WARRIP

WESTERN AUSTRALIAN ROAD RESEARCH AND INNOVATION PROGRAM

Investigation of the use of reclaimed asphalt pavement from crumb rubber modified asphalt – Stage 2

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January 2021

Final

AN INITIATIVE BY:

mainroads WESTERN AUSTRALIA

arrb

VERSION CONTROL

Report version no.	Date	Released to client by	Nature of revision
1	19/08/20	ZR	Draft for comment
2	29/01/2021	ZR	Final

SUMMARY

The implementation of crumb rubber modified (CRM) asphalt 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 therefore 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 was 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 was investigated first through a review of international literature, followed by a local practicality study utilising 10% CRM-RAP into a new asphalt mix via substitution.

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 presence of 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 were proposed for further investigation in Stage 2 of the project which may enable the development of a specific binder extraction method if the optimisation of mix design of CRM-RAP mixes is to be undertaken through binder blending to reach a target viscosity.

The aim of the Stage 2 investigation was understand and document issues with CRM-binder extraction and characterisation through a laboratory investigation in addition to a second practicality study using higher tonnages of CRM-RAP.

The outcome of the laboratory investigation revealed repeatability issues with extraction and characterisation of CRM-RAP binder in addition to demonstrating the unrepresentative and variable nature of CRM-RAP binder viscosity results.

The Stage 2 practicality study also demonstrated issues with processing at high volumes to the inherent stickiness of the CRM-RAP product. However, even with the processing issues, a processed CRM-RAP product was still able to be obtained, but not in an efficient manner.

ACKNOWLEDGEMENTS

This project was supported by a WARRIP industry partners Tyre Stewardship of Australia and Fulton Hogan with input from Asphalt Recyclers Australia.

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CONTENTS

TABLES

FIGURES

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-graded 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.

This report presents the outcomes of both stages of the investigation.

1.1 METHODOLOGY

This project was undertaken in stages to enable the findings from Stage 1 to inform the methodology for Stage 2. The components for each stage were as follows:

- Stage 1:
  - review of international literature to identify any documented issues associated with the reuse of CRM-RAP
  - practicality study looking at each stage of the reuse process, including reclamation, processing, plant mixing and paving utilising low tonnages of CRM-RAP (10 tonnes)
- Stage 2:
  - laboratory investigation to examine CRM-RAP binder extraction and characterisation
  - a second practicality study looking at the implications of increased tonnages of CRM-RAP (20 tonnes) during initial stages of reuse.

2 LITERATURE REVIEW

The following sections present the outcomes of a literature review undertaken in Stage 1 which studied international best practice related to the use of CRM-RAP to identify any potential issues with the reuse of CRM asphalt, and any documentation solutions to these issues.

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 asphalt produced via modification through the dry process, and 'CRM binder' will refer to binder that has been modified through the high-viscosity wet process.

A summary of the two different methods, which are described in detail in Sections 0 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

As this project focused on the influence of wet process CRM binder in open-graded asphalt (OGA), the wet process has been explained in more detail than the dry process.

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 et al. 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 digests, after which the polymers in the rubber become part of the binder structure (APRG 1999).

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

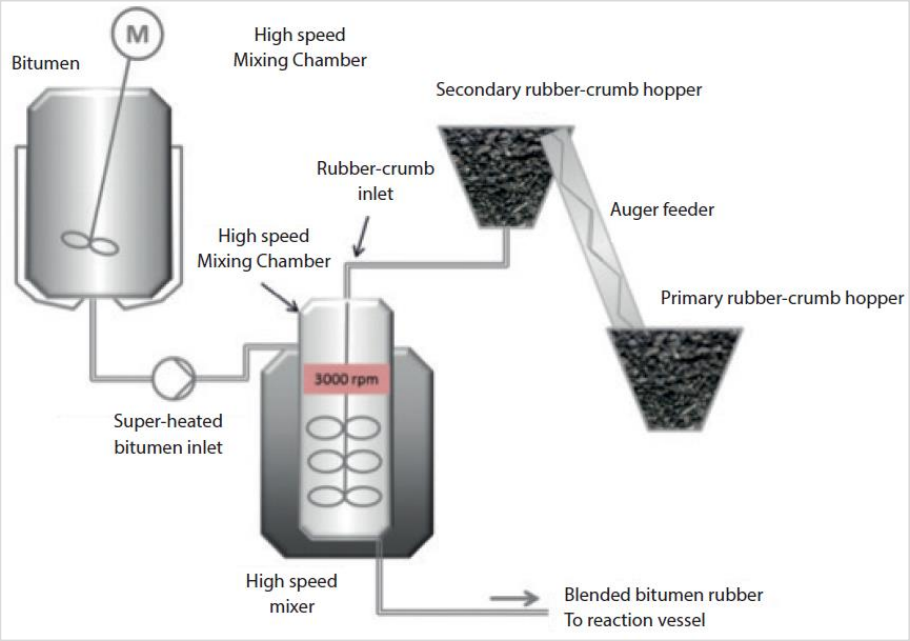
The dry process of modification is straightforward and can be undertaken at a standard asphalt plant (APRG 1999). However, only partial blending of the CR into the binder is achieved during the dry process mixing, which may result in limited performance improvement from the CR modification (Denneman 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-speed mixing until the CR is partially digested (Heitzman 1992). The CR is digested into the bitumen at high temperatures, typically between 175 to 200 °C in Australia, 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



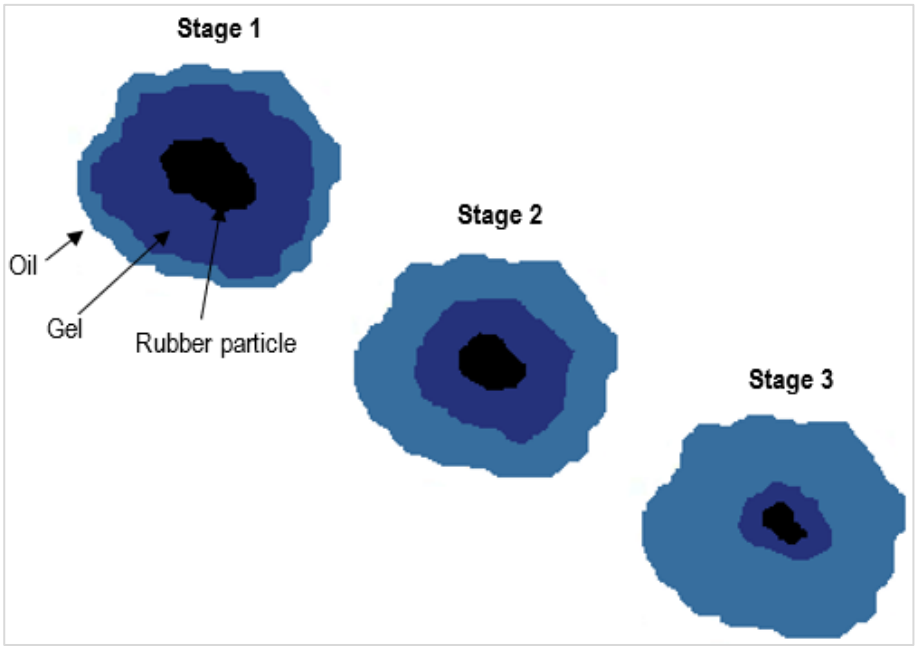
Source: Southern African Bitumen Association (2015).

