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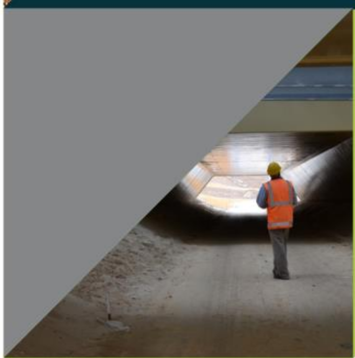
Investigation of the use of reclaimed asphalt pavement from crumb rubber modified asphalt – Stage 1 Interim Report



Zia Rice, Young Choi and Lincoln Latter

AN INITIATIVE BY:

THE GOVERNMENT OF WESTERN AUSTRALIA

mainroads WESTERN AUSTRALIA

arrb

Australian Road Research Board
ABN 68 004 620 651

Victoria
80A Turner Street
Port Melbourne VIC 3207
Australia
P: +61 3 9881 1555
F: +61 3 9887 8104
info@arrb.com.au

Western Australia
191 Carr Place
Leederville WA 6007
Australia
P: +61 8 9227 3000
F: +61 8 9227 3030
arrb.wa@arrb.com.au

New South Wales
2-14 Mountain Street
Ultimo NSW 2007
Australia
P: +61 2 9282 4444
F: +61 2 9280 4430
arrb.nsw@arrb.com.au

Queensland
21 McLachlan St
Fortitude Valley QLD 4006
Australia
P: +61 7 3260 3500
F: +61 7 3862 4699
arrb.qld@arrb.com.au

South Australia
Suite 713, 147 Pirie Street
Adelaide SA 5000
Australia
P: +61 8 8235 3300
F: +61 8 8223 7406
arrb.sa@arrb.com.au

Investigation of the use of RAP from CRM Asphalt – Stage 1 Interim Report

for Main Roads Western Australia

Reviewed

Project Leader	Zia Rice	
Quality Manager	Michael Moffatt	

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SUMMARY

As the demand and cost of virgin aggregates and bituminous materials continues to increase and the development of new specifications requiring the use of recycled materials, reclaimed asphalt pavements (RAP) have become standard practice both in Australia and internationally. Subsequently RAP has become one of the most re-used construction waste materials.

The use of crumb rubber modified (CRM) asphalts has also recently increased, especially domestically; AAPA have recently released specifications for producing CRM open-grade and surface courses and local network trials are being conducted in both Queensland and Western Australia. Similarly to RAP, CRM asphalt presents a broad range of economic and environmental benefits as the technology involves the re-use of end-of-life tyres.

This increased use of CRM asphalt in conjunction with the popularity of RAP presents a future need to understand how, and ultimately if, CRM asphalt can be recycled to produce CRM-RAP, and to identify any barriers which may prevent this technology from being effective.

The aim of this literature review was to identify barriers to the reclamation of pavements containing CRM-binders and the subsequent production and utilisation within new asphalt mixes reported elsewhere. The extraction and characterisation of CRM-binders from CRM-RAP was also investigated to understand if target viscosity binder blending could also be used as a method for the design of new CRM-RAP containing mixes.

Of the limited international documented studies reviewed, no major issues were identified. Reclamation, processing, production and subsequent paving were all documented as being undertaken in the same manner as conventional RAP. However, two studies did note that achieving field compaction was a little more difficult than with conventional RAP mixes possibly due to the residual rubber.

The review also revealed that there is currently no published method to successfully extract CRM-RAP binder material, making subsequent characterisation difficult. Two alternative methods of extraction have been proposed which will need further investigation in Stage 2. This investigation may enable the development of a specific binder extraction method if optimised mix design of CRM-RAP mixes is to be undertaken through binder blending to reach a target viscosity.

The next phase of Stage 1 is the undertaking of a practicality study which will aim to mimic the steps and processes used for the reclamation, processing and subsequent hot plant recycling of CRM-RAP material. This practicality study will provide insight into the ability of CRM-RAP to be used in conjunction with local equipment and practices.

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1 INTRODUCTION

The use of reclaimed asphalt pavement (RAP) has become standard practice both in Australia and internationally as the demand and cost of virgin aggregates and bituminous materials increases. In addition to the economic benefits, the environmental benefits of utilising RAP are broad; ultimately, it optimises the use of natural resources and provides a valuable product to the pavement industry. RAP is now one of the most re-used construction waste materials. Typically RAP materials are derived from asphalts containing conventional (i.e. unmodified) binders.

Similarly to RAP, the implementation of crumb rubber modified (CRM) asphalt also offers a broad range of economic and environmental benefits through the re-use of end-of-life tyres to produce various high-performing bituminous products for both sprayed seal and hotmix asphalt applications. The use of CRM asphalts has recently increased, especially domestically, with the recent publication of AAPA specifications for producing CRM open grade and surface course mixes and local network trials in both Queensland and Western Australia. There is a need to understand how, and ultimately if, CRM asphalt can be recycled to produce CRM-RAP, and to identify any barriers which may prevent this technology from being effective.

Main Roads Western Australia (MRWA), through the Western Australian Road Research and Innovation Program (WARRIP), sponsored a research project, undertaken by ARRB, to examine these issues. The objective of the first stage of the project is to demonstrate and quantify the effects of using CRM-RAP in producing asphalt in order to build confidence within the local asphalt industry, and ultimately to enable and encourage the use of a highly sustainable product. This is being investigated first through a review of international literature, followed by a local practicality study.

This interim report presents the outcomes of a literature review of international best practice related to the use of CRM-RAP.

