGA) and gap graded asphalt (GGA) mixes. The mixes contain a bituminous binder with partially digested crumb rubber (i.e. high-viscosity CRM binder).

The crumb rubber modified binder technology in this specification is based on the technology used in California and Arizona.

The CRM OGA mix design process in this specification has been validated through demonstration trials in Australia.

The CRM GGA mix design process described in this specification is yet to be validated in Australia.

The aim of this pilot specification is to facilitate the construction of demonstration trials of CRM GGA, as well as to promote the wider use of CRM OGA in Australia.

The content of this specification builds on information in the following documents

- *Transport and Main Roads Specification PSTS112 Crumb Rubber Modified Open Graded Asphalt Surfacing*, Queensland Government, 2016 (not published).
- *National Asphalt Specification*, 2nd edition, Australian Asphalt Pavement Association, Melbourne, VIC, 2004.
- State of California Department of Transport (Caltrans) Standard Specifications – Division V – Section 39, Caltrans, 2015.
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Disclaimer

Although the information in this specification guide is believed to be correct at the time of printing, the Australian Asphalt Pavement Association, and agents of that organisation together with individuals involved in the preparation of this specification guide do not accept any contractual, tortious or other form of liability for its contents or any consequences arising from its use. People using the information contained in this guide should apply, and rely upon, their own skills and judgement to the particular issue they are considering.

Suggestions for improvements are welcomed, please forward suggestions to the AAPA head office. Contact details available at aapa.asn.au.

1. General

1.1. Scope

This pilot specification sets out the requirements for crumb rubber modified (CRM) open graded asphalt (OGA) surface layers with a nominal maximum aggregate size of 10 mm and 14 mm. The specification also includes requirements for CRM gap graded asphalt (GGA) mixes with a nominal maximum aggregate size of 14 mm and 20 mm. The specification covers:

- Constituent materials
- OGA and GGA mix design requirements
- Process control in manufacture and placement of asphalt
- Acceptance criteria for the finished CRM asphalt pavement
- Quality systems, minimum process standards, plant requirements and sampling and testing frequencies.

1.2. Quality system requirements

The Contractor shall establish, implement and maintain a Quality System in accordance with this Specification and the requirements of AS/NZS ISO 9001, or an equivalent system approved by the Principal. The Quality System shall include the appropriate Occupational Health and Safety procedures and Safe Working Method Statements.

Where required in the Contract general clauses, the Contractor shall submit a Quality Plan prior to commencement of any works. The Quality Plan shall take into account the specific requirements for inspection and testing, acceptance/rejection criteria, details of proposed methods and other quality requirements that are contained in the Contract Documents. No part of the Quality System shall be used to pre-empt or otherwise negate the technical requirements of the Contract Documents.

1.3. Testing requirements

All testing of properties required by this Specification shall be undertaken in a laboratory accredited by the National Association of Testing Authorities (NATA) or International Accreditation New Zealand (IANZ) for the appropriate tests and performed in accordance with procedures contained in the relevant Australian Standard or Austroads Manual of Test Procedures. Where there is no applicable Australian Standard or Austroads Test Method, or where the Standard/Manual provides a choice of procedures, the method to be adopted shall be agreed between the Principal and the Contractor.

1.4. Defect liability period

During the first 12 months, the product must not rut, shove, strip, ravel or bleed.

2. Constituent materials

2.1. Aggregate & mineral filler

2.1.1. General

All aggregates shall be obtained from established quarries and have established properties. Each individual aggregate fraction shall be obtained from the same quarry as the materials used in the design of the Job Mix.

An appropriate system of stockpile management shall be implemented at the quarry and asphalt plant to ensure contamination does not occur.

All mineral filler shall come from established sources and have established properties.

2.1.2. Coarse aggregate

Coarse aggregate is comprised of crushed rock particles that are substantially retained on the 4.75 mm sieve. Coarse aggregate shall comply with Australian Standard AS 2758.5 with the application of those test properties specified in Table 2-1 as appropriate.

Table 2-1: Coarse aggregate requirements

Property	Test Method	Requirement
Particle size distribution (PSD)	AS 1141.11.1	Report
Crushed particles ⁽¹⁾	AS 1141.18	100% crushed aggregate
Polished aggregate friction value (PAFV)	AS 1141.40, or AS 1141.41	≥ 48 ⁽²⁾
Particle density (Dry basis)	AS 1141.6.1, or AS 1141.6.2	report
Water absorption	AS 1141.6.1, or AS 1141.6.2	≤ 2.5 %
Los Angeles abrasion loss ⁽³⁾	AS 1141.23	≤ 25 %
Ten percent fines value (wet) ⁽³⁾	AS 1141.22	≥ 150 kN
Wet/dry strength variation ⁽³⁾	AS 1141.22	≤ 35 %
Flakiness index	AS 1141.15	≤ 25%

Notes:

1. Test only required on river gravels and metasediments
2. In some regions aggregates that comply with the PAFV requirements in Table 2-1 may not be available. Where this is the case, a lower PAFV requirement may be proposed for acceptance by the Principal.
3. Aggregate to be tested for either Los Angeles abrasion loss, or wet strength and wet/dry strength variation

2.1.3. Fine aggregate

Fine aggregate shall consist of crushed rock particles substantially passing the 4.75 mm sieve and manufactured from an approved source complying with the requirements of Section 2.1.2.

The fine aggregate shall be clean, hard, durable and free from lumps of clay and other aggregations of fine materials, organic material and any other deleterious material. Fine aggregate shall comply with the criteria in Table 2-2.

Table 2-2: Fine aggregate requirements

Property	Test Method	Requirement
Particle size distribution (PSD)	AS 1141.11.1	Report
Particle density (Dry basis)	AS 1141.5	Report
Water absorption	AS 1141.5	≤ 2.5 %
Degradation Factor, Crusher fines ⁽¹⁾	AS 1141.25.3	≥ 60
Sodium Sulfate Soundness (weighted loss) ⁽¹⁾	AS 1141.24	≤ 12%

Notes:

1. Aggregate to be tested for either degradation factor, or Sodium Sulfate Soundness

2.1.4. Mineral filler

Mineral filler is that portion of mineral matter passing a 0.075 mm sieve, and includes rock dust derived from coarse and fine aggregates used in the production of asphalt in accordance with this specification, and any other materials added to supplement the quantity and properties of filler in the mix.

OGA shall contain hydrated lime, or adhesion agent. Where hydrated lime is used a minimum of 1.0% shall apply.

The combined filler shall comply with the requirements in Table 2-3

Table 2-3: Combined filler requirements

Property	Test Method	Requirement
Voids in dry compacted filler	AS/NZS 1141.17	≥ 28 % and ≤ 45 %
Apparent density of filler	AS/NZS 1141.7	Report
Methylene blue test ¹	AS 1141.66	≤ 18 ² ≤ 10 ³

Notes:

This requirement shall only apply for aggregate from New South Wales or Queensland.

This requirement shall apply on the combined filler in asphalt (excluding hydrated lime)

3. Where methylene blue value of the combined filler (excluding hydrated lime) exceeds 10 mg/g, the methylene blue value of combined filler (including hydrated lime) shall not exceed this value.

Added filler (material not derived from the aggregate components) shall comply with the relevant standards listed in Table 2-4. Rock dust that is not derived from the other aggregate components in the mixture may also be used as added filler provided that it is derived from materials that meet the requirements of Clause 2.1.2

Table 2-4: Standards for materials used as filler

Material	Standard ¹
Hydrated lime	AS 1672.1
Fly Ash	AS/NZS 3582.1
Cement Kiln Dust	See note 2
Slag	AS/NZS 3582.2
Ground Limestone	See note 3

Notes:

1. Provision of test certificates for compliance with the relevant Australian Standard and this specification shall be limited to those tests listed in Table 2-4.

2. Cement kiln dust shall be solid material extracted from the flue gases in the manufacture of Portland cement, having a maximum water-soluble fraction of 20% by mass and complying with the grading limits specified in Table 2-5

3. Ground limestone shall consist of rock dust derived from the grinding of limestone.

The particle distribution of all added filler fractions shall comply with the grading limits specified in Table 2-5.

Table 2-5: Grading limits for added filler

Test method	Sieve size (mm)	Percentage passing sieve size (by mass)
AS 1141.11.1	0.600	100
	0.300	95–100
	0.075	75–100

Each type of added filler from each source shall be mineral material, dry and free from lumps, organic material or other deleterious matter, and conform to AS 2150. The added filler shall comply with the requirements in Table 2-6.

Table 2-6 Requirements for added filler

Property	Test Method	Requirement
Moisture content	AS 4489.6.1	≤ 3 %
Apparent density	AS/NZS 1141.7	Report

2.1.5. Tyre derived Crumb Rubber

The rubber crumb must be produced from end-of-life tyres. The use of uncured or devulcanized rubber is not permitted. The crumb rubber must be dry, free-flowing particles that do not stick together. The crumb rubber must not cause foaming when combined with the bituminous binder. The crumb rubber shall be an essentially uniform material and meet the requirements of Table 2-7.

Table 2-7 Requirements for rubber crumb

Property	Test Method	Requirement
Grading	AGPT/T143	
passing 2.36 mm		100
passing 1.18 mm		#
passing 600 µm		#
passing 300 µm		#
passing 150 µm		#
passing 75 µm		#
Particle length (mm) max.	AGPT/T143	3
Bulk density (kg/m³)	AGPT/T144	Report
Water content (%) max.	AGPT/T143	1
Foreign materials – other than iron (%) max.	AGPT/T143	0.1
Foreign materials – metallic iron (%) max.	AGPT/T143	0.1

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

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

2.2. Extender oils

Extender oils, if used, shall be added to the bitumen prior to the addition of the crumb rubber. Extender oils shall be a resinous, high flash point, aromatic hydrocarbon.

2.3. Binder

2.3.1. Binder design

The base binder shall be a bitumen complying with the requirements in AS 2008. The class of source of bitumen to be used for the binder shall be nominated by the Contractor. The crumb rubber modified binder shall contain between 18% and 22% of crumb rubber by mass of total binder.

The contract shall submit a binder design profile with the asphalt mix design based on the testing requirements in Table 2-8.

Table 2-8 CRM binder design profile to be submitted with mix design

Property	Test method	Reaction time (from incorporation of rubber into the binder)				
		60 mins	120 mins	240 mins	360 mins	TBN ²
Penetration @ 4°C, 200 g, 60 sec, 0.10 mm, minimum	AS 2341.12	15	-	15	-	15
Penetration @ 25°C, 100 g, 5 sec, 0.10 mm, minimum	AS 2341.12	TBR ¹		TBR ¹		TBR ¹
Resilience @ 25°C, percent rebound, minimum	ASTM D5329	20	-	20	-	20
Torsional recovery at 25°C 30 s, %	AG:PT/T122	TBR ¹	-	TBR ¹	-	TBR ¹
Softening point, °C, minimum	AG:PT/T131	55	-	55	-	55
Viscosity at 175°C, Pa.s	AG:PT/T111	1.5–4.0	1.5–4.0	1.5–4.0	1.5–4.0	1.5–4.0

Notes:

1. TBR denotes to be reported.

2. TBN denotes to be nominated by the Contractor. Where the contractor desires to store the crumb rubber modified binder in excess of 10 hours (after the initial 60 minutes reaction period) but not more than 4 days (96 hours after the 60 minute reaction period) prior to usage, testing should be completed to confirm compliance with the specification requirements.