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).

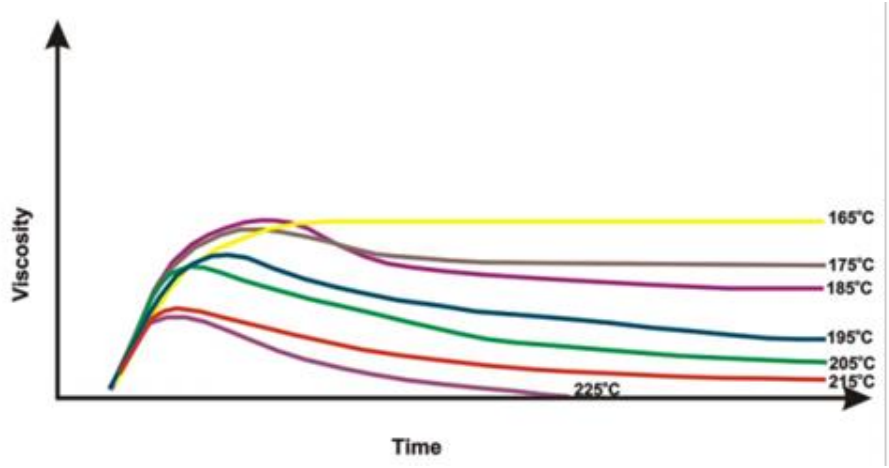
As the process progresses and the rubber crumb is further digested, the viscosity of the CRM binder also changes, and therefore the properties of the final product depend on when the process is finished (Lo Presti 2013). Figure 2.3 demonstrates the change in viscosity of a CRM binder throughout the duration 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 2020a) and Specification 511 *Materials for Bituminous Treatments* (MRWA 2020b). 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 2020b).

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 2020b).

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 2020b).

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 dense graded asphalt (DGA) wearing courses, stone mastic asphalt (SMA) or OGA.

2.2.6 MIX DESIGN

The approval process for asphalt mix designs including RAP is in accordance with 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 particle size distribution (PSD), air void content, binder content, stability, flow and binder film index (MRWA 2020a).

An ongoing WARRIP project includes the development of a technical guidance document, a specification and an 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 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 to specifications; 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 planing.
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. • Minimum 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

Available literature documenting experience relating to recycled CRM asphalt was found to be 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 [rubberised asphalt pavements] pavements can be reclaimed and recycled to produce new recycled [asphalt] 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 [rubberised asphalt pavements].*

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.

The 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 WARRIP 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 various studies undertaken in the United States in addition to various interview outcomes. Table 2.3 summarises the relevant studies discussed.

2.3.2 WISCONSIN

Documented in a report by Bischoff & Toepel (2004), the Wisconsin Department of Transport originally placed a mix containing 65% virgin aggregate and 35% conventional RAP from a 1966 project, combined with CRM binder containing 22% crumb rubber (by mass of the binder). 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 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 binder 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 international literature

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/T191-19 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: TESTINGRECOVERED CRM BINDERS AS NON-MODIFIED BINDERS

Option 1 is to test recovered CRM binders as if they were 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 (Austroads 2015). 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.

2.4.4 OPTION 2: RE-BLENDING OF RECOVERED RUBBER AND RECOVERED BINDER

The AGPT/T191-19 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.

2.4.5 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/T190-19). 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 each test 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 the rubbers normally used for binder-modification must pass through 1.18 mm sieve *Size 30 gradation as specified in AGPT/T190-19). 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 & Davies (1994; 1995), Denneman et al. (2015), Lee, Amirkhanian & Kwon (2007), Ghavibazoo & Abdelrahman (2014), Ghavibazoo, Abdelrahman & Ragab (2013 &, 2015), Khalili et al. (2016), Mturi et al. (2014), Putman & Amirkhanian (2006), Ragab & 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 Austroads Test Method AGPT/T125-18 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 that used by Baumgardner & 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.

2.5 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 standard 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 affect the binder blending design outcome 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 the method reported in the draft Engineering Road Note ERN13B (Main Roads Western Australia 2018) 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 the ability 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. This will ensure that the design is undertaken in the correct manner.

3 PRACTICALITY STUDY – STAGE 1

3.1 OBJECTIVE

Due to the lack of documented international experience and local experience with crumb rubber modified reclaimed asphalt pavement (CRM-RAP) a practicality study was undertaken to investigate the typical steps of CRM-RAP production and utilisation including reclamation, processing, hot plant recycling to produce a new asphalt mix containing CRM-RAP, and subsequent paving.

The study was conducted in two sequential stages. Stage 1, discussed here, focussed on low tonnages of CRM-RAP (10 tonnes) and investigated practicality of CRM-RAP in conjunction with a batch style asphalt plant, which was anticipated to be the worst case type of plant for this type of RAP material. Stage 2, reported in Section 4, focussed on higher volumes.

3.2 METHODOLOGY

Conventional equipment and plant were used in the study to follow the same steps as conventional RAP reclamation and reuse. The following steps were used:

- profiling and reclamation of CRM gap graded asphalt (GGA) using conventional asphalt milling equipment
- processing of CRM-RAP using a crusher and appropriately sized screens
- laboratory testing to determine particle size distribution (PSD) and binder content of processed CRM-RAP
- asphalt mix design utilising 10% CRM-RAP via substitution
- plant production using batch plant to produce a new mix containing CRM-RAP
- subsequent trial paving using the new mix.

3.3 PREVIOUSLY LAID CRM ASPHALT

3.3.1 DETAILS

On 1 March 2019 a plant trial was undertaken at the Fulton Hogan yard in Hazelmere. During this trial, 20 tonnes of CRM gap grade asphalt (GGA) was produced and subsequently paved (Figure 3.1). This paved material was the source of the CRM-RAP used for this practicality.

Figure 3.1: Location of placed CRM GGA, Fulton Hogan Hazelmere

Source: Landgate (2019).

3.3.2 PLANT PRODUCED MIX

The mix design of the CRM GGA mix was undertaken by Fulton Hogan. A binder content of 8%, by mass, CRM binder was chosen. Test results undertaken on laboratory prepared samples made from the plant produced CRM GGA are included in Table 3.1.

3.3.3 CRM BINDER

The CRM binder used for the CRM GGA plant trial was produced by Fulton Hogan prior to the production of the GGA mix. The CRM binder was produced by blending 18% crumb rubber (by mass) with a C170 base binder. The viscosity of the CRM binder after this blending time was measured at 1.6 Pa.S at 175°C using a Rion handheld viscometer.