2 LITERATURE REVIEW

2.1 Crumb Rubber Modification

The following sections investigate the two most common methods used in Australia to modify bituminous binders with crumb rubber (CR): the dry process, and the high viscosity wet process. For the remainder of the report the terms “R-HMA” will refer to modification through the dry process, and “CRM binder” will refer to modification through the high-viscosity wet process. As this project focuses on the influence of wet process CRM binder in OGA, the wet process has been explained in more detail than the dry process.

A summary of the two different methods, which are described in detail in Sections 2.1.1 and 2.1.2 is presented in Table 2.1.

Table 2.1: Summary of common Australian bituminous modification processes using CR

Process	Rubber incorporation method	Product	Uses
Dry process	Rubber crumbs as part of the aggregate	Rubber modified hotmix asphalt (R-HMA)	HMA
Wet process	Rubber crumbs blended into binder	Crumb rubber-modified binder (CRM binder)	HMA Sprayed seals

2.1.1 Dry Process Binder Modification

The dry process of crumb rubber modification is undertaken by replacing a portion (1 to 3% by mass) of the fine virgin aggregate with CR (Ghabchi, Zaman & Arshadi 2016). The virgin aggregate and the CR are mixed together in a pugmill at which point the rubber becomes part of the aggregate (Heitzman 1992; Austroads Pavements Research Group (APRG) 1999). The binder is then added and the rubber partially dissolves, after which the rubber becomes part of the binder (APRG 1999).

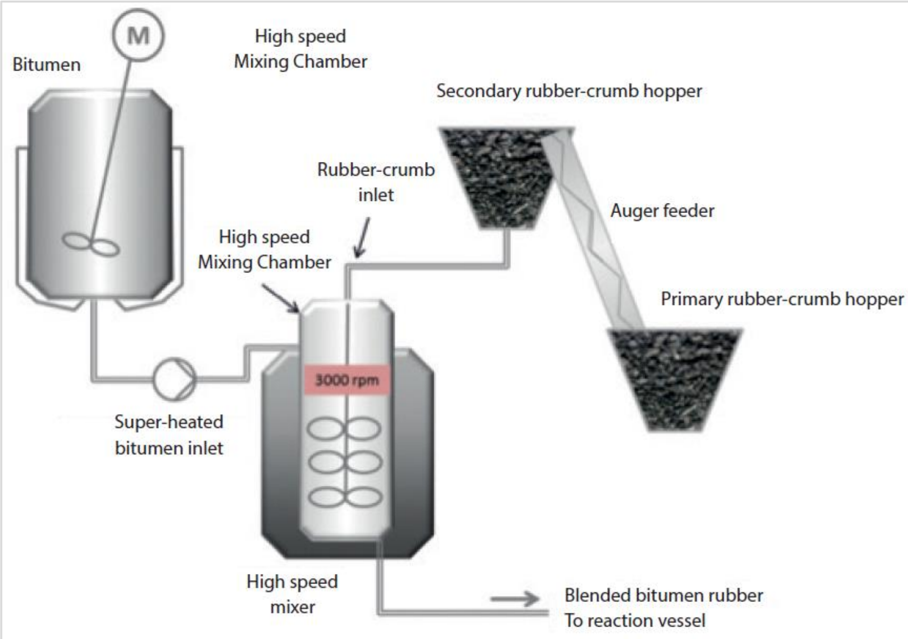
This process uses larger CR sizes typically between 0.85 and 6.4 mm (Ghabchi et al. 2016). The final product of the dry process is termed rubberised asphalt or R-HMA (Ghabchi et al. 2016; Heitzman 1992).

The dry process of modification is straightforward and can be undertaken at a standard asphalt plant (APRG 1999). However, only partial blending of the CR into the binder is achieved during the dry process mixing, which may result in limited performance improvement from the CR modification (Denneman et al. 2015). The properties of the binder blend are also not well-controlled during production using the dry process (Denneman et al. 2015). The dry process is not used for hot sprayed bituminous seals (Denneman et al. 2015).

2.1.2 High Viscosity Wet Process Binder Modification

The high viscosity wet process is the most common process used in Australia for producing CRM binders for both sprayed sealing and HMA applications (Denneman et al. 2015). The final product of this process is termed asphalt rubber or CRM binder (Ghabchi et al. 2016; Heitzman 1992). This process involves blending the CR with the bituminous binder via high-shear mixing until the CR is partially digested (Heitzman 1992). The CR is digested into the bitumen at high temperatures, typically between (175 to 220 °C), for a specified length of time (Ghabchi et al. 2016; Heitzman 1992). The CRM binder is then mixed with aggregate in a mixing plant like conventional HMA (APRG 1999). A schematic of the high viscosity wet process mixing is shown in Figure 2.1.