2.3.2. Binder production testing

The binder for crumb rubber modified open graded and gap graded asphalt shall comply with the requirements in Table 2-9 after a minimum reaction time of 60 minutes. This testing shall apply to the first batch of binder supplied for each project. Subsequent batches be tested for compliance with softening point, resilience and viscosity at 175°C only.

Table 2-9 Requirements for crumb rubber modified binder after min. 60 mins reaction time

Property	Test method	Requirement
Penetration @ 4°C, 200 g, 60 sec, 0.10 mm, minimum	AS 2341.12	15
Penetration @ 25°C, 100 g, 5 sec, 0.10 mm, minimum	AS 2341.12	TBR ¹
Resilience @ 25°C, percent rebound, minimum	ASTM D5329	20
Torsional recovery at 25°C 30 s, %	AG:PT/T122	TBR ¹
Softening point, °C, minimum	AG:PT/T131	55
Viscosity at 175°C, Pa.s	AG:PT/T111, or ASTM D7741/ D7741M ^{2,3}	1.5–4.0
Flash Point, °C, minimum	AG:PT/T112	250
Loss on Heating, %, maximum	AG:PT/T103	0.6

1. TBR denotes to be reported.

2. The viscometer used shall be a Rion (formerly Haake) Model VT-04 viscometer using the No. 1 Rotor. The Rion viscometer rotor, while in the off position, shall be completely immersed in the binder at a temperature from 175 to 180°C for a minimum heat equilibrium period of 60 seconds, and the average

viscosity determined from three separate constant readings (± 0.5 Pa.s), taken within a 30 second time frame with the viscometer level during testing and turned off between readings.

3. The accuracy of the viscometer shall be verified by comparing the viscosity results obtained with the Brookfield viscometer to 3 separate calibration fluids of known viscosities ranging from 1.0 to 5.0 Pa.s. The viscometer will be considered accurate if the values obtained are within 0.3 Pa.s of the known viscosity. The known viscosity value shall be based on the fluid manufacturers standard test temperature or the test temperature versus viscosity correlation table provided by the fluid manufacturer. Viscometers used on the project shall be verified to be accurate. The accuracy verification results shall be provided to the Principal.

2.3.3. Binder testing at time of asphalt production

At the time of asphalt production, the binder shall comply with the requirements in Table 2-11. Binder compliance shall be assessed on samples taken from the feed line connecting the CRM binder tank to the asphalt plant at the time of use in asphalt production.

Table 2-10 Requirements for crumb rubber modified binder at time of asphalt production

Property	Test method	Requirement
Viscosity at 175°C, Pa.s	AG:PT/T111, or ASTM D7741/ D7741M ^{1, 2}	1.5-4.0

1. The viscometer used shall be a Rion (formerly Haake) Model VT-04 viscometer using the No. 1 Rotor. The Rion viscometer rotor, while in the off position, shall be completely immersed in the binder at a temperature from 175 to 180°C for a minimum heat equilibrium period of 60 seconds, and the average viscosity determined from three separate constant readings (± 0.5 Pa.s), taken within a 30 second time frame with the viscometer level during testing and turned off between readings.
2. The accuracy of the viscometer shall be verified by comparing the viscosity results obtained with the Brookfield viscometer to 3 separate calibration fluids of known viscosities ranging from 1.0 to 5.0 Pa.s. The viscometer will be considered accurate if the values obtained are within 0.3 Pa.s of the known viscosity. The known viscosity value shall be based on the fluid manufacturers standard test temperature or the test temperature versus viscosity correlation table provided by the fluid manufacturer. Viscometers used on the project shall be verified to be accurate. The accuracy verification results shall be provided to the Principal.

2.4. Reclaimed asphalt pavement

Reclaimed asphalt pavement (RAP) shall not be used in OGA or GGA.

2.5. Additives

2.5.1. Cellulose fibres

Cellulose fibres may be included in the OGA mix design to ensure compliance with binder drain-off in Table 3.2.

2.5.2. Adhesion agent

Adhesion agent may be added up to 1.0% by mass of bitumen to improve the moisture sensitivity properties of the GGA mix design, where required. The type and proportion of the adhesion agent shall be in accordance with a manufacturer's recommendation, purchaser's specification or as agreed between the Principal and Contractor.

2.5.3. Warm mix asphalt additive

Warm mix asphalt additive must be included in the asphalt mix design to reduce the manufacturing and placement temperature. The type and proportion of the warm mix additive

shall be in accordance with a manufacturer's recommendation, purchaser's specification or as agreed between the Principal and the Contractor.

3. Mix design

3.1. General

The Contractor shall provide a mix design that complies with the requirements of this specification. Where the proposed mix design incorporates additives listed under Clause 2.1, compliance shall be tested on the mix including these additives. Where specified, the Contractor's mix design shall be submitted for approval, or registration.

3.2. Aggregate grading

The target combined aggregate grading (including filler) determined in accordance with AS/NZS2891.3.1, AS/NZS2891.3.2, AS/NZS2891.3.3, or AGPT/T234 shall comply with the limits given in Table 3-1.

Table 3-1: GGA and OGA aggregate grading limits

Sieve Size AS (mm)	Mix designation			
	GGA14	GGA20	OGA10	OGA14
	Percentage passing sieve size (by mass)			
26.5		100		
19.0	100	95-98		100
13.2	90-98	83-87	100	85-100
9.5	83-87	65-70	85-100	45-70
6.7	#	#	35-70	25-45
4.75	28-42	28-42	20-45	10-25
2.36	14-22	14-22	10-20	7-15
1.18	#	#	6-14	6-12
0.600	#	#	5-10	5-10
0.300	#	#	4-8	4-8
0.150	#	#	3-7	3-7
0.075	0-6	0-6	2-5	2-5

Notes:

In some regions aggregates that meet the grading envelope requirements in Table 3-1 may not be available. Where this is the case, adjustments to the requirements may be proposed for acceptance by the Principal.
Target value to be nominated by the Contractor

3.3. Binder content

OGA shall contain a minimum of 6.0 percent CRM binder by mass of total mix.

GGA shall contain a minimum of 7.5 percent CRM binder by mass of total mix.

Note: the specified binder content range is applicable to commonly used natural aggregates and sands. Where the Contractor proposes to use constituents of substantially different density, the Contractor may propose a nonconforming binder content subject to the approval of the Principal. The Contractor must demonstrate that the effective volumetric binder content complies with the intent of the Specification.

3.4. Cellulose fibres

If cellulose fibres are required to meet drain-off requirements for OGA, the minimum application rate shall be 0.15 % by mass of total mix.

3.5. Mix properties

The volumetric design of OGA shall be performed with Marshall laboratory compaction equipment as described below. The asphalt mix for the design shall be prepared in accordance with AS/NZS 2891.2.1. Test specimens compacted in accordance with AS/NZS 2891.5 using 50 blows per face Marshall compaction effort and the resultant test specimens shall comply with the requirements in Table 3-3. The temperature for compaction of Marshall specimens shall be determined in accordance with Appendix B of AS 2891.5.

Table 3-2: OGA mix requirements (Marshall design method)

Property	Test Method	Requirement
Combined mineral aggregate density (t/m ³)	AS/NZS 2891.8	Report
Binder film index	AS/NZS 2891.8	≥ 18
Air voids content (%)	AS/NZS 2891.8	≥ 20
Particle loss (%)	AGPT/T236	≤ 20
Asphalt binder drain off	AGPT/T235	≤ 0.3

The volumetric design of GGA shall be performed using gyratory compaction and be in accordance with the Superpave Mix Design: Superpave Series No. 2 manual published by the Asphalt Institute and comply with the requirements in Table 3-3.

Table 3-3: GGA mix requirements (Superpave design method)

Property	Test Method	Requirement
Air voids content (%)	AS/NZS 2891.9.2	N _{design} = 4.0
Gyratory compaction (no. of gyrations)	AS/NZS 2891.2.2 ^{1,5}	N = 50-150
Voids in mineral aggregate (%)	AS/NZS 2891.8	18 - 23
Filler/binder ratio	n/a	Report
Permanent deformation (min, number of passes at 12 mm rut depth)	TMR Q325 ⁴	20,000 ²
Moisture damage (min, number of passes at the inflection point)	TMR Q325 ⁴	10,000 ²
Moisture sensitivity TSR (%)	AGPT-T232 ³	≥ 80 ²
Determine number of Marshall blows to 4% air voids, or, Determine number of gyrations to 4% air voids	AS/NZS 2891.5 or AS/NZS 2891.2.2, AS/NZS 2891.9.26, AS/NZS 2891.7.3 and AS 2891.8	Report ²

Notes:

1. Gyratory compactor pressure must be increased to a maximum of 825 kPa and specimens may be held at a constant height for a maximum of 90 minutes. An internal gyratory angle of 1.16 degrees and 30 ± 0.5 rev/minute must be used.
2. Testing shall be undertaken on plant produced asphalt samples.
3. Freeze-thaw cycle required.
4. The following test conditions shall apply:

- Target air voids shall equal $7.0 \pm 1\%$
 - Test temperature shall be $50 \text{ }^{\circ}\text{C} \pm 1 \text{ }^{\circ}\text{C}$
 - Specimen height shall be $60 \pm 1 \text{ mm}$
 - The minimum number of test specimens shall be 4 to allow for 2 tests (averaging of the 2 test results will not be allowed)
 - Measurements shall be taken at every 100 passes along the total specimen length)
 - The inflection point is defined as the number of wheel passes at the intersection between the creep slope and stripping slope
 - Condition the specimens in water at the test temperature for 2 and 4 hours prior to testing
 - The test shall be terminated at 25,000 passes.
5. The compaction temperature shall be between $145 \text{ }^{\circ}\text{C} - 160 \text{ }^{\circ}\text{C}$.

The optimum binder content shall be determined as follow:

1. The optimum binder content calculations shall be based on the average of 3 briquettes prepared at each CRM binder content. At least four different binder contents shall be tested, with the minimum content being 7.5%.
2. Confirm that the specimens meet the minimum binder content and voids in mineral aggregate requirements at 50 and 150 gyrations and discard mixes that do not meet these requirements.
3. Plot the CRM binder content against the average air voids content and draw a best-fit curve through the data points.
4. Determine the VMA for each briquette and plot the average of each set against the CRM binder content.
5. Determine the filler/binder ratio and plot this value against the CRM binder content.
6. Select an optimum binder content at 4% air voids from the air voids content curve.
7. Confirm the filler/binder ratio and VMA at the optimum binder content.

3.6. Mix design report

The mix design report shall include the following information:

1. Details of manufacturer and manufacturing plant where the mix will be produced.
2. Design grading and binder content.
3. Details of all constituent materials and their proportions, as well as test results from a NATA accredited laboratory demonstrating that the constituents comply with the requirements in Clause 2.
4. Test results provided by a NATA accredited laboratory demonstrating that the mix design complies with the requirements in Clause 3.5.
5. A signed declaration that the mix design complies with the requirements of this specification.
6. Reference to this specification.