Table 3.1: Gap grade crumb rubber asphalt mix compliance testing

Sieve size, mm	% Passing	
	Sample H2969	Sample H2970
26.5	100	100
19.00	100	100
13.20	97	100
9.50	87	81
6.70	70	66
4.75	52	48
2.36	24	25
1.18	16.1	17.8
0.600	11.6	13.5
0.300	7.7	8.8
0.150	5.0	5.4
0.075	3.7	3.3
Binder content, %[2]	6.4	6.7
Air voids, %[1]	5.2	5.0
Voids in mineral aggregate (VMA), %	23.1	23.7
Voids bitumen filled (VBA), %	77.6	79.1

Source: Van Aswegen (2019)

Notes:

1. *Gyratory compacted.*
2. *CRM binder factor of 0.78 was established at the mix design stage.*

- *The tested binder content is 6.4% for Sample H2969. Total CRM binder content is therefore 6.4/0.78 = 8.2%.*
- *The tested binder content is 6.7% for Sample H2970. Total CRM binder content is therefore 6.7/0.78= 8.6%.*

3.3.4 PAVING INFORMATION

The CRM GGA was paved using a self-propelled paver with no material transfer vehicle. An average thickness of 41.5 mm was achieved. Coring of the paved material 5 days after the trial indicated the in situ air voids of the laid and compacted mix varied between 4.1% and 8.2% with a mean of 6.0%.

Further details on the development and trial of the CRM GGA material used as part of the CRM RAP practicality trial can be found in the WARRIP report *Transfer of appropriate crumb rubber modified bitumen technology to WA, Stage 2: Gap graded asphalt* (Van Aswegen 2019).

3.4 RESULTS

3.4.1 MILLING AND RECLAMATION

Details

Cold milling and subsequent reclamation of the previously placed CRM GGA was undertaken on 7 May 2019 at the Talbot Road Fulton Hogan yard in Hazelmere (Figure 3.2). A Wirtgen W200 cold milling machine was used for the reclamation and was supplied and operated by WA Profiling (Figure 3.3).

The milling was undertaken in two runs of 40 m length and 2 m width. The depth of reclamation was approximately 25 mm. This equated to approximately 10 tonnes of CRM-RAP material.

The approximate air temperature at the time of profiling was 18 °C recorded at Perth Airport (Bureau of Meteorology (BOM) 2019).

The reclaimed CRM-RAP (Figure 3.4) was subsequently stockpiled at the Fulton Hogan yard in a separate area. The material was covered by a tarpaulin with a temporary exclusion zone set-up to ensure no contamination with other RAP material.

Figure 3.2: Location of profiled CRM-RAP, Fulton Hogan Hazelmere

Source: Landgate (2019).

Figure 3.3: Profiling CRM-RAP

Figure 3.4: CRM-RAP millings

Issues and observations

The profiling crew were asked to note any out of the ordinary observations when undertaking the cold milling.

They reported that no issues were encountered during the cold milling. Water usage was normal, and no extra force was required to remove the CRM material. Furthermore, no gumming of the profiler was observed. No abnormal smell was detected during the works.

3.4.2 PROCESSING

Details

Processing of the CRM-RAP was subsequently undertaken on 5 June at the Fulton Hogan yard by Asphalt Recyclers Australia. The CRM-RAP material was crushed and screened with conventional processing equipment.

Processing of the CRM-RAP was undertaken to the MRWA specification (*Specification 511: Materials for bituminous treatments* (MRWA 2020b)) for conventional RAP to produce a nominal minus 10 mm size material.

The approximate air temperature at the time of processing was 19 °C recorded at Perth Airport (BOM 2019).

Issues and observations

Again, the processing crew were asked to note any out of the ordinary observations when undertaking the processing of the CRM-RAP material. No issues were encountered during the processing. There was some CRM-RAP left on the screen but the operators noted that this was no more than typically occurred when processing conventional RAP material.

Figure 3.5: Processing CRM-RAP

Figure 3.6: Processed CRM-RAP

3.4.3 INITIAL CHARACTERISATION

Samples of the processed CRM-RAP were collected from the stockpile immediately after processing by Fulton Hogan laboratory staff and stored in sealed containers.

Samples were sent to the ARRB Port Melbourne laboratory for PSD and binder content analysis. Four PSD and binder content tests were undertaken on the processed CRM RAP sample in accordance with AS/NZS 2891.3.3:2013. These four tests investigated the variability of the PSD and binder content caused by removal of the undigested rubber particles during the binder extraction process.

Fulton Hogan also undertook laboratory PSD and binder content analysis of the material in accordance with WA 730.1 – 2011 (Main Roads Western Australia 2011).

Results of both ARRB and Fulton Hogan testing are shown in Table 3.2 and Table 3.4 respectively. An explanation of the differences in the ARRB tests are presented in Table 3.3.

Table 3.2: ARRB test results – processed CRM-RAP PSD and binder content

sieve size, mm	% passing			
	ARRB test 1[1]	ARRB test 2[2]	ARRB test 3[3]	ARRB test 4[4]
26.5	100	100	100	100
19.00	100	100	100	100
13.20	99	100	100	100
9.50	97	99	98	99
6.70	91	93	92	93
4.75	78	82	82	83
2.36	49	54	54	55
1.18	32	36	36	37
0.600	23	25	26	27
0.300	16	17	18	19
0.150	12.1	12.1	13.1	13.5
0.075	9.3	8.8	9.6	9.9
Binder content, %	6.7	7.2	7.4	7.5

Notes:

- *AS/NZS 2891.3.3*
    1. *All material collected on the 75um sieve reincorporated*
    2. *All material collected on the 75um sieve not reincorporated*
    3. *All material collected on the 75um sieve dried separately and reincorporated*
    4. *All material collected on the 75um sieve dried separately, broken down by hand and reincorporated*

Table 3.3: ARRB test results – explanation of different PSD processes

Test	Comment
Test 1	• *CR and fine material collected of the 75 µm funnel added back on the wet aggregate prior to drying* • *Crumb rubber particles swelled and clumped together (i.e. rubber particles were present as larger particles in the grading process)*
Test 2	• *CR and fine materials collected on the 75 µm funnel dried in a separate tray and added to dry washed aggregate to calculate bitumen content* • *PSD determined excluding crumb rubber and fine materials collected on the 75 µm funnel dried separately*
Test 3	• *CR and fine materials collected on the 75 µm funnel dried separate and added as sheets of material to determine PSD* • *CR and fine material sheets did not really break down substantially*
Test 4	• *CR and fine materials collected on the 75 µm funnel dried separate and sheets of material broken apart by rubbing between nitrile gloved hands* • *CR particles now clearly visible on 600 – 150 µm sieves through the PSD process*

Table 3.4: Fulton Hogan test results- processed CRM-RAP PSD and binder content

Sieve size, mm	% passing	
	FH H3810	FH H3811
26.5	100	100
19.00	100	100
13.20	100	100
9.50	100	97
6.70	95	90
4.75	81	78
2.36	47	48
1.18	30	31
0.600	21	22
0.300	14	15
0.150	9.3	9.5
0.075	5.7	6.0
Binder content, %	7.0	6.9

Notes:

- *WA 730.1 – 2011.*

3.4.4 PLANT TRIAL

A plant trial was undertaken on 9 August 2019 to observe the incorporation of CRM-RAP with virgin aggregate and virgin binder to create a new asphalt mix.

The plant trial was undertaken at the Fulton Hogan yard in Hazelmere using their batch style plant (Figure 3.7 and Figure 3.8).

The approximate ambient temperature at the time of production was 17 °C recorded at Perth Airport (BOM 2019).