Figure 2.1: High viscosity wet process mixing schematic



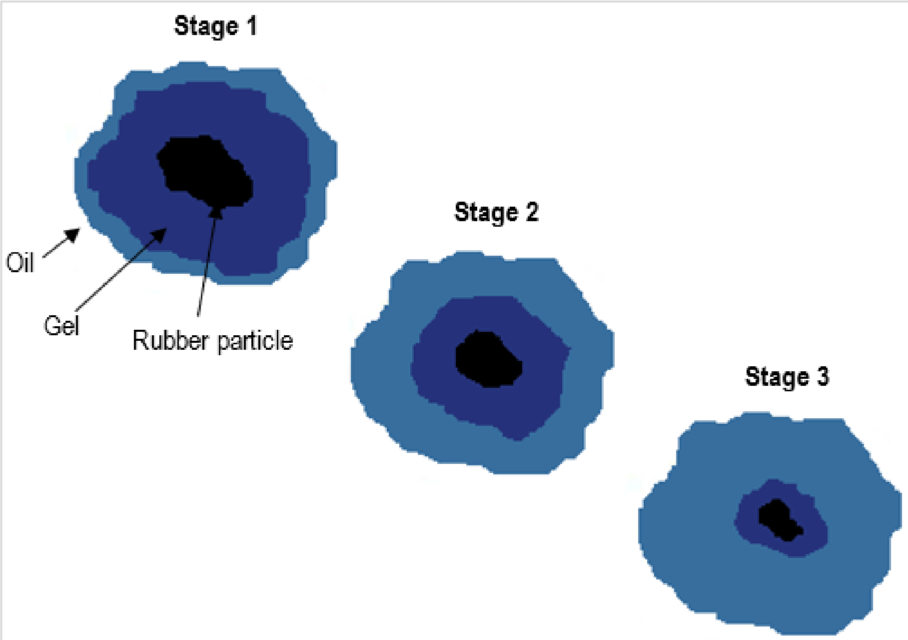
Source: Southern African Bitumen Association (2015).

Figure 2.2 depicts the various stages of digestion during the wet process, and how the proportion of gel and oil produced as a result of the rubber crumb digestion changes throughout the process. The proportion of the gel and oil when digestion is terminated ultimately determines the final properties of the CRM binder. The gel fraction increases the viscosity and softening point whilst the oil fraction improves durability and increases flexibility (Marais et al. 2017). The intended application of the CRM binder will determine the desired properties of the binder and therefore the optimum point of digestion for this to be achieved.

The speed of the CR digestion within the binder is determined primarily by the temperature and duration of the mixing process. Additional factors are the size, shape and amount of CR particles, the base binder properties, and the inclusion of other additives such as extender oils (Denneman et al. 2015).

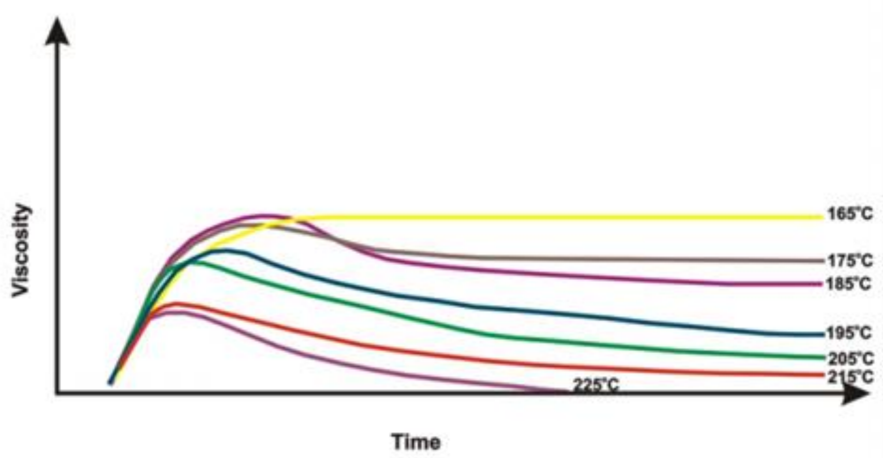
As the process progresses and the rubber crumb is further digested, the viscosity of the CRM binder also changes, and therefore the properties of the final product depend on when the process is finished (Lo Presti 2013). Figure 2.3 demonstrates the change in viscosity of a CRM binder throughout the duration of the digestion process, and at different digestion temperatures. If the rubber crumbs are completely digested, the advantages that the rubber crumbs produce when mixed with the bitumen will be reduced and eventually lost (Southern African Bitumen Association (SABITA) 2015). Therefore, tracking the digestion process through constant viscosity monitoring using a field rotational viscometer is often undertaken to optimise the final binder properties to the desired requirements (Federal Highway Administration (FHWA) 2014).

Figure 2.2: Stages of rubber crumb digestion during wet process



Source: Adapted from Marais et al. (2017).

Figure 2.3: Changes in viscosity with varying digestion temperatures and duration



Source: SABITA (2016).

Handling and storage of the final CRM binder should be at temperatures lower than 165 °C to prevent further digestion and product degradation (Wu, Herrington & Neaylon 2015). Applying continuous agitation is also required during storage and transportation to prevent the partially-digested CR separating from the binder due to differences in density (Ghabchi et al. 2016; Denneman et al. 2015). However, excessive agitation can reduce the CRM binder shelf life and also cause premature degradation (Marais et al. 2017).

Compared to the dry process, it is much easier to control the final binder properties when using the wet process (APRG 1999). Furthermore, the superior digestion and chemical interaction between the CR and the binder during the wet process creates a more homogenous modified binder compared with the dry process (Wu et al. 2015).

2.2 Conventional RAP Requirements MRWA

The current RAP management and mix design practice for MRWA is covered in Specification 510 *Asphalt Intermediate Course* (MRWA 2018) and Specification 511 *Materials for Bituminous Treatments* (MRWA 2017). Generally, these specifications cover aspects such as sourcing, processing, stockpiling, characterisation, approved applications and maximum RAP proportions permitted in MRWA-approved mixes based upon the percentage of mass by total aggregate and other volumetric properties.

This section summarises the current MRWA requirements of the use of conventional RAP. It is important to note that an ongoing separate WARRIP project aims to develop a process to enable the increased use of RAP in MRWA asphalt mixes and, as such, this may alter the outlined RAP specifications currently employed by MRWA.