4. Manufacture and storage

4.1. General

Asphalt manufacturing plant shall be capable of consistently producing asphalt mixes with the properties specified and at a rate suitable for smooth, continuous asphalt placing.

4.2. Binder production

The temperature of the crumb rubber modified binder immediately after the initial dispersion of the crumb rubber into the bitumen shall be between 165 and 200°C . The producer shall ensure that the crumb rubber and bitumen are thoroughly mixed prior to the beginning of the reaction period. The reaction period shall be a minimum of 60 minutes, during which time the crumb rubber modified binder is continued to be mixed while the temperature between 165 and 200°C . The producer shall ensure the crumb rubber particles have been uniformly incorporated into the mixture and that they have been "wetted". The occurrence of the crumb rubber floating on the surface or agglomerations of crumb rubber particles is evidence of insufficient mixing.

4.3. Storage of aggregate and filler

Raw materials shall be stored at the mixing site in sufficient quantities to ensure continuity of production and enable effective sampling and testing prior to use. The facilities for handling particular materials shall comply with the following:

- a. Aggregates shall be handled and stored in such a manner as to prevent contamination and avoid segregation.
- b. Filler shall be handled and stored in such a manner as to keep it dry and free flowing at all times. Where more than one type of filler is to be used, each shall be handled and stored separately.
- c. Additives shall be protected from moisture or contamination.

4.4. Binder storage

- a. Tanks for heating and storage of bitumen shall be thermostatically controlled and each shall be fitted with a thermometer that is located so that the temperature can be read conveniently.
- b. An appropriate bitumen sampling point shall be provided.

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

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

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

The reheating of crumb rubber modified binder that has cooled below 165 °C shall not be allowed more than once, unless otherwise approved by the Administrator.

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

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

- The temperature of the bitumen prior to the addition of crumb rubber
- The source, grade, amount and temperature of the bitumen prior to the addition of crumb rubber
- The crumb rubber content expressed as percent by the weight of total binder
- Times and dates of the crumb rubber additions and resultant binder viscosity.
- A record of the temperature, with time and date reference for each load or batch. The record shall begin at the time of the addition of crumb rubber and continue until the load or batch is completely used. Readings and recordings shall be made at every temperature change in excess of 10 °C, and as needed to document other events which are significant to batch use and quality.

Immediately prior to use, the viscosity of the crumb rubber modified binder shall be tested by the Contractor with a rotational viscometer (ASTM D7741/D7741M or AG:PT/T111). The binder shall meet the viscosity requirements of Table 2-11.

4.5. Mixing temperatures

The temperature of the modified binder delivered into the mixer shall not exceed 190 °C. The exit temperature of the material from the mixer shall not exceed 165 °C.

4.6. Addition of filler

Filler systems shall be designed or modified to provide for the appropriate quantity of added filler. In drum mix plants, loss of filler shall be minimised by feeding direct into the mixer alongside addition of binder.

4.7. Addition of fibres

The following requirements shall apply to the process of adding cellulose fibres:

- Fibre shall be added in a manner that ensures good dispersion of fibres, avoids loss of fibre through dust collection systems and avoids damage to fibre by overheating.
- Mixing times shall be increased, where necessary, to ensure adequate dispersal and mixing of fibre.

4.8. Particle coating

The degree of particle coating shall be not less than 99%, when determined in accordance with AS/NZS 2891.11, once discharged from the asphalt plant into delivery vehicles.

4.9. Production tolerances

The proportion of the different aggregate fractions may be varied for the purpose of process control provided that the asphalt produced remains essentially uniform and consistent and in compliance with the nominated mix submission. The actual particle size distribution and binder content of the production mix may vary from the values nominated in the mix design report within the limits shown in Table 4-1.

Table 4-1: Production tolerances

Description	Test method	Tolerance
Permissible variation to nominated combined particle size distribution during production (% by mass of total aggregate)	AS/NZS 2891.3.1, or AG:PT/T234 ¹	
Passing 4.75 mm sieve and larger		± 7
Passing 2.36 mm and 1.18 mm sieves		± 5
Passing 0.600 mm and 0.300 mm sieves		± 4
Passing 0.150 mm sieve		± 2.5
Passing 0.075 mm sieve		± 1.5
Permissible variation to the nominated binder content during production (% by mass of total mix)	AS/NZS 2891.3.1 ² , or AG:PT/T234 ³	± 0.5
Permissible variation to the nominated maximum density during production (t/m ³)	AS/NZS 2891.7.1	± 0.035
Permissible variation to the nominated air voids content during production ⁴ (%)	AS 2891.8	± 1.5
Moisture content (%)	AS/NZS 2891.10.	0.5

Notes:

- The particle size distribution shall be adjusted using the 'wet' method in Appendix A of AG:PT/T234.
- When using test method AS/NZS 2891.3.1, the binder content shall be adjusted using the procedure described in Section 5 of Manual 19 – May 2016 Guidelines for the design, manufacture and construction of bitumen-rubber asphalt wearing courses published by the South African Bitumen Association (www.sabita.co.za).
- The binder content determined shall be adjusted using the 'wet' method in Appendix A of AG:PT/T234.
- At number of blows Marshall 4.0 design air voids determined as per Table 3.3, or number of gyrations to 4.0% air voids as per Table 3.3.

4.10. Storage of mixed asphalt

Asphalt may be stored prior to delivery to the purchaser, subject to the following requirements being observed:

- The mix is consigned to and deposited in the storage bins in such a manner as to minimise segregation.
- The storage bin shall be insulated.
- The method of discharge shall be such as to minimise segregation. Any caked or segregated portions of mix shall be discarded.

5. Sampling and testing during production

5.1. General

The Contractor shall arrange for all relevant testing.

Samples from asphalt production shall be taken at the required frequency in Table 5-1 in accordance with AS/NZS 2891.1.1. Samples shall not be mixed. In addition, each loaded truck shall be visually inspected for segregation, uncoated particles, excess bitumen or overheating, before dispatch from the plant.

5.2. Frequency of sampling and testing

Frequency of sampling and testing shall be not less than that shown in Tables 5-1 and 5-2. Table 5-1 provides for two levels of minimum frequency. The reduced frequency may only be adopted where the process is demonstrated to be under statistical control as specified in Section 5.3. Where a non-conformance occurs in any test requirement, the frequency of sampling and testing for that particular property shall be increased to the normal level until conforming results have been obtained on five consecutive samples.

Table 5-1: Frequency of sampling and testing of produced asphalt

Property	Test Method	Normal minimum frequency	Reduced minimum frequency
Binder content and grading	AS/NZS 2891.3.1 ¹ , or AG:PT/T234 ²	One test per 300 t of asphalt production, or part thereof over 30 t.	One test per 500 t of asphalt production, or part thereof over 30 t.
Maximum density	AS/NZS 2891.7.1	One test per 300 t of asphalt production, or part thereof over 30 t.	One test per 500 t of asphalt production, or part thereof over 30 t.
Moisture content	AS/NZS 2891.10	One test per 2,500 t of asphalt production, or 1 test per shift, whichever is greater.	One test per 2,500 t of asphalt production, or 1 test per shift, whichever is greater.
Air voids content (Marshall compacted specimens) ³	AS/NZS 2891.5, AS/NZS 2891.9.2, AS/NZS 2891.7.3 and AS 2891.8	One test per 300 t of asphalt production, or part thereof over 30 t.	One test per 500 t of asphalt production, or part thereof over 500 t.
Air voids content (Gyratory compacted specimens) ³	AS/NZS 2891.2.2, AS/NZS 2891.9.2, AS/NZS 2891.7.3 and AS 2891.8	One test per 300 t of asphalt production, or part thereof over 30 t.	One test per 500 t of asphalt production, or part thereof over 500 t.
Voids in mineral aggregate	AS/NZS 2891.8	One test per 300 t of asphalt production, or part thereof over 30 t.	One test per 500 t of asphalt production, or part thereof over 500 t.
Moisture sensitivity	AGPT-T232 ⁴	One test per 5,000 t of asphalt production, or 1 test per project, whichever is greater.	One test per 10,000 t of asphalt production, or 1 test per project, whichever is greater.
Temperature of asphalt discharged from plant	Probe digital thermometer	Each loaded truck	Lesser of each loaded truck or one per 15 minutes

Notes:

1. When using test method AS/NZS 2891.3.1, the binder content shall be adjusted using the procedure described in Section 5 of Manual 19 – May 2016 Guidelines for the design, manufacture and construction of bitumen-rubber asphalt wearing courses published by the South African Bitumen Association.
2. The particle size distribution and binder content shall be adjusted using the 'wet' method in Appendix A of AG:PT/T234.
3. Either Marshall compaction or gyratory compaction shall be used.
4. Freeze-thaw cycle required.

Table 5-2: Frequency of testing of constituent materials

Property	Test Method	Normal minimum frequency
Crushed particles ⁽¹⁾	AS 1141.18	3 Monthly
Aggregate density and water absorption	AS 1141.6.1, or AS1141.6.2	3 Monthly
Los Angeles abrasion loss ⁽²⁾	AS 1141.23	3 Monthly
Ten percent fines value (wet) ⁽²⁾	AS 1141.22	3 Monthly
Wet/dry strength variation ⁽²⁾	AS 1141.22	3 Monthly
Flakiness index of coarse aggregate	AS 1141.15	Monthly
Voids in dry compacted filler (combined filler)	AS/NZS 1141.17	Monthly
Binder blend design	As per Table 2-9	At time of mix design
Binder properties at binder production	As per Table 2-9	Certification of each batch/delivery This testing shall apply to the first batch of binder supplied for each project. Subsequent batches be tested for compliance with resilience, softening point and viscosity at 175 °C only.
Binder properties at time of asphalt production	As per Table 2-11	At time of asphalt production
Added filler	As per Table 2-4	Certification of each batch/delivery

Notes:

1. Test only required on river gravels and metasediments
2. Aggregate to be tested for either Los Angeles abrasion loss, or wet strength and wet/dry strength variation

5.3. Process control

The Contractor shall implement process control measures in accordance with or exceeding the requirements in Austroads / AAPA Pavement work tips No. 15 *Asphalt Statistical Process Control*. Statistical process control shall include results for tests in Table 5.1

6. Delivery

Asphalt shall be transported to the point of delivery in vehicles complying with the following requirements:

- a. The inside of vehicle bodies shall be kept clean and coated with a thin film of an appropriate release agent to prevent asphalt sticking to the body of the vehicle. Care shall be taken to remove surplus release agent before loading asphalt into the vehicle.
- b. After loading with asphalt, the body of the vehicle shall be covered to prevent contamination and reduce the rate of cooling of the mix.
- c. Where the length of the haul or the weather is such that the temperature of the asphalt may drop below a suitable placing temperature, or where excessive local cooling of the mix may occur, the vehicles shall be suitably insulated.

7. Placing

7.1. General

Prior to tack coating and placing of asphalt, the surface shall be free of all deleterious material. Where required, the Contractor shall sweep clean the area on which asphalt is to be placed.

The Contractor shall prevent tack coat, binder, aggregate, asphalt or other material used on the work from entering, adhering or obstructing gratings, hydrants, valve boxes, inspection pit covers, kerbs and other road fixtures.