Details

The new mix contained a 10% substitution with the CRM-RAP material to produce a 14 mm nominal mix with a reported bitumen content of 4.3% (i.e., no viscosity blend deign). Test results on the produced mix are presented in Table 3.5.

No further testing was undertaken on the mix as the intention was only to observe the CRM-RAP run through the plant.

Table 3.5: New asphalt mix containing 10% CRM-RAP compliance testing

Sieve size, mm	% passing
	H4129
26.5	100
19.00	100
13.20	99
9.50	76
6.70	54
4.75	42
2.36	25
1.18	15.0
0.600	10.9
0.300	7.7
0.150	5.3
0.075	3.6
Binder content, %	4.3%

Figure 3.7: Fulton Hogan batch plant, Hazelmere

Figure 3.8: Asphalt mix containing 10% CRM-RAP

Issues and observations

The production crew were asked to note any out of the ordinary observations when undertaking the mix production. No issues were identified during the mix production process. The plant operator did not observe any problems as the CRM-RAP material passed through the plant and into the new mix.

3.4.5 PAVING

Paving of the new mix was also undertaken on 9 August 2019 immediately after the production of the new mix containing the CRM-RAP. The material was paved within the Fulton Hogan yard in Hazelmere (Figure 3.9).

The approximate ambient air temperature at the time of paving was 17 °C recorded at Perth Airport (BOM 2019).

Details

The new mix was paved by the same Fulton Hogan paving crew and self-propelled paver which was used to pave the original CRM GGA.

No testing was undertaken on the paved material as the intention was only to observe the new mix containing the CRM-RAP being placed.

Issues and observations

The paving crew were asked to note any out of the ordinary observations when undertaking the paving works. The crew noted that paving the mix containing CRM-RAP was no different to paving a mix containing conventional RAP material. No problems were encountered.

Figure 3.9: Location of paved mix containing CRM-RAP, Fulton Hogan Hazelmere

Source: Landgate (2019).

Figure 3.10: Paving new asphalt mix containing CRM-RAP

3.5 CONCLUSIONS

This practicality study was undertaken to investigate the typical stages of CRM-RAP production and utilisation including reclamation, processing, hot plant recycling to produce a new asphalt mix containing 10% CRM-RAP, and subsequent paving of the new mix.

The main objective of this study was to identify any problems with the CRM-RAP recycling and reuse process.

The investigation did not identify any issues or problems throughout the reclamation and re-use process.

4 PRACTICALITY STUDY – STAGE 2

4.1 OBJECTIVE

The main objective of the Stage 2 practicality study was to identify any problems with the CRM-RAP recycling process at higher tonnages (20 tonnes) than the small (10 tonne) trial conducted in Stage 1. The use of CRM-RAP in conjunction with a drum-style plant was also considered for this stage; however, as this was not considered to present the worst case, the Stage 2 study was confined to reclamation and processing only.

4.2 METHODOLOGY

Conventional equipment and plant were used in the study to allow the same steps to be followed as conventional RAP reclamation and reuse. The following steps were used:

- profiling and reclamation of CRM gap graded asphalt (GGA) using conventional asphalt milling equipment
- processing of CRM-RAP using a crusher and appropriately-sized screens

4.3 PREVIOUSLY-LAID CRM ASPHALT

The same source of CRM asphalt used in the Stage 1 study was also used in the Stage 2 study. Details are included in Section 3.3.

4.4 RESULTS

The following sections detail the results of each phase of the practicality study; any issues encountered during the trial are identified.

4.4.1 MILLING AND RECLAMATION

Details

The milling was undertaken in four runs 40 m long and 2 m wide. The depth of reclamation was approximately 25 mm. This equated to approximately 20 tonnes of CRM-RAP material (Figure 4.1 and Figure 4.2).

The approximate air temperature at the time of profiling was 25 °C, recorded at Perth Airport (BOM 2019).

The reclaimed CRM-RAP (Figure 2.4 and Figure 2.5) was subsequently stockpiled at the Merger Contracting yard in a separate area. The material was covered by a tarpaulin with a temporary exclusion zone set-up to ensure no contamination with other RAP material.

Figure 4.1: Location of profiled CRM-RAP, Fulton Hogan Hazelmere

Source: Landgate (2019).

Figure 4.2: Profiling CRM-RAP

Issues and observations

No issues were encountered during the cold milling. Water usage was normal, and no extra force was required to remove the CRM material and gumming of the profiler was not observed. No abnormal smell was detected during the works.

The rubber component of the CRM-RAP material was more apparent during the Stage 2 profiling works compared with the previous Stage 1 works; however, it did not cause any issues with the plant equipment (Figure 4.3 and Figure 4.4).

Figure 4.3: CRM-RAP millings

Figure 4.4: CRM-RAP millings

4.4.2 PROCESSING

Details

Processing of the 20 tonnes of CRM-RAP was subsequently undertaken on 27 May by Asphalt Recyclers Australia. The CRM-RAP material was crushed and screened with conventional processing equipment (Figure 4.5).

Processing of the CRM-RAP was undertaken to the MRWA specification (*Specification 511: Materials for bituminous treatments* (MRWA 2020b)) for conventional RAP to produce a nominal minus 10 mm size material.

The approximate air temperature at the time of processing was 20°C recorded at Perth Airport (BOM 2019).

Issues and observations

The processing crew were asked to note any out of the ordinary observations when undertaking the processing of the CRM-RAP material. During processing, some plant issues were encountered. It was apparent that the high volume of CRM-RAP through the processing equipment caused build up, subsequently stalling the processor approximately three times over the 20 tonne volume of CRM-RAP.

Further discussion with Asphalt Recyclers Australia revealed that processing CRM-RAP outside of this study has caused problems in the past, especially when processing high volumes. The build-up on the return belt caused the processing equipment to stall, resulting in stoppages during past crushing campaigns. The material was still able to be crushed but not in an efficient manner (Figure 4.6).

Figure 4.5: Processing CRM-RAP

Figure 4.6: Processed CRM-RAP

4.5 CONCLUSIONS

The purpose of this practicality study was to investigate the typical preliminary stages of CRM-RAP production, including reclamation and processing, when high volumes of CRM-RAP are expected.

This investigation identified potential processing issues, with high volumes of CRM-RAP causing several stoppages during the processing of 20 tonnes of material. The CRM-RAP was still able to be processed to the correct size; however, the number of stoppages demonstrated the reduced efficiencies associated with processing this material.

5 LABORATORY INVESTIGATION

The literature review in Section 2 was not able to provide significant insight into the characterisation of CRM-RAP material that could be used as the basis of optimising mix design through binder blending to reach a target viscosity.

The standard methods of binder extraction were found to ultimately remove undissolved rubber particles, subsequently jeopardising the representative viscosities obtained from the extracted CRM-binder.

To overcome this, a laboratory investigation was scoped to investigate the characterisation of CRM-RAP binder for use in the target viscosity blend method. For this investigation the following two alternative methods were proposed:

- Option 1: characterising recovered CRM binders like non-modified binders (i.e. viscosity of extracted CRM-RAP binder without reblending recovered rubber).
- Option 2: reblending of recovered rubber and recovered binder for characterisation

5.1 OBJECTIVE

The objective of the laboratory investigation was to further examine the two options of CRM-RAP binder characterisation and to quantify the effect of each method on the CRM-RAP binder viscosity results and assess the repeatability and representative nature of the viscosity results.