2.2.1 Reclamation

RAP shall be sourced from surplus plant mix or the material reclaimed from an asphalt wearing or intermediate course by cold planing. Material obtained from cold planing shall be free from contaminants such as granular pavement material, clay, soil, organic matter, construction materials and other deleterious materials (MRWA 2017).

2.2.2 Processing

Once the RAP has been sourced through either cold planing or from surplus plant mix, it must undergo crushing and screening to produce a nominal 7 mm or 10 mm sized material incorporating fines, or a nominal 14 mm size having less than 2% of the material passing the 6.7 mm sieve. The processed RAP shall be free flowing and consistent in appearance. If the stored RAP is not free flowing it shall be screened and/or crushed again (MRWA 2017).

2.2.3 Stockpiling

Storage of RAP includes maintaining separate stockpiles prior-to and post-processing for use in the asphalt mix in lots that allow the materials to maintain traceability. There is currently no limit to the permitted size or quantity of the stockpiles. Processed RAP shall be stored in a facility covered on at least three sides that does not allow rainfall or other moisture sources to wet the processed RAP. The facility shall also have a concrete sloping floor that leads to a drain, allowing drainage of excess moisture (MRWA 2017).

2.2.4 Characterisation

The asphalt suppliers must have a RAP management plan detailing stockpiling, processing, storage and testing of RAP. This includes a minimum of three samples to be taken for every 1,000 tonnes in each lot of processed RAP, testing for particle size distribution (PSD) and bitumen content in accordance with WA 730.1 (MRWA 2011) and moisture content in accordance with WA 212.1 (MRWA 2012a) or 212.2 (MRWA 2012b). There are otherwise no unique characterisation requirements for mixes containing RAP.

2.2.5 Applications

Specification 511 states that up to 10% RAP by mass of total aggregate may be used in 14 mm or 20 mm intermediate or basecourse asphalt without any additional mix design or testing requirements for both conventional and PMB mixes. However, MRWA does not permit the inclusion of RAP in DGA wearing courses, SMA or OGA.

2.2.6 Mix Design

The approval process for asphalt mix designs including RAP is in accordance for the general process for 14 mm and 20 mm DGA as outlined in Specification 510. This specifies that C320 bitumen is used for the design of both 14 mm and 20 mm mixes using 75 blow Marshall compaction to meet a number of volumetric properties including PSD, air void content, binder content, stability, flow and binder film index (MRWA 2018).

An ongoing WARRIP project includes the development of a technical guidance document, specification and implementation strategy for increasing the use of RAP in WA. It is envisaged that this will focus on managing the binder blend viscosity of the mix, and minimum effective binder volume, by adjusting the binder grade to meet target mix viscosities or by using the Austroads binder blend method, AG:PT/T193 (Austroads 2015). This is intended to be released as MRWA Engineering Road 13B *Asphalt Mix Design with RAP* following industry consultation, field validation and MRWA approval.

2.2.7 Paving

Approved asphalt mixes containing RAP may be placed in accordance with typical practice for 14 mm and 20 mm asphalt intermediate course containing C600 or A15E bitumen.

2.2.8 Summary

Table 2.2 presents a summary of the current requirements specified by MRWA regarding RAP management practice, mix design proportioning and paving. Generally, current practice for RAP inclusion into an asphalt mix is based upon ensuring the volumetric properties conform; however, ongoing research is focused on developing guidance using laboratory characterisations.

Table 2.2: Summary of current MRWA practice

Criteria	Current requirements
Source	▪ Surplus asphalt plant mix. ▪ Material reclaimed from asphalt wearing course or intermediate course by cold planning.
Processing/fractionating	▪ Free-flowing and consistent in appearance, free from contaminants. ▪ Crushed and screened to produce 7 mm or 10 mm material with fines or 14 mm without fines and less than 2% passing 6.7 mm sieve.
Storage and stockpiling	▪ Separate stockpiles for processed/unprocessed RAP. ▪ Processed RAP shall be stored under cover. ▪ Floor of storage facility shall be concrete sloping down to a drain. ▪ Processed RAP shall be maintained in lots, ensuring traceability.
Inspection, test plans and auditing	▪ RAP management plan detailing stockpiling, processing and testing is required. ▪ Min. of 3 samples/1 000 tonnes in each lot of processed RAP. ▪ Processed RAP tested for PSD, bitumen content and moisture content.
Mix proportions	▪ Up to 10% RAP by mass of total aggregate may be used in 14 mm or 20 mm intermediate course asphalt. ▪ Not permitted in DGA wearing course, SMA or OGA.
Paving	▪ No variation from typical practice.

2.3 Recyclability of CRM to produce CRM-RAP

Documented experience relating to recycled CRM asphalt was limited. The following sections summarise the information that could be sourced.

2.3.1 California Department of Transportation Study

The State of California Department of Transportation (Caltrans) 2005 study *Feasibility of Recycling Rubber-Modified Paving Materials* (Caltrans 2005) was conducted to meet a similar objective to that of this project:

"...if RAC pavements can be reclaimed and recycled to produce new recycled AC pavements that meet or exceed current performance standards. The results of this study are intended to help eliminate the concerns regarding "recyclability" that have acted as barriers to increasing Caltrans use of RAC."

The study included a literature review in addition to the results of interviews with CRM-RAP users and contractors in North America to supplement the limited literature available.