Handwork shall be minimised.

7.2. Tack coating

Tack coat shall be applied to the cleaned surface prior to placing asphalt.

Tack coat shall consist of bituminous emulsion complying with AS 1160. The type and breaking rate shall be suitable to the climatic and surface conditions of use such that it is fully broken, free of surface water and intact before the commencement of asphalt spreading.

Unless otherwise directed, tack coat shall be applied to provide a uniform application rate of residual binder of between 0.15 and 0.25 L/m².

Tack coat shall be applied by spray bar fitted to a mechanical sprayer, or purpose-built tack coat spray truck. Hand spraying shall be carried out only in those areas where it is impracticable to use a spray bar.

Precautions shall be taken to protect kerbs, channels, adjoining structures, traffic and parked vehicles from tack coat spray.

Where asphalt is to be spread over clean, freshly placed asphalt, or over a clean primed surface, the Contractor may propose, to the Superintendent, the omission of the tack coat.

7.3. Spreading

Unless otherwise specified, self-propelled mechanical pavers shall be employed to place asphalt except for areas where the use of a paver is impracticable.

Asphalt shall be spread without tearing or segregation.

The Contractor shall conduct spreading operations to ensure that the paver speed matches the rate of supply so that the number of paving stops is minimised.

The paver shall not be left stationary for prolonged periods with the screed box in contact with either the previously placed asphalt or loose asphalt in front of the screed.

The Contractor shall nominate minimum temperature for spreading of asphalt in Project Quality Plan.

7.4. Ambient Conditions for Placing

Unless otherwise approved by the Principal, asphalt shall be placed only when the temperature of the surface on which the asphalt is to be placed is at least 15°C and the ambient temperature at the beginning of placement is at least 13°C. The placement shall be stopped when the ambient temperature is 13°C or less and falling.

Tack coat and/or asphalt shall not be placed when the pavement surface is wet or rain is imminent.

7.5. Layer Thickness

The target thickness of the compacted layer shall be as specified in project particulars.

7.6. Level Control

The method of paver level control shall be as specified in the Schedule of Job Details. If no method is specified in the Schedule of Job Details, the Contractor shall apply suitable automatic or manual screed level controls to achieve the standards specified in Clause 9.

7.7. Compaction

Asphalt shall be uniformly compacted to the standards specified in Clause 9.4 as soon as the asphalt has cooled sufficiently to support the rollers without undue displacement. The Contractor shall nominate minimum temperature for compaction of asphalt in Project Quality Plan.

Compaction shall be achieved using suitable sized steel wheeled or vibratory rollers or a combination of steel wheeled or vibratory rollers. Pneumatic tired rollers shall not be used.

7.8. Temperature before trafficking

Surface temperature shall be below 65 °C before opening to traffic.

7.9. Surface gritting

Unless otherwise agreed with the Principal the GGA surface layers shall be gritted.

The grit shall be uniformly spread and rolled into the surface of the hot asphalt during the compaction process. The temperature at which the grit material is applied shall be such that the grit forms a strong bond with, and is partially coated by, the binder in the asphalt mix. The spread rate to be adopted for the grit material shall be nominated by the Contractor and be applied at a rate $\geq 0.2 \text{ kg/m}^2$. After consultation with the Administrator, the nominated spread rate may be adjusted to ensure an adequate coverage of grit is achieved.

Prior to the pavement section being opened to traffic, any loose grit material shall be removed from the road surface.

The material used for gritting shall consist of natural sand particles having a grading complying with the requirements shown in Table 7-1 or other material as approved by the Superintendent.

The grit shall be dry, clean, hard, angular, durable, and free from clay and other aggregations of fine material, soil, organic matter and any other deleterious material.

Table 7-1: Grading limits for grit

AS Sieve Size (mm)	Percentage passing by mass
4.75	100
2.36	90 – 100
0.600	0 - 20
0.075	0 - 0.5

7.10. Joints

7.10.1. General

Joints shall be provided as follows:

- Longitudinally, if the width of the pavement is such that more than one paving run is necessary.
- Transversely, after the completion of a day's paving operations, or where a delay in paving operation allows asphalt to cool and adversely affect placing, and elsewhere if a break in a longitudinal run is required.

The location of joints shall be planned before work commences.

The number of joints shall be minimised by adopting good asphalt paving practices.

All joints shall be well constructed and comply with the compaction requirements specified in Clause 8.

7.10.2. Longitudinal Joints

Longitudinal joints in the wearing course shall coincide with traffic lane lines unless otherwise specified or agreed. Longitudinal joints shall be offset from layer to layer by not less than 150 mm provided that no joint is placed directly below a trafficked wheel path.

Where asphalt is placed against the edge of a preceding lane that has not cooled below 80 °C it shall be considered a hot joint. Hot joints shall be constructed by leaving a 150 mm strip of asphalt unrolled along the free edge until the adjoining lane is placed, and then compacting the unrolled strip simultaneously with the material in the adjoining lane.

Where asphalt is placed against the edge of a preceding lane that has cooled below 80 °C it shall be considered a cold joint. Asphalt placed against a cold edge should overlap the previous edge by 25 mm to 50 mm. The overlap should be pushed back using lutes, immediately after spreading, to form a slight ridge that is compacted with the steel wheel roller.

7.10.3. Transverse Joints

Transverse joints shall be offset by not less than 1 m from layer to layer.

8. Production control and construction trial

8.1. General

Where a production and construction trial is specified in the Schedule of Job Details, and not less than two days before the site work is due to commence, all the Contractor's plant and personnel proposed for use on the job shall be subjected to a production and construction trial in the presence of the Superintendent. If more than one asphalt mix is specified, each mix shall be subjected to the trial not less than 24 hours before the proposed commencement of production of that mix.

Asphalt manufactured in the production trial may also be used in the construction trial provided that it meets the requirements of the specification.

8.2. Manufacture

The mixing plant shall be operated at approximately the rate intended for full scale production to produce the 50 to 200 tonne of CRM asphalt required for the trial.

The Contractor shall sample and test the asphalt in accordance with Clause 4.9 and the binder in accordance with Table 2-11.

If the tests on the samples indicate that the asphalt does not conform to the Specification, the Contractor shall make such alterations in the procedures or adjustments to the plant and equipment as necessary to produce asphalt in accordance with this Specification. The mixing trial shall be repeated as necessary until asphalt of the quality specified is being consistently produced.

8.3. Placing compaction and finishing

The Contractor shall subject all of the material transfer, placing, compaction and finishing equipment and operating personnel, proposed for use in the works, to a trial using the construction procedures proposed for the work. The trial shall consist of at least two adjacent lanes 3 metres wide and at least 50 metres long and shall be constructed in the designated area, in accordance with all the requirements of this Specification, or as directed.

8.4. Testing of trial section

The Contractor shall test the trial section for the finished pavement properties of this Specification. In the event that the tests indicate that the asphalt in the test section does not conform to the specification requirements, the Contractor shall make any necessary adjustments and, if necessary, repeat the production and construction trials, as specified above, until the

Superintendent is satisfied that asphalt of uniform quality is being consistently produced, placed, compacted and finished in accordance with the requirements of this Specification.

A hold point shall be designated in the Contractor's Quality System at the conclusion of the trial and the Contractor shall not commence full scale production of any asphalt for the works until the hold point has been released.

9. Finished pavement properties

9.1. Lot size

Compliance testing of asphalt shall be undertaken on a lot basis. A pavement lot shall be an essentially homogeneous and contiguous section of work completed within a 24 hour period of production, unless otherwise specified in the Schedule of Job Details

9.2. Level

The level at the top of the asphalt surfacing shall not differ from the specified design level by more than 10 mm, except that where asphalt is placed against kerb and channel, the surface at the edge of the wearing course shall be flush with, or not more than 5 mm above, the lip of the channel, unless otherwise specified or shown on the Drawings.

9.3. Thickness

The average total compacted thickness of the combined asphalt layers shall be not less than the specified thickness and not be greater than specified thickness + 10 mm. Where confirmation of asphalt thickness is required, it shall be determined by coring to a recognised random sampling plan, based on a minimum of 5 cores per lot.

9.4. Surface shape at joints

No point on the finished surface shall deviate by more than 5 mm below a 3 m straightedge, measured between two points across a joint.

9.5. In situ air voids

This clause shall only apply to GGA

Bulk density testing shall not be performed on lots of less than 30 tonnes.

The location of each in situ bulk density test shall be chosen by a method of random stratified sampling. A minimum of 6 bulk density tests shall be performed per lot. For core sample tests, the layer thickness is the mean thickness of the core samples and for nuclear gauge tests, the layer thickness is the nominal thickness. All core holes shall be repaired by an appropriate method.

Density testing shall be carried out as soon as practicable after completion of work. Cores shall be taken in accordance with AS/NZS 2891.1.2. For cores, the bulk density shall be determined in accordance with AS/NZS 2891.9.2. The bulk density from nuclear gauge tests shall be determined in accordance with AS/NZS 2891.14.2

Relative compaction is the percentage ratio of the in situ bulk density of the compacted asphalt and the reference density of the asphalt of a particular lot. The reference density shall be the mean of the five most recent maximum density measurements determined in accordance with AS/NZS 2891.7.1, or AS/NZS 2891.7.3 of the same mix, provided that:

- a. The tests have been completed within the previous 4 weeks.
- b. The binder content of samples tested is within $\pm 0.3\%$ of the job mix binder content.
- c. There has been no change in the mix components or proportions.

The characteristic value of relative compaction is calculated as $\text{Mean} - K \times S$ where,

Mean = The mean of the relative compaction results

S = The sample standard deviation of the relative compaction results

K = A factor that depends on the number of tests as shown in Table 9.1.

Table 9-1: acceptance constant

Number of Tests or Measurements	Acceptance Constant (K)
6	0.72
7	0.76
8	0.78
9	0.81
10	0.83

The work represented by a lot shall be assessed as the characteristic value of in situ voids where: Characteristic value of in situ air voids (%) = 100 – Characteristic relative compaction.

The maximum characteristic value of in situ air voids shall not exceed 8.0%.

The characteristic value of in situ air voids shall not be less than 3.0%.

The density at the joints is not usually tested unless the Superintendent suspects the specified requirements have not been achieved. Where this occurs, the Superintendent may order tests to confirm compliance.

10. Measurement and payment

This clause shall only apply where not covered elsewhere in the contract for the work

10.1. General

Payment for tack coat shall be included in payment for asphalt.

Payment for asphalt shall be by mass for quantities determined in accordance with Clause 10.2 or 10.3 as appropriate.

Measurement for payment will include all works shown on the plans or as specified but will not include asphalt lost in transit, works not shown on the plans and variations in quantities due to variations in actual thickness exceeding the specified tolerances.

10.2. Measurement by mass

Unless otherwise specified in the Schedule of Job Details, the quantity of asphalt shall be measured by mass (tonnes).

The quantity of asphalt shall be determined from dockets supplied by the Contractor and issued at a certified weighing system unless measurement by batch weights using certified scales is approved by the Superintendent.

Separate pay items shall be included in the Schedule of Rates for each nominal course thickness and each nominal size and type of asphalt specified.

10.3. Measurement by volume

Where specified in the Schedule of Job Details, the quantity of asphalt shall be determined from measurement of area and thickness.