5.2 METHODOLOGY

In attempting to isolate crumb rubber particles from samples of CRM-RAP, a variety of laboratory processes were explored. All of the laboratory trials were in line with Austroads test method AGPT/T191-19 *Extractions of bituminous binder from asphalt*, for the most part, with each trial variation altering the methodology slightly (see Section 5.3.1).

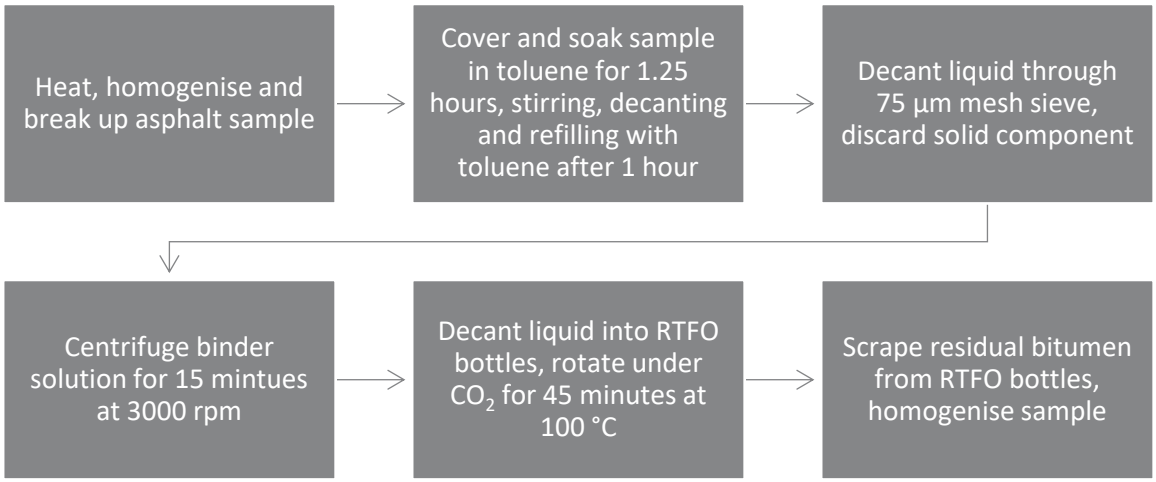
For this work, two sample binders were used: a sample of 18% CRM binder (#5837) and a sample of CRM-RAP produced with 18% CRM binder (#6099).

5.3 INVESTIGATION

5.3.1 OVERVIEW OF AGPT/T191

The methodology in AGPT/T191–19 outlines the manner in which binder may be extracted from a sample of asphalt. A summary flowchart is shown in Figure 5.1.

Figure 5.1: Summary of binder extraction method



As one main intention of this research was to isolate the crumb rubber component from the binder and other solids through this extraction process, the main change carried out was that the solid component was not discarded from the 75 µm sieve, but rather retained and further investigated. Other changes made to the method were changed soaking times and changed solvents. Multiple variations were also trialled to separate the crumb rubber component from the other solid aggregate component. Sections 5.3.2 and 5.3.3 discuss these various experimentations.

5.3.2 CRM BINDER

The first trial attempts were conducted using a sample of crumb rubber-modified binder. Although the extraction process in AGPT/T191-19 is for asphalt samples, this was undertaken with a binder in order to determine the effect the extraction process may have on the crumb rubber component. Impacts such as prolonged soaking in toluene and heating in the rolling thin film oven (RTFO) were considered.

Two different attempts were made as outlined below. For all trials, regardless of the methodology used for the solid crumb rubber component, the binder itself was extracted by following the centrifuge and RTFO methodology in AGPT/T191-19.

Trial A

Whilst Trial A saw AGPT/T191-19 followed for the most part, the sample was soaked for 2 hours total in place of the specified 1.25 hours. This was because the sample was a binder sample, without the presence of aggregate, and more soaking was expected to be required due to the larger amount of binder. It was found that much of the CRM binder stuck to the base of the beaker, and all the binder was not able to be extracted. Due to this issue, only 30.9% of the binder was extracted.

In place of discarding the solids retained in the 75 µm sieve, as is typical practice with AGPT/T191–19, the solids were rinsed with solvent until the solvent became a light straw colour. After washing and oven drying at 100 °C the crumb rubber was mostly powdery; there was, however, a slight residue of binder seen around the dried crumb rubber. This indicated more washing may be required. A total of 72.2% of the crumb rubber was recovered.

Trial B

For Trial B, a smaller amount of CRM binder was used to attempt to combat the issue of the binder settling on the base of the beaker. The sample was again soaked for 2 hours; however, more solvent was used, and it was stirred more often and more vigorously, resulting in all the binder successfully combining in solution. As a result, 86.8% of crumb rubber was retained and 52.7% of bitumen was recovered. More solvent was used to wash the retained crumb rubber and, as a result, less residue was seen around the dried sample.

The sample was, however, found to be clumpy upon drying, indicating that the use of an 100 °C oven to dry the sample may have a detrimental effect.

Summary

After the two trial attempts it was found that, while the binder and crumb rubber were able to be extracted, there was a disparity in the amount of each retained, with the crumb rubber retained at a much higher rate compared to the binder. This is likely due to the extraction process of the binder involving more steps in which the binder may be lost, compared to the process required to recover rubber.

Visually, the crumb rubber collected was found to contain some clumps, a potential result of the soaking in toluene or the inability of all the binder residue to be washed from the sample. It was also determined that drying the crumb rubber in a 100 °C oven may not provide desirable results and that ambient air drying or lower oven temperatures may provide better solutions. As a workplace health and safety (WHS) consideration, it is also ideal to avoid heating the rubber where possible, due to the undesirable fumes generated.

In terms of laboratory practices, it was found that a large volume of toluene is required to wash the extracted crumb rubber solids. For a repeatable practice this is not ideal, in terms of cost, solvent wastage and WHS.

5.3.3 CRM-RAP

Five attempts were made with the CRM-RAP sample as discussed in this section. For all trials, regardless of the methodology used for the solid component, where the binder itself was extracted, the centrifuge and RTFO steps outlined in AGPT/T191–19 was followed.

Trial C

Approximately 50 g of the CRM-RAP per beaker was used for this procedure, in line with the typical mass outlined in AGPT/T191–19, and the regular soaking procedure was followed. The solid extracted contained mostly aggregate particles; however, a small amount of the crumb rubber particles could be seen. A total of 83 g of solid particles was retained, and 2 g of binder was extracted. As was highlighted in Section 5.3.2, a large of volume of toluene was found to be necessary to wash the solid particles of bitumen residue.

Crockford et al. (1995) suggested that the crumb rubber proponent may be segregated from the other solid particles using a floatation method, i.e. using a liquid with a specific gravity between that of the rubber particles and aggregate materials; or 1.0 g/cm^3 and 2.4-3.0 g/cm^3. Whilst sodium bromide is the main suggested solvent, having a specific gravity of 1.25 g/cm^3, Crockford et al. (1995) reported no information regarding the success, or otherwise, of this method. Citrus terpene was also postulated as an option.