Majority of the projects reported on included incorporation of virgin CRM binders and aggregate with conventional RAP to produce a new hotmix asphalt. Furthermore, some of the studies also pertained to dry-process CRM material and therefore are not relevant to this project. However, of the documented projects which did investigate recycling of CRM asphalt specifically (as related to this project) the following results were observed (Caltrans 2005):

- The original CRM asphalt pavements were able to be milled with conventional equipment and did not cause gumming of teeth.
- CRM-RAP was successfully used in conjunction with hot plant recycling to produce new asphalt mixes.
- The new asphalt mixes containing CRM-RAP were able to be placed and compacted using conventional equipment and practices.
- The resulting pavements containing CRM-RAP appeared to perform at least as well as pavements containing conventional RAP.
- Results of emissions testing during production of mixes containing CRM-RAP were similar to those for virgin mixes and conventional RAP mixes and rarely exceeded EPA limits.
- Hot plant recycling allowed better control with up to 15% CRM-RAP recommended.

The following sections further detail the relevant studies documented in the Caltrans study in addition to various interview outcomes. Table 2.3 summarises the relevant studies discussed.

2.3.2 Wisconsin

Documented in a report by Bischoff and Toepel (2004), the Wisconsin DOT originally placed a mix containing 65% virgin aggregate and 35% conventional RAP from a 1966 project, combined with CRM binder containing 22% CRM (by mass of the asphalt). This trial was subsequently reclaimed six years later in 1993 to study CRM-RAP.

During the milling of the CRM asphalt the operator reported the mix to be harder to mill than conventional asphalt (Bischoff & Toepel 2004). However, it was still removed with conventional equipment.

The CRM-RAP was mixed with 80% virgin aggregate and 5.5% conventional asphalt binder at a local asphalt plant (Bischoff & Toepel 2004). The resulting CRM content of the new recycled mix was calculated to be approximately 0.15% by total weight of the mix (Bischoff & Toepel 2004).

The report contained one comment on the handling of the CRM-RAP which pertained to the tip-truck boxes requiring a coating of release agent for each load during paving (Bischoff & Toepel 2004). It was also noted that the CRM-RAP responded in a similar manner to conventional RAP mixes. There were no comments on the processing or production of the new HMA mix utilising the CRM-RAP. However, it was noted that a double drum plant was utilised.

Emission testing undertaken at the plant and during paving indicated that there was no increased health and safety concerns with recycling CRM asphalt (Bischoff & Toepel 2004).

2.3.3 Los Angeles

In another study published by the City of Los Angeles (1995), both the recyclability of CRM asphalt and the air quality impact of the various stages of implementing CRM-RAP were investigated. The new asphalt mix was designed utilising the Marshall mix design criteria.

The original CRM asphalt was laid in 1982 and comprised 3% rubber (by mass of dry aggregate) incorporated using the wet process of CRM modification (City of Los Angeles 1995). Once milled, the CRM-RAP was utilised in a new mix comprising 15% CRM-RAP, 85% virgin aggregate and extender oil in addition to 6.6% binder (% total mass of millings and aggregate).

The only comments made about this CRM-RAP process was that there was no significant barriers to its use and the CRM-RAP was no more difficult to remove than conventional RAP. The new asphalt mix which incorporated the CRM-RAP met all gradation and Marshall specification limits. The asphalt plant utilised for this project was the City of Los Angeles Asphalt Plant II located on Olympic Boulevard which is a batch plant (CH2M Consultants 2016)

Dust sampling during the milling and emissions testing undertaken at the plant and during paving indicated that there was no increased health and safety concerns when working with CRM-RAP (City of Los Angeles 1995).

2.3.4 Mississippi

The Mississippi Department of Transportation (MDOT) conducted a similar study which involved the reclaiming of the surface course of three separate test sections which were each constructed using a wet process CRM binder with 8, 10 and 12% CRM by weight of binder (Albrtitton, Barstis & Gatlin 1999). The sections were milled separately and utilised in a three new surface course mixes comprising 15% CRM-RAP with 6.5% total binder content produced using a counter flow drum plant.

It was noted that no gumming of teeth was observed during milling operations, and paving of the new surface courses containing the CRM-RAP went smoothly. A modification to the paver hopper included rotary blades to prevent segregation of the mix. The compaction roller pattern included four vibratory passes and one static pass. Laboratory testing demonstrated difficulty in achieving design air voids at the design binder content for the surface course mix containing CRM-RAP (Albrtitton et al. 1999).

Emission testing undertaken at the plant indicated that there was no increased health and safety concerns with recycling CRM asphalt (Albrtitton et al. 1999).

2.3.5 Arizona Questionnaire

Arizona DOT’s experience with CRM-RAP was documented through a questionnaire (Caltrans 2005) and included hot-in-place recycling of CRM open-grade mix containing 9.0 to 9.5% CRM binder.

The milling of the CRM surface course produced minimal smoke and the material was noted as being very workable. The contractor had been concerned about gumming of the scarifiers and other equipment, but no problems were encountered.

2.3.6 General Industry Questionnaire

Limited industry experience with CRM-RAP was also documented through a questionnaire (Caltrans 2005) which reported no problems with crushing, screening or blending of the CRM-RAP, or with paving the new asphalt mix containing CRM-RAP. Issues with achieving compaction were noted.

2.3.7 Texas Transportation Institute

The Texas Transportation Institute (TTI) study *Recycling Crumb Rubber Modified Asphalt Pavements* (Crockford et al. 1995) was also conducted to meet a similar objective to that of this project:

The study made the following conclusions:

- CRM material is recyclable and the recycled material (CRM RAP), if properly designed and constructed, should have acceptable long-term performance.
- Mix design procedures must take the rubber into account, both in the design of the blended aggregate gradation and in the design of the blended binder.