The area and thickness shall be determined from the dimensions on the plans or as specified for the work being measured.

The density of asphalt in a lot shall be taken as the mean of the in situ densities of the lot.

Separate pay items shall be included in the Schedule of Rates for each nominal course thickness and each nominal size and type of asphalt specified.

10.4. Non-complying materials

In the event that the material supplied is not within the tolerances and standards defined for manufacture or placing of asphalt, the Principal may direct:

- The removal of non-complying material; or,
- That the reduced service life arising from the non-complying material is offset by reducing payment for the non-complying material by the method defined in the Schedule of Job Details; or,
- With the consent of the Contractor, any other remedial treatment that is expected to provide the required level of service, or,
- The Contractor to propose a "use as is" disposition where the Contractor can substantiate that the non-conformance will have no adverse impact on the life or performance of the pavement.

Appendix B Emissions Monitoring Report



Assured Environmental

WORKPLACE AIR MONITORING – PIMPAMA

AUSTRALIAN ROAD RESEARCH BOARD

Project ID. 11535

R_O

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Accreditation ID: 19703



EXECUTIVE SUMMARY

Personal exposure monitoring was performed at Pimpama Jacobs Well Road in Pimpama, Queensland. Sampling was performed on four Fulton Hogan employees, whilst fulfilling their duties resurfacing the road on the 29th of June 2018, during day shift operations at the site.

Where appropriate, comparison is provided with the time-weighted average (TWA) workplace exposure standards published in the Safe Work Australia Workplace Exposure Standards for Airborne Contaminants (2013). In comparing the results, reference is made to the guidance provided in Guidance on the Interpretation of Workplace Exposure Standards for Airborne Contaminants (2013). Compounds that were not referenced by Safe Work Australia Workplace Exposure Standards as having an exposure limit, were referenced to the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of the United States (2007). While compounds where no exposure limit was found have been denoted with 'nf' in the tables below.

It is noted that TWA exposure values are based on a work shift of 8-hours per day, 5 days per week standard work shift. Where workers have a working day longer than eight hours or a working week longer than 40 hours, the TWA exposure standard needs to be adjusted to compensate for the greater length of exposure during the longer work shift and the reduced recovery time between work shifts. Formulas such as the Brief and Scala Model can be used to adjust the 8-hour TWA limits based on actual hours worked.

Formula:	
Adjusted exposure standard (TWA)	$= \frac{8 \times (24 - h) \times \text{Exposure Standard (8-hour TWA)}}{16 \times h}$
where h = hours worked/day	

Figure 1: Brief and Scala Model formula

Table 3 presents the exposure standards relevant to the exposure monitoring undertaken at the Pimpama site. Note that 10-hour TWA values are presented.

Table 3: List of exposure standards

Compound	Unit of measure	TWA (10hrs)
Inhalable dust	mg/m ³	7
PAH:		
Naphthalene	mg/m ³	36
Acenaphthylene	mg/m ³	nf
Acenaphthene	mg/m ³	nf
Fluorene	mg/m ³	nf
Phenanthrene [a]	mg/m ³	0.14
Anthracene [a]	mg/m ³	0.14
Fluoranthene	mg/m ³	nf
Pyrene [a]	mg/m ³	0.14

Compound	Unit of measure	TWA (10hrs)
Benzo(a)anthracene	mg/m ³	nf
Chrysene [a]	mg/m ³	0.14
Benzo(b,j+k)fluoranthene	mg/m ³	nf
Benzo(a)pyrene [a]	mg/m ³	0.14
Indeno(1,2,3-c,d)pyrene	mg/m ³	nf
Dibenzo(a,h)anthracene	mg/m ³	nf
Benzo(g,h,i)perylene	mg/m ³	nf
VOC:		
Benzene	mg/m ³	2.2
Toluene	mg/m ³	134
Ethylbenzene	mg/m ³	304
m,p Xylene	mg/m ³	245
o Xylene	mg/m ³	245
total Xylene	mg/m ³	245
Styrene	mg/m ³	nf
a-methylstyrene	mg/m ³	169
Isopropylbenzene (Cumene)	mg/m ³	88
Naphthalene	mg/m ³	36
Cyclohexanone	mg/m ³	70
Diisobutylketone (DIBK)	mg/m ³	105
Methyl Ethyl Ketone (MEK)	mg/m ³	312
4-Methyl-2-Pentanone (MIBK) [a]	mg/m ³	287
Hexane	mg/m ³	50
Nonane	mg/m ³	735
Decane [b]	mg/m ³	245
Dodecane [b]	mg/m ³	245
Acrylonitrile	mg/m ³	3.0
Ethyl Acetate	mg/m ³	504
1,2-Dichloroethane	mg/m ³	28
Carbon Tetrachloride	mg/m ³	0.44
Cyclohexane	mg/m ³	245
Ethyl Acrylate	mg/m ³	14
Trichloroethene (TCE) [a]	mg/m ³	189
1,4-Dioxane	mg/m ³	25
Epichlorohydrin	mg/m ³	5.3
n-Butyl Acetate	mg/m ³	499
Tetrachloroethene (PCE) [a]	mg/m ³	119
Chlorobenzene	mg/m ³	32
Benzyl Chloride	mg/m ³	3.6
Acetone	mg/m ³	830

- a- Inhalable dust assumes that the composition up of the dust is general 'low toxicity' particles.
- b- OSHA permissible exposure limit (PEL) was used for this compound, as there is currently no Safe Work Australia exposure standard for this compound.
- c- No direct exposure limit for this compound was found, therefore the NIOSH regular exposure limit for total petroleum distillates (in which these compounds are common) was used as a guide.

It is noted that exposure standards do not represent 'no effect' levels which guarantee protection to every worker. Given the nature of biological variation and the range of individual susceptibility, it is inevitable that a very small proportion of workers who are exposed to concentrations around or below the exposure standard may suffer mild and transitory discomfort. An even smaller number may exhibit symptoms of illness. Exposure standards are not fine dividing lines between satisfactory and unsatisfactory working conditions, but rather that they are best used to assess the quality of the working environment and indicate where appropriate control measures are required.

A summary of the results of the exposure monitoring is presented in the tables below for each of the work duties assessed. Overall, the results of the occupational air sampling indicate that concentrations of air contaminants during operation were within the TWA exposure standards established by Safe Work Australia or Occupational Safety and Health Administration.

The total inhalable dust result for all samples were below 1 mg/m^3 except for the level hand which returned a result of 1.1 mg/m^3 .

No PAHs were detectable in any of the samples. The analytical limit of detection was $1 \text{ }\mu\text{g/sample}$ for the filter and $0.5 \text{ }\mu\text{g/sample}$ for the tube fraction (except for benzo (b,j+k) fluoranthene which had a limit of detection of 2 and $1 \text{ }\mu\text{g/sample}$ respectively).

The VOCs were also largely un-detectable in the samples except for decane and dodecane, which were found in the truck spotting sample slightly above the limit of detection. The limit of detection for each VOC compound varies slightly and ranges from $5 \text{ }\mu\text{g/sample}$ to $20 \text{ }\mu\text{g/sample}$.

Table 4: Summary of results – Truck spotting

Compound	Unit of measure		Test result	TWA Standard (10hr)
Inhalable dust	mg/m ³		0.66	7
PAH:				
Naphthalene	mg/m ³	<	0.0031	36
Acenaphthylene	mg/m ³	<	0.0031	-
Acenaphthene	mg/m ³	<	0.0031	-
Fluorene	mg/m ³	<	0.0031	-
Phenanthrene	mg/m ³	<	0.0031	0.14
Anthracene	mg/m ³	<	0.0031	0.14
Fluoranthene	mg/m ³	<	0.0031	-
Pyrene	mg/m ³	<	0.0031	0.14
Benzo(a)anthracene	mg/m ³	<	0.0031	-
Chrysene	mg/m ³	<	0.0031	0.14
Benzo(b,j,k)fluoranthene	mg/m ³	<	0.0061	-
Benzo(a)pyrene	mg/m ³	<	0.0031	0.14
Indeno(1,2,3-c,d)pyrene	mg/m ³	<	0.0031	-
Dibenzo(a,h)anthracene	mg/m ³	<	0.0031	-
Benzo(g,h,i)perylene	mg/m ³	<	0.0031	-
VOC:				
Benzene	mg/m ³	<	0.055	2.2
Toluene	mg/m ³	<	0.055	134
Ethylbenzene	mg/m ³	<	0.055	304
m&p Xylene	mg/m ³	<	0.11	245
o Xylene	mg/m ³	<	0.055	245
total Xylene	mg/m ³	<	0.16	245
Styrene	mg/m ³	<	0.055	-
a-methylstyrene	mg/m ³	<	0.055	169
Isopropylbenzene (Cumene)	mg/m ³	<	0.055	88
Naphthalene	mg/m ³	<	0.055	36
Cyclohexanone	mg/m ³	<	0.055	70
Diisobutylketone (DIBK)	mg/m ³	<	0.055	105
Methyl Ethyl Ketone (MEK)	mg/m ³	<	0.11	312
4-Methyl-2-Pentanone (MIBK)	mg/m ³	<	0.055	287
Hexane	mg/m ³	<	0.055	50
Nonane	mg/m ³	<	0.055	735
Decane	mg/m ³		0.077	245
Dodecane	mg/m ³		0.098	245
Acrylonitrile	mg/m ³	<	0.055	3.0
Ethyl Acetate	mg/m ³	<	0.055	504
1,2-Dichloroethane	mg/m ³	<	0.055	28
Carbon Tetrachloride	mg/m ³	<	0.055	0.44
Cyclohexane	mg/m ³	<	0.055	245
Ethyl Acrylate	mg/m ³	<	0.055	14
Trichloroethene (TCE)	mg/m ³	<	0.055	189
1,4-Dioxane	mg/m ³	<	0.055	25
Epichlorohydrin	mg/m ³	<	0.055	5.3
n-Butyl Acetate	mg/m ³	<	0.11	499
Tetrachloroethene (PCE)	mg/m ³	<	0.055	119
Chlorobenzene	mg/m ³	<	0.055	32
Benzyl Chloride	mg/m ³	<	0.055	3.6
Acetone	mg/m ³	<	0.22	830