Although Crockford et al. (1995) suggested sodium bromide or citrus terpene, an initial trial was conducted using water with a mixture of clean crumb rubber particles and fines. If effective, simple water would be a cost effective, easier and safer option than other specific liquids.

In this initial trial, the crumb rubber was found to float in the water, whilst the fines sunk. Figure 5.2 shows the crumb rubber floating on the surface. The filter paper shown had been swiped across the surface of the water, collecting floating crumb rubber particles. No visible aggregate particles were picked up from the surface of the water.

Figure 5.2: Rubber particles on filter paper – water floatation

After this successful initial trial, the same method was trialled with the extracted solids from Trial C, with less conclusive results. It was found that some fine aggregate particles floated, along with the crumb rubber, and that some particles of crumb rubber cohered to other aggregates and therefore sunk (Figure 5.3, Figure 5.4).

The difference in success between the initial trial conducted with clean fines and rubber and the Trial C extracted materials sample may be due to the bitumen residue cohering the two materials, or solvent absorption potentially impacting the density of the crumb rubber.

Figure 5.3: Water floatation – trial C

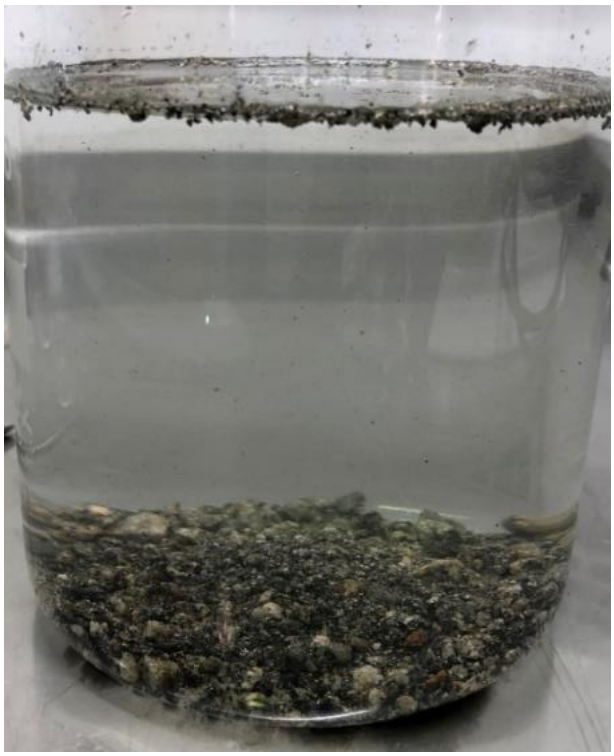


Figure 5.4: Rubber particle and fine – trial C

The cohesion seen in Figure 5.4 leads to the conclusion that, regardless of the solvent chosen (sodium bromide, citrus terpene or water), or their varying specific gravities, the floatation method could not guarantee significant separation of crumb rubber from the remainder of the solid mix.

Trial D

For the next CRM-RAP extraction trial, a larger mass (500 g) was used and the material was soaked in the toluene overnight. This was carried out due to the challenges observed with such a small mass of crumb rubber visible in Trial C. Instead of attempting to recover all solid materials, a decanting method was used. It was found that the material floating on the toluene after soaking was mainly composed of crumb rubber plus a small number of fines. Upon washing and drying, it was noted that the retained solid material was composed of crumb rubber, some fines and some fibrous material, likely identified as asphalt filler. In the face of the issues associated with drying the crumb rubber particles in the oven, for this trial and the subsequent attempts air drying was used. As can be seen in Figure 5.5, the fines and fibrous material are cohered to the crumb rubber particles, and the solid overall is clumpy, demonstrating it is unlikely that the rubber particles and the other solid components can be separated in this manner.

Figure 5.5: Extracted, washed and dried rubber particles – trial D

Approximately 9.46 g of binder and 2.60 g of crumb rubber and other solids were obtained. This resulted in a 21.6% mix of retained rubber, slightly different to the known value of 18% rubber in the CRM-RAP. This aligns with what was discussed in Section 5.3.2, where there was a disparity between the amount of binder extracted compared to the amount of solids retained.

Trial E

Trial E was conducted in the same manner as Trial D, except that mineral turpentine was used in place of toluene for the overnight soaking. The floatation method and decanting were less successful with the solvent, with more silt and less rubber observed in the particles. The binder was not extracted as the change in solvent provided uncertainty regarding the effectiveness and safety of the RTFO extraction procedure in AGPT/T191–19. A total of 1.80 g of solid was retained, and as can be seen in Figure 5.6, the dried material was clumpy and fibrous material cohered to the crumb rubber.

Figure 5.6: Extracted, washed and dried rubber particles – trial E

Trial F

For the next trial, the mass of sample was decreased to 300 g. As quite a substantial volume of solid was able to be extracted in trials D and E, 500 g was deemed unnecessary. It also provided the benefit of reduced the amount of solvent needed for washing. Toluene was used once again as the solvent, and sample soaked overnight. Again, the top layer of soaked sample was decanted, washed and air dried. A total of 6.38 g of binder and 1.29 g of solid were obtained, representing a ratio of 17% crumb rubber, which was quite close to the actual mix percentage.

It should be noted, however, that overnight soaking did not appear to provide any benefit to the amount extracted, with the masses gathered similar the masses collected in trial E and G, discussed below. The sample, however, was less clumpy than other attempts, as Figure 5.7 displays.

Figure 5.7: Extracted, washed and dried rubber particles – trial F

Trial G

In the last trial, the mass of sample was again decreased to 300 g and toluene was again used as the solvent; however, soaking was only carried out for 1.25 hours overall. Again, the top layer of the soaked sample was decanted (see Figure 5.8), washed and air dried. Fines and fibrous material were once again seen, as demonstrated by Figure 5.9. A total of 7.1 g of binder and 2.37 g of solid were obtained, providing an extracted ratio of 25% crumb rubber to 75% binder. This was once again different to the actual content of 18% rubber.

Figure 5.8: Decanted particles – trial G

Figure 5.9: Extracted, washed and dried rubber particles – trial G

Summary

The large volume of toluene, or in the case of Trial E, mineral turpentine, required suggests that the methodology is not feasible on a large scale in terms of WHS, cost or sustainability. A sample size within the range of 50 g to 500 g of CRM-RAP was deemed suitable, with 300 g selected in the final two trials. This was able to return approximately 7 g of binder and 2 g of crumb rubber.

In relation to timeframes, it was found that overnight soaking was not required and the typical procedure of 1 hour and 15 minutes may be appropriate. The methodology was able to be conducted in a comparable timeframe to that of the AGPT/T191–19 method, with some additional time required for washing and drying the rubber.

Once again, a disparity was seen, with the volume of binder and solids extracted not matching the actual rubber content of 18%. Should this procedure be attempted with a sample of unknown rubber content it is clear that this method would not be able to gather any quantitative data on the crumb rubber modification present in a RAP sample.

Overall these trials did not successfully separate out the crumb rubber solids from the other CRM-RAP components, with separation of fines and fibres, likely from asphalt filler, posing the biggest challenge. Whilst it was possible to remove larger aggregates from the collected crumb rubber, there was no significant difference in terms of size, density or material characteristics that may be leveraged to isolate crumb rubber from the other fines and fibrous matter present. Table 5.1 provides a summary of all the work undertaken.