The study also developed a draft guideline for the design of bituminous mixtures containing CRM-RAP. Unlike the method developed for MRWA Engineering Road 13B, which focuses on managing the binder blend viscosity of the mix to meet target mix viscosities, the TTI method focuses on managing the binder blend penetration of the mix. It also provides guidance on optimizing the amount of rejuvenating agent required for the new mix containing CRM-RAP. This optimisation is undertaken by preparing four mixes, each with varying amounts of virgin asphalt and rejuvenating agent for the same CRM-RAP amount. Penetration of each of these mixes is subsequently measured and plotted to enable the selection of the exact proportion of virgin asphalt and rejuvenating agent in conjunction with the chosen percentage of CRM-RAP, in order to produce a mix which meets the desired penetration (Crockford et al. 1995). This method does not require characterisation of the CRM-RAP binder, only characterisation of the subsequently produced new asphalt mix containing CRM-RAP.

It was noted that an accurate measure of asphalt and rubber content and properties is not possible due to the interaction of the solvent and the rubber particles. It was also noted that, in cases when it is necessary to separate the rubber from the binder, the floatation method is suggested using either sodium bromide or citrus terpene (Crockford et al. 1995). The rubber can then be re-blended with the extracted binder and subsequently characterised; however, the characteristics of the re-blended mix may not be representative of the CRM-RAP.

Table 2.3: Summary of studies investigating CRM RAP

Location and date	Plant Type	Reclaimed CRM asphalt details	New asphalt mix details	Comments
Wisconsin, 1993	Double drum	– Dense-graded mix – 6.5% total binder ▪ 4.3% added CRM wet process binder (18% CRM) ▪ 2.2% residual binder from RAP – 65% virgin aggregate – 35% conventional DGA RAP	– Dense-graded mix – 5.5% total binder ▪ 4.4% added 120/150 binder ▪ 2.2% residual binder from CRM-RAP – 80% virgin aggregate – 20% CRM-RAP	– Truck boxes required a coating of release agent for each load during paving – The CRM-RAP responded in a similar manner to conventional RAP mixes – Emission testing indicated no increased health and safety concerns
Los Angles, 1995	Batch	– Wet process binder (3% rubber by weight of dry aggregate)	– 6.6% total binder – 85% virgin aggregate – 15% CRM-RAP	– CRM-RAP was no more difficult to remove than conventional RAP – New asphalt mix which incorporated the CRM-RAP met all gradation and Marshall specification limits – Emission testing indicated no increased health and safety concerns
Mississippi, 1999	Counter flow drum	– Wet process binder (8 to 12% CRM) – Surface course ▪ 5.5% binder content	– Surface course – 6.5% total binder – 15% CRM-RAP	– No gumming of teeth was observed – Modification to the paver hopper include rotary blades to prevent segregation of the mix – The roller pattern included four vibratory passes and one static pass – Difficulty in achieving design air voids at the design binder content for the surface course mix containing CRM-RAP
Arizona, 2004	N/A, Hot in-place recycling	– Wet process binder (20% CRM) – Open-graded mix ▪ 9% binder content	N/A	– Milling produced minimal smoke and the material was very workable – No gumming of scarifiers or other equipment was observed
Industry comments	N/A	N/A	N/A	– No problems with crushing, screening or blending the CRM-RAP – No problems with paving the new asphalt mix containing CRM-RAP – Issues with achieving compaction was noted

2.4 Laboratory Characterisation of CRM-RAP

2.4.1 Extraction of Binders from CRM RAP Mixes

Conventional procedures for extracting binders from RAP mixes, including the AGPT/T191 method commonly used in Australia, have the same principle in that solid particles (i.e. coarse/fine aggregates and fillers) are removed from the RAP materials in order to obtain samples of residual binders. Viscosity testing can then be undertaken on the extracted residual binder to enable an optimised asphalt mix design which includes the RAP material.

When these conventional procedures are used in conjunction with CRM RAP mixes, the undissolved rubber particles present in the CRM binder are also removed with other aggregate particles. Due to the removal of rubber particles, the residual CRM-RAP binder is not a representative sample and the properties of the CRM binder as present in the RAP mix cannot be fully characterised or quantified.

A large number of publications were reviewed to investigate the extraction of binders from CRM-RAP mixes. Several studies documented different methods of CRM binder extraction; however, these studies focussed on extraction of rubber from CRM binders rather than extraction of CRM binders from RAP. A brief summary of notable studies follows:

- Shen et al. (2006) investigated the effect of using recycled CRM mixes in hotmix asphalt. They included a study on RAP binder properties but they purposely filtered out rubber particles so that only the binder portions were obtained for testing.
- Ghavibazoo and Abdelrahman (2014) investigated the effect of crumb rubber modification on the short-term ageing susceptibility of asphalt binder. They separated out the rubber particles from the CRM binders so that the effects of short-term ageing on the properties of rubber particles and binders could be investigated separately.
- Putman and Amirkhanian (2006) investigated the effect of crumb rubber as a filler in binder. They divided the effect of rubber-modifications into the interaction effect (IE) and particle effect (PE). The IE is the effect of the rubber absorbing the aromatic oils from the binder whereas the PE is the effect of the rubber a filler in the binder. These two different effects were investigated by filtering out the rubber particles from a number of CRM binders. The properties of CRM binders were then compared with those of the ‘rubber-less’ binders to determine the relative influence of the IE and PE on binder properties.

The literature review therefore confirmed that binder extraction methods that could retain rubber particles in the CRM binders do not exist at present.

2.4.2 Discussion on CRM Binder Extraction Methods

As there are no established or documented methods to extract CRM binders from CRM RAP mixes, a method would need to be developed to allow optimised mix design of hotmix asphalt containing CRM RAP material. The following discussion provides two options for the possible development of an extraction and characterisation procedure including expected barriers to development. The information discussed in this section has not been validated and thus should be only be used as ‘food for thought’ for future investigation.