Table 5: Summary of results – Level hand

Compound	Unit of measure		Test result	TWA Standard
Inhalable dust	mg/m ³		1.1	7
PAH:				
Naphthalene	mg/m ³	<	0.0032	36
Acenaphthylene	mg/m ³	<	0.0032	-
Acenaphthene	mg/m ³	<	0.0032	-
Fluorene	mg/m ³	<	0.0032	-
Phenanthrene	mg/m ³	<	0.0032	0.14
Anthracene	mg/m ³	<	0.0032	0.14
Fluoranthene	mg/m ³	<	0.0032	-
Pyrene	mg/m ³	<	0.0032	0.14
Benzo(a)anthracene	mg/m ³	<	0.0032	-
Chrysene	mg/m ³	<	0.0032	0.14
Benzo(b,j,k)fluoranthene	mg/m ³	<	0.0064	-
Benzo(a)pyrene	mg/m ³	<	0.0032	0.14
Indeno(1,2,3-c,d)pyrene	mg/m ³	<	0.0032	-
Dibenzo(a,h)anthracene	mg/m ³	<	0.0032	-
Benzo(g,h,i)perylene	mg/m ³	<	0.0032	-
VOC:				
Benzene	mg/m ³	<	0.059	2.2
Toluene	mg/m ³	<	0.059	134
Ethylbenzene	mg/m ³	<	0.059	304
m,p Xylene	mg/m ³	<	0.12	245
o Xylene	mg/m ³	<	0.059	245
total Xylene	mg/m ³	<	0.18	245
Styrene	mg/m ³	<	0.059	-
a-methylstyrene	mg/m ³	<	0.059	169
Isopropylbenzene (Cumene)	mg/m ³	<	0.059	88
Naphthalene	mg/m ³	<	0.059	36
Cyclohexanone	mg/m ³	<	0.059	70
Diisobutylketone (DIBK)	mg/m ³	<	0.059	105
Methyl Ethyl Ketone (MEK)	mg/m ³	<	0.12	312
4-Methyl-2-Pentanone (MIBK)	mg/m ³	<	0.059	287
Hexane	mg/m ³	<	0.059	50
Nonane	mg/m ³	<	0.059	735
Decane	mg/m ³	<	0.059	245
Dodecane	mg/m ³	<	0.059	245
Acrylonitrile	mg/m ³	<	0.059	3.0
Ethyl Acetate	mg/m ³	<	0.059	504
1,2-Dichloroethane	mg/m ³	<	0.059	28
Carbon Tetrachloride	mg/m ³	<	0.059	0.44
Cyclohexane	mg/m ³	<	0.059	245
Ethyl Acrylate	mg/m ³	<	0.059	14
Trichloroethene (TCE)	mg/m ³	<	0.059	189
1,4-Dioxane	mg/m ³	<	0.059	25
Epichlorohydrin	mg/m ³	<	0.059	5.3
n-Butyl Acetate	mg/m ³	<	0.12	499
Tetrachloroethene (PCE)	mg/m ³	<	0.059	119
Chlorobenzene	mg/m ³	<	0.059	32
Benzyl Chloride	mg/m ³	<	0.059	3.6
Acetone	mg/m ³	<	0.24	830

Table 6: Summary of results – Shuttle buggy operator

Compound	Unit of measure	Test result	TWA Standard
Inhalable dust	mg/m ³	0.61	7
PAH:			
Naphthalene	mg/m ³	<	0.0031
Acenaphthylene	mg/m ³	<	0.0031
Acenaphthene	mg/m ³	<	0.0031
Fluorene	mg/m ³	<	0.0031
Phenanthrene	mg/m ³	<	0.0031
Anthracene	mg/m ³	<	0.0031
Fluoranthene	mg/m ³	<	0.0031
Pyrene	mg/m ³	<	0.0031
Benzo(a)anthracene	mg/m ³	<	0.0031
Chrysene	mg/m ³	<	0.0031
Benzo(b,j,k)fluoranthene	mg/m ³	<	0.0062
Benzo(a)pyrene	mg/m ³	<	0.0031
Indeno(1,2,3-c,d)pyrene	mg/m ³	<	0.0031
Dibenzo(a,h)anthracene	mg/m ³	<	0.0031
Benzo(g,h,i)perylene	mg/m ³	<	0.0031
VOC:			
Benzene	mg/m ³	<	0.054
Toluene	mg/m ³	<	0.054
Ethylbenzene	mg/m ³	<	0.054
m,p Xylene	mg/m ³	<	0.11
o Xylene	mg/m ³	<	0.054
total Xylene	mg/m ³	<	0.16
Styrene	mg/m ³	<	0.054
a-methylstyrene	mg/m ³	<	0.054
Isopropylbenzene (Cumene)	mg/m ³	<	0.054
Naphthalene	mg/m ³	<	0.054
Cyclohexanone	mg/m ³	<	0.054
Diisobutylketone (DIBK)	mg/m ³	<	0.054
Methyl Ethyl Ketone (MEK)	mg/m ³	<	0.11
4-Methyl-2-Pentanone (MIBK)	mg/m ³	<	0.054
Hexane	mg/m ³	<	0.054
Nonane	mg/m ³	<	0.054
Decane	mg/m ³	<	0.054
Dodecane	mg/m ³	<	0.054
Acrylonitrile	mg/m ³	<	0.054
Ethyl Acetate	mg/m ³	<	0.054
1,2-Dichloroethane	mg/m ³	<	0.054
Carbon Tetrachloride	mg/m ³	<	0.054
Cyclohexane	mg/m ³	<	0.054
Ethyl Acrylate	mg/m ³	<	0.054
Trichloroethene (TCE)	mg/m ³	<	0.054
1,4-Dioxane	mg/m ³	<	0.054
Epichlorohydrin	mg/m ³	<	0.054
n-Butyl Acetate	mg/m ³	<	0.11
Tetrachloroethene (PCE)	mg/m ³	<	0.054
Chlorobenzene	mg/m ³	<	0.054
Benzyl Chloride	mg/m ³	<	0.054
Acetone	mg/m ³	<	0.21

Table 7: Summary of results – Paver operator

Compound	Unit of measure	Test result	TWA Standard
Inhalable dust	mg/m ³	0.68	7
PAH:			
Naphthalene	mg/m ³	<	0.0032
Acenaphthylene	mg/m ³	<	0.0032
Acenaphthene	mg/m ³	<	0.0032
Fluorene	mg/m ³	<	0.0032
Phenanthrene	mg/m ³	<	0.0032
Anthracene	mg/m ³	<	0.0032
Fluoranthene	mg/m ³	<	0.0032
Pyrene	mg/m ³	<	0.0032
Benzo(a)anthracene	mg/m ³	<	0.0032
Chrysene	mg/m ³	<	0.0032
Benzo(b,j,k)fluoranthene	mg/m ³	<	0.0063
Benzo(a)pyrene	mg/m ³	<	0.0032
Indeno(1,2,3-c,d)pyrene	mg/m ³	<	0.0032
Dibenzo(a,h)anthracene	mg/m ³	<	0.0032
Benzo(g,h,i)perylene	mg/m ³	<	0.0032
VOC:			
Benzene	mg/m ³	<	0.057
Toluene	mg/m ³	<	0.057
Ethylbenzene	mg/m ³	<	0.057
m,p Xylene	mg/m ³	<	0.11
o Xylene	mg/m ³	<	0.057
total Xylene	mg/m ³	<	0.1705
Styrene	mg/m ³	<	0.057
a-methylstyrene	mg/m ³	<	0.057
Isopropylbenzene (Cumene)	mg/m ³	<	0.057
Naphthalene	mg/m ³	<	0.057
Cyclohexanone	mg/m ³	<	0.057
Diisobutylketone (DIBK)	mg/m ³	<	0.057
Methyl Ethyl Ketone (MEK)	mg/m ³	<	0.11
4-Methyl-2-Pentanone (MIBK)	mg/m ³	<	0.057
Hexane	mg/m ³	<	0.057
Nonane	mg/m ³	<	0.057
Decane	mg/m ³	<	0.057
Dodecane	mg/m ³	<	0.057
Acrylonitrile	mg/m ³	<	0.057
Ethyl Acetate	mg/m ³	<	0.057
1,2-Dichloroethane	mg/m ³	<	0.057
Carbon Tetrachloride	mg/m ³	<	0.057
Cyclohexane	mg/m ³	<	0.057
Ethyl Acrylate	mg/m ³	<	0.057
Trichloroethene (TCE)	mg/m ³	<	0.057
1,4-Dioxane	mg/m ³	<	0.057
Epichlorohydrin	mg/m ³	<	0.057
n-Butyl Acetate	mg/m ³	<	0.11
Tetrachloroethene (PCE)	mg/m ³	<	0.057
Chlorobenzene	mg/m ³	<	0.057
Benzyl Chloride	mg/m ³	<	0.057
Acetone	mg/m ³	<	0.23

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1 INTRODUCTION

Assured Environmental (AE) was appointed by Australian Road Research Board to perform workplace air monitoring at a Fulton Hogan road resurfacing site, located in Pimpama, Queensland.

Personal exposure (breathing zone) samples were collected over one shift at the site, whilst four Fulton Hogan employees carried out their regular duties resurfacing a road with a trial crumbed rubber and bitumen mix in substitute for the more conventional bitumen and aggregate mix. Each employee was analysed for a range of target compounds potentially present in the workplace air environment.

2 SAMPLING METHODOLOGY

2.1 Overview

A range of methodologies and specific sample media were utilised to collect the range of samples required. The following sections describe the methodologies employed for the monitoring program.

2.2 Methodology

Personal sampling pumps and filters/tubes were attached directly on staff members working in the target area. The samplers were worn throughout their work activities and were collected at the end of the shift. The sampling apparatus was positioned within their breathing zone.

The samplers were operated for approximately four hours during the actual asphalt laying operations. The samplers were started at 09:30 and ended at 13:30, this included laying the asphalt in two batches, with a rest break in between.

All sampling arrangements were flow checked before and after each use to determine accurate flow rates throughout the sampling period. The variation in flow from the beginning and post sampling were all found to be within acceptable variation and the average flow rate was used to calculate the total sample volume.

The dust filters were pre-weighed by MPL laboratories and returned to MPL following sampling and the dust loading was gravimetrically determined. Where sorbent tube media (SKC™) was used, tubes were purchased new for this project and following sample were capped and sent to MPL for analysis.

Instruments and sampling materials utilised for the monitoring included:

SKC™ AirChek Touch personal sampling pump
SKC™ XR3000 personal sampling pump
SKC™ 225-3-01 PTFE filters
SKC™ 226-09 tubes
SKC™ 226-30-04 tubes

2.3 Test Methods

All sampling at Pimpama site was undertaken in accordance with the methodologies provided in Table 8 below. This included the selection of sampling flow rates and sample volumes.

Table 8: Test Methods

Parameter	Test Method	NATA accreditation	Notes	Analysis by
Dust - inhalable	AS3640	Sampling & analysis	Nil	4
Polynuclear Aromatic Hydrocarbons	NIOSH 5515	Analysis only	A	4
Hydrocarbons	NIOSH 1501	Sampling & analysis	B	4
Sampling Notes: A. The PTFE filter was pre and post weighed to determine total particulate weight gain prior to analysis for PAH compounds. B. The sample flow rate was set slightly higher than the recommended 0.2 lpm, this was done primarily to achieve a larger sample volume with the reduced sampling time (4 hours) encountered onsite. Additionally, a slightly larger charcoal tube was used for the sampling, 200/400mg instead of the standard 50/100mg.				

Following completion of the sampling, all samples were recovered, labelled with a unique sample identifier and forwarded to the library for analysis. Table 9 below presents a summary of the laboratories responsible for undertaking the analysis of collected samples.

Table 9: Analytical companies

Note	Company	Work performed	NATA accreditation	Report Number
1	Assured Environmental	Sampling	19703	11535
2	MPL (Envirolab Services Pty Ltd)	Analysis	2901	212868

2.4 Sampling Locations

Table 10 below provides a summary of the sample locations considered in the assessment of occupational air exposure within the Australian Road Research Board facility. Where personal sampling was undertaken, the employees name is provided to allow the results of monitoring to be considered in light of the duties undertaken.