Table 5.1: Trial summary – 18% CRM binder (#5837)

Trial	Sample size (g)	Solvent	Soaking	Washing	Drying	Binder extracted (g)	Solid retained (g)
A	8.53	Toluene	25 mL 1 hour 25 mL 1 hour	Wash until solvent straw coloured (~500 mL) Some binder retained on base of beaker after soaking	1.5 hours 100 °C Air dry Solids composed of crumb rubber	14.19 (30.9% total binder extracted)	3.12 (72.2% total solid retained)
	8.78		25 mL 1 hour 25 mL 1 hour				
B	5.01	Toluene	25 mL 1 hour 25 mL 0.5 hours 20 mL 0.5 hours	Wash until solvent straw coloured (~1 L) No binder retained on base of beaker after soaking	1 hour 100 °C Air dry Solids composed of crumb rubber	8.24 (52.7% total binder extracted)	1.81 (86.8% total solid retained)
	5.04		25 mL 1 hour 25 mL 0.5 hours 20 mL 0.5 hours				
C	50.00	Toluene	60 mL 1 hour 25 mL 0.25 hours	Wash until solvent straw coloured (~1 L)	1 hour 100 °C Air dry Solids composed of crumb rubber, aggregate and fibrous filler	2.00	83.00
	49.98		60 mL 1 hour 25 mL 0.25 hours				
D	500.35	Toluene	1 L overnight	Decant top ~300 mL Wash decanted solids until solvent straw coloured (~1 L)	Air dry Solids composed of crumb rubber, fines and fibrous filler	9.46	2.60
E	503.45	Mineral turpentine	1 L overnight	Decant top ~300 mL Wash decanted solids until solvent straw coloured (~500 mL)	Air dry Solids composed of crumb rubber, fines and fibrous filler	Binder not extracted	1.80
F	300.64	Toluene	200 mL overnight + 0.25 hours	Decant top ~100 mL, cover 0.25 hours, decant top ~30 mL Wash decanted solids until solvent straw coloured (~2 L)	Air dry Solids composed of crumb rubber, fines and fibrous filler	6.38	1.29
G	300.74	Toluene	200 mL 1 hour + 0.25 hours	Decant top ~100 mL, cover 0.25 hours, decant top ~30 mL Wash decanted solids until solvent straw coloured (~2.5 L)	Air dry Solids composed of crumb rubber, fines and fibrous filler	7.10	2.37

5.4 SAMPLE ANALYSIS

In order to further analyse the impacts of the various alterations to a typical extraction methodology, as discussed in Section 5.3, the viscosities of the binders were assessed. Austroads Test Method AGPT/T192–15 *Characterisation of the viscosity of reclaimed asphalt pavement (RAP) binder using the dynamic shear rheometer (DSR)* was used. Duplicate tests were not possible due to the limited numbers of samples obtained for each extraction process. This analysis was carried out to better understand the potential impact that the extraction procedure – involving prolonged soaking in solvents, such as toluene, and heating – may have had on the binder and the crumb rubber.

Fresh binder and extracted binder were analysed, with the complex viscosities of each obtained using the DSR. Attempts were also made to recombine extracted binder and extracted crumb rubber particles to produce a reconstituted CRM binder for analysis.

Considering the limited number of samples, it was not possible to recombine the crumb rubber with the binder in the manner of a typical CRM binder blend. Instead, the binder was heated under a heat lamp and mixed with the extracted, washed and dried crumb rubber. The main challenge faced was the crumb rubber containing clumps, irregular sized particles and, in the case of the CRM-RAP samples, inseparable fines and fibrous materials. Table 5.2 provides an overview of the complex viscosity for each sample tested.

Table 5.2: Complex viscosity at 60°C

Sample	Trial	Sample description	Complex viscosity at 60 °C (Pa.S)
X	N/A	18% CRM binder (virgin)	2,508
A.1	A	Extracted CRM binder, toluene, 2 hours	280
A.2		Extracted CRM binder, 2 hours 18% extracted CR, toluene, 2 hours	1,057
C.1	C	Extracted CRM-RAP binder, toluene, 1.25 hours	623
D.1	D	Extracted CRM-RAP binder, toluene, overnight	64
D.2		Extracted CRM-RAP binder, toluene, overnight 18% extracted CR, toluene, overnight	4,218
DE.1	D/E	Extracted CRM-RAP binder, toluene, overnight 18% extracted CR, mineral turpentine, overnight	15,410
F.1	F	Extracted CRM-RAP binder, toluene, overnight	870
F.2		Extracted CRM-RAP binder, toluene, overnight 17% extracted CR, toluene, overnight	6,406
G.1	G	Extracted CRM-RAP binder, toluene, 1.25 hours	787
G.2		Extracted CRM-RAP binder, toluene, 1.25 hours 25% extracted CR, toluene, 1.25 hours	97,682

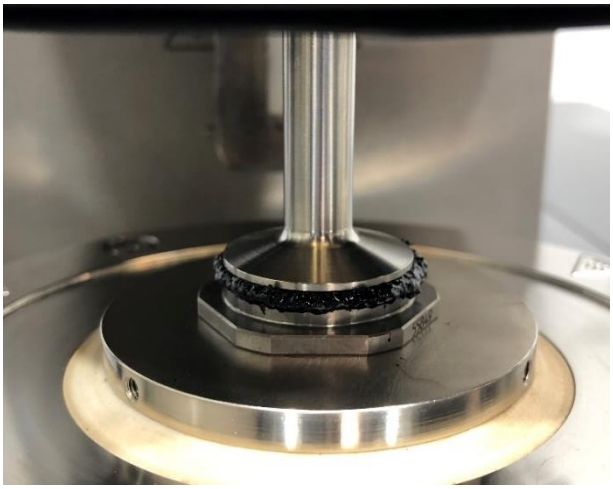
5.4.1 IMPACT OF EXTRACTION PROCEDURE

The first complex viscosity result, denoted as Sample X in Table 5.2, was obtained from 18% CRM binder, prior to undergoing any extraction procedure. This was carried out to compare the potential impact of the extraction procedure on the viscosity of the binders.

As can be noted by referring to the complex viscosity of X and A.1, the viscosity decreased quite significantly after the CRM binder underwent the extraction process as per AGPT/T191–15. The decrease in viscosity is evidently a result of the removal of crumb rubber in this instance. However, when considering the results of the A.2 extraction, which contained recombined crumb rubber, the viscosity also decreased by approximately 50% from the base case. This is possibly an indication of the toluene, or heat, affecting the properties of the crumb rubber itself.

As the crumb rubber was only recombined through mixing under a heating apparatus, it is also possible that the difference in blending methodology played a part. Further research would be required to fully understand the differences that arise with this comparison.

Figure 5.10: CRM binder sample on DSR – prior to trimming



5.4.2 IMPACT OF SOAKING TIME

As some samples were soaked for just over an hour, and some overnight, it was valuable to compare the difference in viscosity between these samples. Considering Samples C.1, D.1 and G.1 appears to suggest that soaking overnight in toluene reduced the viscosity drastically. However, a discrepancy does arise in F.1: the viscosity, despite the overnight soaking, did not decrease compared to C.1 and G.1, the samples soaked for only 1.25 hours. These results are therefore inconclusive and further experimentation may be required to understand the impact of soaking time on viscosuty.