2.4.3 Option 1: Re-blending of Recovered Rubber and Recovered Binder

The AGPT/T191-15 method is a RAP binder extraction method typically used in Australia. A brief summary of the test procedure is described below:

1. An appropriate amount of RAP material is placed into a container filled with a solvent (toluene), so that the binder portion of the RAP material is dissolved into the toluene.

2. The binder solution is decanted into a clean sample container passing it through a funnel that is fitted with a 75 μm mesh.
3. An appropriate amount of binder solution is transferred to centrifuge tubes and subjected to a centrifuging process so that any remaining fine particles which may have passed the 75 μm mesh can be collected at the bottom of the centrifuge tubes.
4. The binder solution in the centrifuge tubes is collected and heated to 100 °C for about 45 minutes in a rolling thin film oven (RTFO). This process evaporates the toluene from the binder solution.
5. Residual binder from the RTFO bottles is collected and used for subsequent characterisation testing.

The barrier to extracting binders from CRM RAP is associated with Step 2 where most rubber particles in the binder are filtered out by the 75 μm mesh as with other coarse/fine aggregates. Currently the residual aggregate material is discarded unless required for other purposes.

A possible way to overcome this barrier would be to separate the rubber particles from the residual aggregate (after decanting the binder solution at Step 2), and subsequently re-mixing the rubber particles with the final residual binder (in Step 5). This would produce a rubber-binder blend that may have similar properties to those of the binder in the CRM RAP.

The separation of the rubber particles from the residual aggregate could be undertaken through floatation. The rubber-aggregate mix would be added to a liquid with a specific gravity between that of the rubber particles (slightly higher than 1.0 g/cm^3) and aggregate materials (2.4 to 3.0 g/cm^3). As discussed previously, TTI suggested sodium bromide solution (1.25 g/cm^3) or citrus terpene solution (0.84 g/cm^3) for floatation of rubber particles (Crockford et al. 1995). Theoretically this would cause the rubber particles to float and the heavier aggregates to sink making extraction of the rubber component possible.

However, potential issues with this method of rubber particle extraction include the following:

- The final test procedure may be too onerous and labour intensive in addition to jeopardising repeatability.
- Re-blending the recovered rubber and recovered binder may prove to be a very complex procedure. It is expected that this will need to be undertaken at high temperatures. The selection of the blending temperature and duration will need to be investigated to ensure rubber and binder materials have sufficient interactions while minimising degradation of the rubber and oxidisation of the binder.

2.4.4 Option 2: Testing Recovered CRM Binders like Non-modified Binders

An alternative approach which may also be considered is to test recovered CRM binders as non-modified bitumen. The extracted residual binder (minus the rubber particles) would be characterised using the AGPT/T192-15 test method and the resulting binder viscosity used in the design of the new RAP containing mix via the procedure detailed in AGPT/T193-15. The rubber particles not included in the residual binder would subsequently be treated as a filler within the new mix containing CRM RAP.

This approach will require validation studies to determine whether the current RAP mix design procedure is directly applicable and, if not, an alternative design procedure may need to be developed.

2.4.5 Characterisation of Crumb Rubber Binders

To enable characterisation of CRM binders, test equipment and procedures need to account for the effect of the rubber particles, particularly if testing specimens are small. The following discussion highlights the necessary modifications to the test procedures when used in conjunction with CRM binders.

2.4.6 Viscosity at 165 °C

The viscosity of various Polymer Modified binders (PMBs) at 165 °C is determined using a rotational-viscosity test method (AS/NZS 2341.4 or AGPT/T111-06) in accordance with the Austroads PMB specification (AGPT/T190-14). When determining the viscosity of an S45R-grade binder (typically manufactured with about 15% of rubber) at 165 °C, it is recommended that a smaller-diameter test spindle be implemented for the testing. The smaller spindle provides a larger gap from the inner wall of the sample tube to prevent rubber particles dispersed in the binder being caught between the two metal surfaces and therefore affecting viscosity measurements.

2.4.7 Complex Viscosity at 60 °C

The complex viscosity (η^*) at 60 °C of a binder is determined using a 25 mm parallel-plate spindle and 1 mm gap setting on a dynamic shear rheometer (DSR). When characterising binders which have been extracted from RAP, the sample size available for testing is typically very limited (i.e. several grams). The DSR is an ideal device for characterising RAP binders as it typically only requires a very small sample size (less than 2 g). The AGPT/T192-15 test method has been developed for this purpose and provides a DSR-test procedure for characterising RAP binders.

Similarly to velocity testing the sample thickness of 1 mm used for complex viscosity testing may be too small for testing CRM binders due to possible contact of rubber particles with the test plates. The size of the rubber particles in CRM binders in Australia is expected be up to about 1 mm in typical cases as crumb rubbers meeting the grading requirements of Size 30 (as specified in AGPT/T190-14) are normally used for the binder-modification purposes. It is very likely that large-size rubber particles in CRM binders will make direct contact with both testing plates, leading to erroneous test results, if the gap between two testing plates is not sufficiently larger than the rubber particles in the binder.