Table 10: Sample location

Location	Sampling Type	Inhalable Particulate	PAHs	VOCs
Truck Spotting	Personal	1	1	1
Level Hand	Personal	1	1	1
Shuttle Buggy Operator	Personal	1	1	1
Paver Operator	Personal	1	1	1



Figure 2: Truck spotting



Figure 3: Level hand



Figure 4: Shuttle Buggy operator



Figure 5: Paver Operator

3 QUALITY ASSURANCE AND CONTROL

AE operates within a quality system based upon the requirements of ISO17025. Our quality system defines specific procedures and methodologies to ensure any project undertaken by AMG is conducted with the highest level of quality given the specific confines of each project.

The overall objective of our QA/QC procedures is to representatively sample and accurately analyse components in the gas streams and therefore report valid measurements of emission concentrations. To ensure representativeness of field work our quality procedures target correct sampling locations, time, frequencies and methods, in addition to appropriate sample preservation, chain of custody, sample preparation and analytical techniques.

AE maintains strict quality assurance throughout all our sampling programs, covering on-site 'field work' and the analytical phase of our projects. Our QA program covers the calibration of all sampling and analytical apparatus where applicable and the use of spikes, replicate sample and reference standards.

The test methodologies used for this project are outlined in section 2 of this document. Field test data has been recorded and calculated using direct entry into Microsoft Excel spreadsheets following the procedures of the appropriate test methods. Determination of emission concentrations has been performed using the same Microsoft Excel spreadsheets which are partially supplied as an attachment to this report. More detailed information can be supplied upon request.

QA/QC checks for this project will use validation techniques and criteria appropriate to the type of data and the purpose of the measurement to approve the test report. Records of all data will be maintained. Complete chain of custody (COC) procedures have been followed to document the entire custodial history of each sample. The COC forms also served as a laboratory sheet detailing sample ID and analysis requirements.

4 DEFINITIONS

The following terms and abbreviations may be used in this report. The test methodologies used for this project are outlined in section.

Table II: Definitions

Symbol	Definition
AE	Assured Environmental Pty Ltd
<	The analytes tested for was not detected; the value stated in the reportable limit of detection
Am ³	Gas volume in cubic metres at measured conditions
AS	Australian Standard
°C	Degrees Celsius
f/ml	Fibres per millilitre
g	Grams
kg	Kilograms
m	Metres
m ³	Gas volume in cubic metres at 1 atmosphere and 25 degrees Celsius
mb	Millibars
mg	Milligrams (10 ⁻³ grams)
min	Minute
ml	Millilitres
mmH ₂ O	Millimetres of water
Mole	SI unit that measures the amount of substance
N/A	Not applicable
ng	Nanograms (10 ⁻⁹ grams)
TWA	Time Weighted Average

5 RESULTS

Table 12: Sample information – Inhalable dust and PAH's (Truck spotting & Level Hand)

Client:	ARRB	ARRB
Site:	Pimpama	Pimpama
Sample ID	I1534-I-162	I1534-I-364
Sample Type	Personal sample	Personal sample
Area of Work / SEG	Truck Spotting	Level Hand
Worker	Susie Brazda	Ben O'Reilly
Analytes	PAH's & Inhalable Dust	PAH's & Inhalable Dust
Date	dd:mm:yy	Friday, 29 June 2018
Time start	hh:mm	9:24:00 AM
Time finish	hh:mm	1:31:00 PM
Volume	mins	181.00
Barometric pressure	hPa	1020
Wind speed	m/sec	1-5m/sec
Average Flow Rate	L/min	1.97
Sample volume	L	357.1130
	m ³	0.3571
	ref temp.	25
	m ³ at 25°C	0.364
Inhalable dust:		
Total inhalable dust	mg/filter	0.24
Workplace concentration	mg/m ³	0.66
PAH Total:		
Naphthalene Concentration	mg/m ³	< 0.0031
Acenaphthylene concentration	mg/m ³	< 0.0031
Acenaphthene concentration	mg/m ³	< 0.0031
Fluorene concentration	mg/m ³	< 0.0031
Phenanthrene concentration	mg/m ³	< 0.0031
Anthracene concentration	mg/m ³	< 0.0031
Fluoranthene concentration	mg/m ³	< 0.0031
Pyrene concentration	mg/m ³	< 0.0031
Benzo(a)anthracene concentration	mg/m ³	< 0.0031
Chrysene concentration	mg/m ³	< 0.0031
Benzo(b,j,k)fluoranthene concentration	mg/m ³	< 0.0061
Benzo(a)pyrene concentration	mg/m ³	< 0.0031
Indeno(1,2,3-c,d)pyrene concentration	mg/m ³	< 0.0031
Dibenzo(a,h)anthracene concentration	mg/m ³	< 0.0031
Benzo(g,h,i)perylene concentration	mg/m ³	< 0.0031

Table 13: Sample information – Inhalable dust and PAH's (Shuttle buggy & Paver)

Client:	ARRB	ARRB
Site:	Pimpama	Pimpama
Sample ID	I1534-I-566	I1534-I-768
Sample Type	Personal sample	Personal sample
Area of Work / SEG	Shuttle Buggy Operation	Paver Operation
Worker	Jamie Williams	Brian Trost
Analytes	PAH's & Inhalable Dust	PAH's & Inhalable Dust
Date	dd:mm:yy	Friday, 29 June 2018
Time start	hh:mm	9:21:00 AM
Time finish	hh:mm	1:33:00 PM
Volume	mins	179.00
Barometric pressure	hPa	1020
Wind speed	m/sec	1-5m/sec
Average Flow Rate	L/min	1.99
Sample volume	L	356.6873
	m ³	0.3567
	ref temp.	25
	m ³ at 25°C	0.363
Inhalable dust:		
Total inhalable dust	mg/filter	0.22
Workplace concentration	mg/m ³	0.61
PAH Total:		
Naphthalene Concentration	mg/m ³	< 0.0031
Acenaphthylene concentration	mg/m ³	< 0.0031
Acenaphthene concentration	mg/m ³	< 0.0031
Fluorene concentration	mg/m ³	< 0.0031
Phenanthrene concentration	mg/m ³	< 0.0031
Anthracene concentration	mg/m ³	< 0.0031
Fluoranthene concentration	mg/m ³	< 0.0031
Pyrene concentration	mg/m ³	< 0.0031
Benzo(a)anthracene concentration	mg/m ³	< 0.0031
Chrysene concentration	mg/m ³	< 0.0031
Benzo(b,j,k)fluoranthene concentration	mg/m ³	< 0.0062
Benzo(a)pyrene concentration	mg/m ³	< 0.0031
Indeno(1,2,3-c,d)pyrene concentration	mg/m ³	< 0.0031
Dibenzo(a,h)anthracene concentration	mg/m ³	< 0.0031
Benzo(g,h,i)perylene concentration	mg/m ³	< 0.0031

Table 14: Sample information – VOC's (Truck spotting & Level Hand)

Client:	ARRB	ARRB
Site:	Pimpama	Pimpama
Sample ID	I1534-2-1	I1534-2-2
Sample Type	Personal sample	Personal sample
Area of Work / SEG	Truck Spotting	Level Hand
Worker	Susie Brazda	Ben O'Reilly
Analytes	VOC's	VOC's
Date	dd:mm:yy	Friday, 29 June 2018
Time	hh:mm	9:24:00 AM
Time	hh:mm	1:31:00 PM
Volume	mins	181
Baro	hPa	1020
Wind Speed	m/sec	1-5m/sec
Sample volume	L	89.7
	m ³	0.0897
	ref temp.	25
	m ³ at 25°C	0.091
		0.085
VOC:		
Benzene Concentration	mg/m ³	< 0.055
Toluene concentration	mg/m ³	< 0.055
Ethylbenzene concentration	mg/m ³	< 0.055
m6p Xylene concentration	mg/m ³	< 0.11
o Xylene concentration	mg/m ³	< 0.055
total Xylene concentration	mg/m ³	< 0.16
Styrene concentration	mg/m ³	< 0.055
a-methylstyrene concentration	mg/m ³	< 0.055
Isopropylbenzene (Cumene) concentration	mg/m ³	< 0.055
Naphthalene concentration	mg/m ³	< 0.055
Cyclohexanone concentration	mg/m ³	< 0.055
Diisobutylketone (DIBK) concentration	mg/m ³	< 0.055
Methyl Ethyl Ketone (MEK) concentration	mg/m ³	< 0.11
4-Methyl-2-Pentanone (MIBK) concentration	mg/m ³	< 0.055
Hexane concentration	mg/m ³	< 0.055
Nonane concentration	mg/m ³	< 0.055
Decane concentration	mg/m ³	0.077
Dodecane concentration	mg/m ³	0.098
Acrylonitrile concentration	mg/m ³	< 0.055
Ethyl Acetate concentration	mg/m ³	< 0.055
1,2-Dichloroethane concentration	mg/m ³	< 0.055
Carbon Tetrachloride concentration	mg/m ³	< 0.055
Cyclohexane concentration	mg/m ³	< 0.055
Ethyl Acrylate concentration	mg/m ³	< 0.055
ZincTrichloroethene (TCE)	mg/m ³	< 0.055
1,4-Dioxane concentration	mg/m ³	< 0.055
Epichlorohydrin concentration	mg/m ³	< 0.055
n-Butyl Acetate concentration	mg/m ³	< 0.11
Tetrachloroethene (PCE) concentration	mg/m ³	< 0.055
Chlorobenzene concentration	mg/m ³	< 0.055
Benzyl Chloride concentration	mg/m ³	< 0.055
Acetone concentration	mg/m ³	< 0.22
		< 0.24

Table 15: Sample information – VOC's (Shuttle buggy & Paver)

Client:	ARRB	ARRB
Site:	Pimpama	Pimpama
Sample ID	I1534-2-3	I1534-2-4
Sample Type	Personal sample	Personal sample
Area of Work / SEG	Shuttle Buggy Operation	Paver Operation
Worker	Jamie Williams	Brian Trost
Analytes	VOC's	VOC's
Date	dd:mm:yy	Friday, 29 June 2018
Time	hh:mm	9:21:00 AM
Time	hh:mm	1:33:00 PM
Volume	mins	179
Baro	hPa	1020
Wind Speed	m/sec	1-5m/sec
Sample volume	L	91.5
	m ³	0.0915
	ref temp.	25
	m ³ at 25°C	0.093
		0.088
VOC:		
Benzene Concentration	mg/m ³	< 0.054
Toluene concentration	mg/m ³	< 0.054
Ethylbenzene concentration	mg/m ³	< 0.054
m6p Xylene concentration	mg/m ³	< 0.11
o Xylene concentration	mg/m ³	< 0.054
total Xylene concentration	mg/m ³	< 0.16
Styrene concentration	mg/m ³	< 0.054
a-methylstyrene concentration	mg/m ³	< 0.054
Isopropylbenzene (Cumene) concentration	mg/m ³	< 0.054
Naphthalene concentration	mg/m ³	< 0.054
Cyclohexanone concentration	mg/m ³	< 0.054
Diisobutylketone (DIBK) concentration	mg/m ³	< 0.054
Methyl Ethyl Ketone (MEK) concentration	mg/m ³	< 0.11
4-Methyl-2-Pentanone (MIBK) concentration	mg/m ³	< 0.054
Hexane concentration	mg/m ³	< 0.054
Nonane concentration	mg/m ³	< 0.054
Decane concentration	mg/m ³	< 0.054
Dodecane concentration	mg/m ³	< 0.054
Acrylonitrile concentration	mg/m ³	< 0.054
Ethyl Acetate concentration	mg/m ³	< 0.054
1,2-Dichloroethane concentration	mg/m ³	< 0.054
Carbon Tetrachloride concentration	mg/m ³	< 0.054
Cyclohexane concentration	mg/m ³	< 0.054
Ethyl Acrylate concentration	mg/m ³	< 0.054
Zinc Trichloroethene (TCE)	mg/m ³	< 0.054
1,4-Dioxane concentration	mg/m ³	< 0.054
Epichlorohydrin concentration	mg/m ³	< 0.054
n-Butyl Acetate concentration	mg/m ³	< 0.11
Tetrachloroethene (PCE) concentration	mg/m ³	< 0.054
Chlorobenzene concentration	mg/m ³	< 0.054
Benzyl Chloride concentration	mg/m ³	< 0.054
Acetone concentration	mg/m ³	< 0.21
		< 0.23

