The reuse of end-of-life tyres to enhance the performance of chipseal binders

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Contents

Executive summary

The objective of this project was to investigate the viability of implementing crumb rubber modified (CRM) chipsealing in New Zealand.

Based on the literature review, there is a wealth of knowledge in Australia and South Africa clearly documented in guidance notes and specifications on the criteria for crumb rubber and the expected binder performance after modification. The key to successful production is the fundamental understanding of the interaction between crumb rubber and the bitumen through control of the composition, careful temperature and time management.

While the seal designs are different between countries, the fundamental principles of chipsealing practice remain, and the specific requirements of CRM binder and chipseals can be adapted to New Zealand conditions. In order to minimise the risks associated with the construction of a highly modified bituminous binder, construction requirements such as pre-coating are a must-do in CRM chipsealing, and liquid additives are incorporated to improve bitumen compatibility, aggregate adhesion, and workability.

There is an emission and odour risk with the use of CRM products, which is unavoidable if conventional crumb rubber technology is used. Overseas studies have shown that the emission levels are often well within the maximum allowance, but it remains a risk if the operating temperature is high. Having the ability to reduce the handling and spraying temperature of the modified binder would certainly help in the implementation of crumb rubber technology in New Zealand in terms of minimum surface temperature requirements as well as the general health and safety of workers and those surrounding the work site.

While emulsification of CRM binders would be the ultimate mitigating measure to these health and safety risks, it is not a mature technology, and both Australia and South Africa have managed to progress the use of crumb rubber seals without the need for such technology. An advance over the past decade or so is the introduction of warm mix additives to reduce the operating temperatures. In addition, there are commercially available odour suppressants that can be deployed to mitigate odour. At a cost, some of these practices can be implemented in conjunction with careful monitoring of the emission/odour.

Recent work in Australia has demonstrated the viability of recycling CRM asphalt as a reclaimed asphalt pavement component. Therefore, this provides a potential end-use for end-of-life CRM chipseals.

Another part of the equation for the technology to be viable in New Zealand is the security of crumb rubber supply. While there is no issue of supply of end-of-life tyres (ELTs), crumb rubber manufacturing capability is currently limited in New Zealand. However, this is likely to change with the introduction of a regulated product stewardship scheme. At the time of preparing this report, there are potential suppliers in New Zealand with capacity to produce materials that would meet the necessary specifications. The general principle of the product stewardship scheme would enable the flow of funds collected at the start of the supply chain to go towards the collectors and processors of ELT wastes, and thus subsidising the final product. The potential benefit of this is to keep the price of crumb rubber related products economically competitive.

The final piece of the puzzle for the technology to be viable in New Zealand would depend on the economics for New Zealand contractors to ‘gear-up’ for crumb rubber binder production and construction of CRM chipseals. As the literature shows, there are some specific requirements for pumps and sprayers for effective use of conventional CRM binders, and training would be required.

While examples of life cycle assessments on crumb rubber and CRM road materials have demonstrated environmental benefits over conventional polymer-modified materials, these studies have alluded to the fact that the results need to be treated carefully as indicative information because calculations are often based on

assumptions and estimates. It is envisioned that in future studies these problems will be overcome by directly monitoring production and construction activities, and this will likely fill the gaps of life cycle inventory data, which are an essential component of assessment. This supports the recommendation that a detailed assessment of energy consumption and greenhouse gas emissions should be part of any New Zealand field trial of CRM chipseals.

The remaining obstacle for the technology to be implemented in chipsealing in New Zealand is the industry's move away from cutback bitumen towards emulsion products. Due to the difficulty with emulsifying CRM binders, this could significantly impact further progress in the uptake. While potential solutions exist that would enable implementation of crumb rubber bitumen emulsions (eg, devulcanisation and warm mix additives), further research and development is required to demonstrate the feasibility of the new technologies.