5.4.3 IMPACT OF SOLVENT

As the binder was not extracted from the mineral turpentine, it was not possible to compare binder samples with differing solvents. However, the impact of solvents can be noted by comparing the results for Samples D.1 and DE.1: the mineral turpentine crumb rubber resulted in a much higher viscosity value. This is likely due to the clumpy, more irregular shaped crumb rubber extracted with mineral turpentine. The mineral turpentine resulted in more fines and fibrous materials mixed within the crumb rubber, resulting in the solid being composed of larger particles which increased the viscosity quite significantly.

5.4.4 IMPACT OF RUBBER PROPERTIES

Similar to the discussion in Section 5.4.3, the impact of crumb rubber content on the samples was evident. Overall, the addition of crumb rubber back into a binder sample resulted in an increase in viscosity, and clumpier samples of extracted crumb rubber resulted in an even greater increase. Overall, the rubber extracted using the various methods outlined in Section 5.3 was inconsistent. It can be noted that the rubber combined in Sample A.2 had a powdery consistency, and thus the viscosity increase was less drastic compared to the other sample containing larger pieces of rubber. The addition of a larger percentage of rubber, as with the 25% in Sample G.2, resulted in the greatest increase in viscosity, as would be expected.

Figure 5.11: Recombined CRM-RAP binder and CR particles

5.5 FINDINGS OF LABORATORY INVESTIGATION

Two alternative methods of CRM-RAP binder extraction and characterisation were proposed for examination through this laboratory investigation:

- Option 1: characterising recovered CRM binders like non-modified binders (i.e. viscosity of extracted CRM-RAP binder without reblending recovered rubber).
- Option 2: reblending of recovered rubber and recovered binder for characterisation

The objective of the laboratory investigation was to further examine the two options of CRM-RAP binder characterisation and to quantify the effect of each method on the CRM-RAP binder viscosity results.

A summary of the results is presented in Table 5.3. The findings of the investigation, which relate to either option 1 or option 2, were as follows:

- The removal of the rubber particles decreased the viscosity of the CRM-RAP binder by an unquantifiable amount (option 1).
- Overall, the repeatability of the rubber extraction from the CRM-RAP was poor due to variables such as soaking time and solvent type. This in turn effected the repeatability of option 2.
- It is possible that toluene or heat affect the properties of the crumb rubber which was to be reblended (option 2).
- The impact of soaking time on the final viscosity results (option 1 and option 2) is unclear.
- The type of solvent impacted the size of the crumb rubber particles through swelling subsequently increasing the viscosity when reblending the larger particles (option 2).

Table 5.3: Summary of results

Trial	Solvent	Extraction method	Complex viscosity sample	Complex viscosity at 60 °C (Pa.S)
N/A	N/A	N/A	X; 18% CRM binder (virgin)	2508.44
A	Toluene	Soak 2 hours Wash all samples Oven dry rubber	A.1; Extracted CRM binder	280.14
			A.2; Extracted CRM binder blended with 18% extracted CR	1057.18
B	Toluene	Soak 2 hours Wash all samples Oven dry rubber		
C	Toluene	Soak 1.25 hours Wash all samples Oven dry rubber	C.1; Extracted CRM-RAP binder	622.79
D	Toluene	Soak overnight Decant samples Air dry rubber	D.1; Extracted CRM-RAP binder	64
			D.2; Extracted CRM-RAP binder blended with18% extracted CR	4218
			DE.1; Extracted CRM-RAP binder (toluene) blended with 18% extracted CR (mineral turpentine)	15410
E	Mineral turpentine	Soak overnight Decant sample Air dry rubber Binder not extracted		
F	Toluene	Soak overnight Decant samples Air dry rubber	F.1; Extracted CRM-RAP binder	870
			F.2; Extracted CRM-RAP binder blended with 17% extracted CR	6406
G	Toluene	Soak 1.25 hours Decant samples Air dry rubber	G.1; Extracted CRM-RAP binder	787
			G.2; Extracted CRM-RAP binder blended with 25% extracted CR	97682

5.6 IMPLICATIONS AND AREAS FOR FURTHER INVESTIGATION

The first barrier to the use of laboratory characterisation of extracted CRM-RAP using the viscosity blend design method is that the current extraction method is an unrepeatable process which produces variable and unrepresentative results. As a result, it is not currently possible to accurately use the viscosity blend method to design level 2 and level 3 CRM-RAP mixes. However, this may not be an issue if the CRM-RAP is diluted with conventional RAP. An investigation into the appropriate level of dilution which reduces the effect of the rubber on the characterisation method and subsequent blend design should be undertaken as a future investigation.

If it is intended to use CRM-RAP undiluted, then further investigation could be undertaken to quantify the suitability of an alternative design approach rather than the viscosity blend method. An alternative approach could be a performance-based design approach which may consider final mix properties such as penetration or modulus.

If the viscosity blend design method is to be maintained for undiluted CRM-RAP, then further investigation into the effects of using viscosity results obtained using option 1 (i.e. viscosity of binder with rubber filtered out) on the final mix properties could be conducted by comparing mix performance properties such as modulus to quantify the contribution of rubber on actual CRM-RAP binder viscosity.

6 AND CONCLUSIONS AND RECOMMENDATIONS

The aim of this project was to create a foundation understanding of the potential issues associated with the use of reclaimed asphalt pavement containing crumb rubber modified binders and the subsequent production and utilisation of new asphalt mixes containing CRM-RAP material.

There was limited literature available which documented experience with CRM-RAP usage, with all of the studies conducted in the USA. 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 presence of 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 the literature also demonstrated that available methods of binder extraction will ultimately remove undissolved rubber particles, subsequently jeopardising the representative viscosities obtained from the extracted CRM-binder.

The outcome of the Stage 1 practicality study was positive with no processing or construction barriers identified with the use of CRM-RAP. The Stage 2 practicality study identified some issues associated with processing at high volumes, which may have been due to the inherent stickiness of the CRM-RAP product. However, even with the processing issues, it was still possible to obtain a processed CRM-RAP, just not in an efficient manner.

The outcome of the laboratory investigation revealed repeatability issues associated with extraction and characterisation of CRM-RAP binder in addition to demonstrating the unrepresentative and variable nature of CRM-RAP binder viscosity results.

6.1 RECOMMENDATIONS FOR FUTURE WORK

Due to the inability to extract and characterise the CRM-RAP binder viscosity, further work is recommended to investigate an alternative design method to the target viscosity blend method currently used for conventional RAP as detailed in the draft ERN13B (Main Roads 2018). 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 the ability 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. Traceability of RAP also introduces the potential for RAP dilution. Further investigation could be undertaken to understand the effect on mix performance of RAP used in new mixes and design using the target blend viscosity method when varying proportions of CRM-RAP are present within the RAP material as a whole. The dilution of CRM-RAP with conventional RAP may remove the need to be able to correctly characterise the CRM-binder in the laboratory.

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