6 OBSERVATIONS & COMMENTS

In summary, a comparison of the results of measurements conducted on the 29th of June at the Pimpama site with the national exposure standards has identified that all measurements were below the applicable standards. Following is a brief overview of the results of monitoring observed across each of the work roles:

Truck spotting

- Sample collected showed, inhalable dust returned results below TWA exposure limit.
- All measured PAH's were below limit of detection.
- Sample collected detected, decane and dodecane in the work area, though below recommended exposure limits. All remaining measured VOC's were below limit of detection.

Level hand

- Sample collected showed, inhalable dust returned the highest inhalable dust result of 1.1 mg/m³, though below TWA exposure limits.
- All measured PAH's were below limit of detection.
- All measured VOC's were below limit of detection.

Shuttle buggy operator

- Sample collected showed, inhalable dust returned results below TWA exposure limits.
- All measured PAH's were below limit of detection.
- All measured VOC's were below limit of detection.

Paver operator

- Sample collected showed, inhalable dust returned results below TWA exposure limits.
- All measured PAH's were below limit of detection.
- All measured VOC's were below limit of detection.

7 REFERENCES

1. Worksafe Australia, Guidance on the Interpretation of Workplace Exposure Standards for Airborne Contaminants (2013)
2. Australian Standard 2985
3. Worksafe Australia, Workplace Exposure Standards for Airborne Contaminants (2013)
4. National Institute for Occupational Safety and Health, NIOSH Pocket Guide to Chemical Hazards (2007)

8 LIMITATIONS OF INSPECTION

Any measurement results and interpretations presented in this report are limited by the methods of sample collection and analysis, relevant published literature, preliminary observations, and the discussions and information provided by the client during the project consultancy. The findings presented in this report are therefore only representative of the knowledge, conditions and circumstances, which were present at that time of the sampling. Consequently, the results of this assessment should be at best an estimate of potential exposure risks (and not absolutes) and not necessarily representative of all operating conditions, or at other periods of time in the facilities operation.

This inspection cannot be regarded as absolute. Future inspections and/or demolition of structures may reveal additional situations that were not discovered or identified during this inspection. The survey did not include access-ways and/or items of essential plant (such as air-conditioning units). That is, separate items of machinery, portable equipment, and furnishings were not inspected.

The extent of the sampling was restricted to areas which were accessible at the time of inspection:

- Without contravention of relevant Acts, Legislation or Code of Practice;
- Without demolition and/or damage to furnishings or structures; and
- Subject to the guidance and information provided by site staff.

The results of the sampling provided by Assured Environmental is for the use of the Client to manage potential exposure risks at the site and must not be relied upon in any way whatsoever other than what was intended. Assured Environmental Pty Ltd will be responsible for the quality and accuracy of the information provided in this report, but will not be liable for the outcomes, consequences or any loss resulting from decisions and/or actions taken by the client or any other party, as a result of the advice and information provided in this report.

Assured Environmental will not accept liability for any loss or outcome which exceeds the level of insurance and/or any limitations assigned to the insurance policies held by Assured Environmental at the time of writing this report, for which the client should maintain its own insurance.

Appendix C Modulus and Fatigue Results

Flexural modulus results:

			Dynamic modulus (MPa)			
Mix	Temperature (°C)	Frequency (Hz)	Beam-1	Beam-2	Beam-3	Beam-4
Queensland	5	0.1	4,366	4,184	4,370	4,672
	5	0.5	5,388	5,599	5,727	5,690
	5	1	6,467	6,597	6,875	6,657
	5	3	7,325	7,464	7,470	7,293
	5	5	7,638	7,823	7,919	7,742
	5	10	8,331	8,565	8,709	8,496
	5	15	8,633	9,100	9,181	8,783
	5	20	8,809	9,237	9,355	9,292
	5	30	8,790	8,874	9,007	8,865
	15	0.1	2,088	2,158	2,231	2,195
	15	0.5	2,877	2,777	3,012	2,755
	15	1	3,341	3,406	2,999	3,454
	15	3	4,347	4,393	4,328	4,209
	15	5	4,638	4,594	4,692	4,553
	15	10	5,134	5,205	5,285	5,195
	15	15	5,590	5,683	5,527	5,550
	15	20	5,599	5,887	5,811	5,862
	15	30	5,904	5,967	5,689	5,403
	25	0.1	946	1,040	997	925
	25	0.5	1,416	1,358	1,364	1,351
	25	1	1,747	1,536	1,735	1,796
	25	3	1,955	1,897	1,940	1,906
	25	5	2,351	2,378	2,289	2,192
	25	10	2,560	2,691	2,682	2,575
	25	15	2,675	2,876	2,805	2,667
	25	20	2,964	2,961	3,186	2,902
	25	30	3,810	4,146	3,410	3,452
	30	0.1	735	657	693	749
	30	0.5	954	925	998	842
	30	1	1,085	1,109	1,084	1,094
	30	3	1,368	1,340	1,518	1,190
	30	5	1,464	1,415	1,423	1,442
	30	10	1,812	1,803	1,691	1,780
	30	15	1,961	1,948	1,885	1,860
	30	20	2,140	2,133	2,077	2,077
	30	30	3,270	3,136	2,950	2,492

			Dynamic modulus (MPa)			
Western Australia	5	0.1	4,786	4,930	4,243	4,896
	5	0.5	6,039	6,198	5,723	6,216
	5	1	6,303	6,324	5,851	6,778
	5	3	7,374	7,441	6,624	7,518
	5	5	7,778	7,853	7,037	7,924
	5	10	8,275	8,363	7,480	8,422
	5	15	8,438	8,432	7,683	8,527
	5	20	8,549	8,555	7,823	8,704
	10	0.1	3,486	3,655	3,052	3,622
	10	0.5	4,653	4,738	4,169	4,617
	10	1	5,438	4,955	4,635	5,236
	10	3	6,107	6,090	5,576	6,083
	10	5	6,367	6,347	5,910	6,406
	10	10	6,896	6,842	6,369	6,929
	10	15	7,117	6,949	6,680	7,157
	10	20	7,319	7,339	6,808	7,376
	15	0.1	2,184	2,132	1,888	2,253
	15	0.5	3,101	3,102	2,840	3,290
	15	1	3,631	3,716	3,330	3,786
	15	3	4,396	4,445	4,014	4,621
	15	5	4,793	4,927	4,452	5,049
	15	10	5,392	5,512	5,081	5,667
	15	15	5,571	5,668	5,257	5,820
	15	20	5,546	5,745	5,298	5,933
	20	0.1	1,551	1,681	1,492	1,544
	20	0.5	2,291	2,252	2,106	2,414
	20	1	2,678	2,580	2,527	2,842
	20	3	3,401	3,447	3,194	3,690
	20	5	3,735	3,811	3,513	4,052
	20	10	4,066	4,136	3,806	4,388
	20	15	4,261	4,324	3,952	4,600
	20	20	4,406	4,547	4,047	4,762
	25	0.1	1,134	1,138	992	1,151
	25	0.5	1,565	1,559	1,516	1,539
	25	1	1,716	1,824	1,629	1,989
	25	3	2,457	2,554	2,124	2,637
	25	5	2,839	2,906	2,611	2,964
	25	10	3,196	3,307	2,930	3,318
	25	15	3,296	3,491	3,036	3,596
	25	20	3,482	3,629	3,037	3,593
	30	0.1	762	789	652	728
	30	0.5	1,006	1,044	939	1,183
	30	1	1,183	1,204	1,069	1,236
	30	3	1,525	1,604	1,448	1,572
	30	5	1,953	1,937	1,840	2,079
	30	10	2,249	2,289	2,154	2,362
	30	15	2,375	2,286	2,203	2,539

			Dynamic modulus (MPa)			
	30	20	2,263	2,539	2,426	2,598

Flexural fatigue results:

Mix	Specimen	Temperature (°C)	Strain (microstrain)	Cycles until failure
Queensland	5862-32	10	225	1,454,026
	5862-36	10	225	6,683,440
	5850-29	10	310	135,278
	5850-25	10	310	142,230
	5850-30	10	310	71,578
	5835-13	10	390	70,070
	5850-24	10	390	21,549
	5850-28	10	390	39,610
	5835-16	20	240	1,175,053
	5835-18	20	240	1,853,901
	5835-19	20	240	656,158
	5824-4	20	350	142,188
	5824-6	20	350	100,351
	5824-9	20	350	95,502
	5824-7	20	420	69,895
	5824-8	20	420	31,158
	5824-10	20	420	56,981
	5862-37	30	365	513,238
	5862-38	30	320	1,287,625
	5862-39	30	320	1,714,912
	5835-12	30	350	337,330
	5835-14	30	470	279,417
	5850-23	30	470	139,120
	5835-15	30	570	74,060
	5850-21	30	570	51,258
	5862-35	30	570	256,089
Western Australia	6603-4	10	150	8,655,960
	6610-2	10	175	1,232,100
	6611-1	10	175	1,629,080
	6598-1	10	210	2,923,399
	6597-3	10	220	156,540
	6603-3	10	220	211,510
	6597-2	10	250	53,650
	6593-1	10	350	23,160
	6593-3	10	350	10,443
	6593-4	10	350	14,900
	6597-1	20	140	4,074,659
	6603-1	20	160	1,422,680
	6604-3	20	160	3,111,206
	6597-4	20	210	352,842
	6595-4	20	290	47,708
	6595-3	20	330	32,842

Mix	Specimen	Temperature (°C)	Strain (microstrain)	Cycles until failure
	6585-1	20	420	12,928
	6595-1	20	420	17,831
	6595-2	20	420	14,307
	6611-4	30	200	430,500
	6611-3	30	270	55,210
	6610-4	30	285	120,064
	6610-3	30	310	531,535
	6610-1	30	325	238,046
	6004-1	30	350	599,554
	6604-2	30	370	254,024
	6604-4	30	370	437,432
	6593-2	30	470	18,660
	6598-2	30	470	17,810
	6603-2	30	470	58,061