Mezger (2014) stated that gap setting for DSR tests using a parallel-plate spindle should be at least 5 times to ideally 10 times larger than the largest dimension of the semi-solid or rigid components of the sample. According to this recommendation, the sample thickness for CRM binders may need to be as large as 10 mm which cannot be readily prepared on a DSR. Numerous Australian and international studies commonly utilised a much smaller sample thickness of 2 mm when conducting DSR tests to characterise CRM binders at intermediate to high road temperatures (e.g. 60 °C) for various purposes. These studies included Bahia and Davies (1994; 1995), Denneman et al. (2015), Lee, Amirkhanian & Kwon (2007), Ghavibazoo and Abdelrahman (2014), Ghavibazoo, Abdelrahman & Ragab (2013 and 2015), Khalili et al. (2016), Mturi et al. (2014), Putman and Amirkhanian (2006), Ragab and Abdelrahman (2015), Shen, Amirkhanian & Lee (2005) and Tayebali, Vyas & Malpass (1997). Even though a sample thickness of 2 mm may not be sufficiently large according to the sample size recommendation of Mezger (2014), these studies commonly found it appropriate for testing CRM binders. This suggests that CRM binders that were recovered from the CRM RAP mixes can be appropriately characterised using the DSR (e.g. η^* at 60 °C property) with a 2 mm gap parallel-plate setup.

The use of 25 mm parallel-plate spindle at any larger gaps than 2 mm was not reported in any of the reviewed studies, but such testing conditions (up to about 3 mm) may be trialled if CRM binders that contain relatively larger size rubber particles need to be tested. A DSR sample preparation procedure provided in the AGPT/T125 test method may be utilised to prepare DSR samples 3 mm thick on a 25 mm parallel-plate spindle, and the properties characterised like conventional DSR tests.

Another possible approach is to use a cup-and-bob setup like the study of Baumgardner and D'Angelo (2012). The cup-and-bob setup is not commonly used for asphalt-binder applications, but samples of a much large thickness (up to about 7 mm) can be readily prepared using this setup. They found that the results obtained using their cup-and-bob setup were comparable to those obtained using the parallel-plate setup with 1 mm and 2 mm gaps. It should, however, be noted that the cup-and-bob setup would require a larger amount of binder to be extracted from the RAP material, and therefore may not be an ideal method for testing RAP binders.

2.4.8 Other Characterisation Tests

For other binder properties specified (i.e. consistency 6% at 60 °C, torsional recovery at 25 °C, softening point, etc.) modification of the test procedure is not required for CRM binders as testing specimens are considered sufficiently large and do not affect the final results.

3 CONCLUSIONS AND RECOMMENDATIONS

The aim of this literature review was to identify barriers to the reclamation of pavements containing CRM-binders and the subsequent production and utilisation of new asphalt mixes containing CRM-RAP material. There was limited documented experience with CRM-RAP usage, with all of the studies conducted in the United States.

Of the studies which were documented, no major issues were identified. Reclamation, processing, production and subsequent paving were all documented as being undertaken in the same manner as conventional RAP. However, two studies did note that achieving field compaction was a little more difficult than with conventional RAP mixes, possibly due to the residual rubber. This preliminary literature assessment suggests that the conventional RAP requirements as currently stated in MRWA Specification 511 could therefore also be applied to CRM-RAP.

The review of literature pertaining to the characterisation of CRM-RAP material for use in optimised mix design through binder blending to reach a target viscosity returned minimal insight. The available methods of binder extraction will ultimately remove undissolved rubber particles, subsequently jeopardising the representative viscosities obtained from the extracted CRM-binder. Two alternative methods have been proposed which will need further investigation to enable the development of a specific binder extraction method for the characterisation of CRM-RAP. However, the exclusion of rubber particles from the viscosity testing may not jeopardise the binder blending design due to the eventual dilution of CRM-RAP in the new mix.

Depending on the outcome of a new method applicable to CRM-binder extraction, an alternative design method to ERN13B may need to be developed to allow optimised mix design of new asphalt mixes containing CRM-RAP. This alternative design method could consider target properties of the final mix, such as penetration, to remove the need to characterise the CRM-RAP binder specifically.

Another issue, not documented in the literature available, is being able to track the location of CRM asphalts along the MRWA network so when subsequent cold planing for RAP recovery is undertaken, it is clear that the material is CRM-RAP rather than conventional RAP to ensure the design is undertaken in the correct manner.

4 NEXT STEPS

4.1 Stage 1: Practicality Study

Due to the lack of documented international experience and local experience with CRM-RAP, a practicality study is currently being undertaken. This study aims to investigate the typical stages of CRM-RAP production and utilisation including reclamation, processing, and subsequent hot plant recycling to produce a CRM-RAP asphalt. The main objective will be to identify and document problems with the CRM-RAP recycling and reuse process, in addition to investigating potential rectifications to overcome these problems.

The methodology of the practicality study follows the same steps as conventional RAP reclamation and reuse and includes the following:

1. Profiling and reclamation of CRM gap-graded asphalt using conventional asphalt milling equipment to obtain CRM-RAP.
2. Processing of CRM-RAP to the appropriate size.
3. Laboratory testing to determine the PSD, binder content and moisture content of the processed CRM-RAP.
4. Plant production using a batch plant to produce a new mix containing 10% CRM-RAP (non-optimised mix).
5. Subsequent paving trial using the produced mix.

The outcomes of this local CRM-RAP practicality study will be detailed in a separate report anticipated to be published in the second half of 2019.

4.2 Stage 2

Depending on the outcome of the practicality study, Stage 2 is anticipated to further investigate the design process for the inclusion of CRM-RAP at varying percentages and the subsequent performance of these mixes.

To allow for this, an investigation into the extraction and characterisation of the CRM-binder from the CRM-RAP will first need to be undertaken to understand if representative viscosities can be obtained; if so, a new test method will need to be developed. If an appropriate method of extraction is found not to be possible, then an alternative design method may need to be developed.

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