Abstract

The objective of this project is to investigate the viability of implementing crumb rubber modified chipseal practice in New Zealand. We conducted a comprehensive literature review to examine best practice in Australia and South Africa. The review included material specifications, guidance on construction requirements, and health, safety and environmental concerns associated with crumb rubber chipsealing. We examined each country's practice of using additives to reduce the risk of failure and compared them against current New Zealand practice.

We found that there are specific construction requirements such as pre-coating and temperature conditions that are critical to the success of crumb rubber modified chipsealing. While most of the requirements can be met in New Zealand, these measures would pose additional seal construction costs. These additional costs need to be measured against the potential life extension of the seal. The only remaining obstacle to implementing crumb rubber technology in New Zealand is the road construction industry's move towards using bitumen emulsions to reduce the risk of injury from the use of hot cutback bitumen in chipsealing. In general, current crumb rubber bitumen technology has not advanced to a point where emulsification is practicable, and additional investigation or specialised proprietary products would be required.

1 Introduction

1.1 Background

It has been estimated that about 74,000 tonnes – or 8 million passenger tyre equivalents – of end-of-life tyres (ELTs) are generated annually in New Zealand (3R Group Ltd, 2020). The Ministry for the Environment has provided funding to industry to process used tyres into tyre-derived fuel to reduce the problem. In 2017 it was reported that Golden Bay Cement was planning to burn 3.1 million shredded used tyres per year as a heat/energy source for manufacturing cement at their plant near Whangārei. This leaves approximately 4 million used tyres per year going into stockpiles around New Zealand. While some are being disposed of legitimately, many are being illegally buried or dumped and polluting the environment.

A possible solution is to use some of the 4 million tyre stockpile as tyre-derived crumb rubber as an additive to bituminous binders. The use of crumb rubber has become common practice around the world since the 1960s for addressing pavement performance issues as well as tackling the disposal problem of ELTs. While early New Zealand trials of crumb rubber in both hot mix asphalt and chipseal pavements resulted in mixed performances, technological advances and ongoing research and practices internationally have demonstrated that crumb rubber can be effectively incorporated into road surfacing.

Although elastomers in the form of natural rubber latex or virgin styrene-butadiene-styrene (SBS) block copolymer have been used in New Zealand roads since the 1970s, crumb rubber has not been used to any extent in normal road pavement and surfacing maintenance or construction. Many countries in Europe and some states in the USA have been using crumb rubber bitumen (CRB) for decades with good results, but most has been used in hot mix asphalt. Crumb rubber modified (CRM) asphalt was also introduced in Canada in the early 2000s and has been primarily tested in Alberta, British Columbia, Ontario, and Saskatchewan. Unfortunately, the performance of past test sections has not been considered as successful as in the USA.

It is estimated that approximately 160,000–170,000 tonnes of bitumen is used in surfacings on New Zealand's roads each year. Of the 65,000 km sealed road network, 88% is chipseal and the rest is asphalt mix (Ministry of Transport, 2021). We can conservatively estimate that about 120,000 tonnes of bitumen is used in chipseals annually (Olsen, 2014). Hypothetically speaking, if 15% crumb rubber is added to all of the chipseals, there is an opportunity to use about 17,000 tonnes (> 1,100,000 tyres) per year of crumb rubber from the waste stream. In a more conservative approach, if we consider the use of crumb rubber only in high-stress sites in the network where imported synthetic polymers are used, then the market for CRB chipseals would be in the order of 2,500 tonnes per year, assuming that high-stress sites make up 20% of the network. This is discussed again in section 3.1.

Many recycled materials are used in road surfacing materials to remove them from the waste stream with little or no clear benefit to the road, but CRB may be a cost-effective option that not only disposes of used tyres but also improves the road surfacing performance. Currently, only Australia and South Africa are using significant quantities of CRB chipseals, with surfacings containing up to 25% crumb rubber. While crumb rubber can be applied to hot mix asphalt, the focus of this study will primarily be on best practices of crumb rubber chipsealing in Australia and South Africa.

1.2 Objectives

The purpose of this research is to investigate whether using CRB for chipseal construction has economic, technical and environmental benefits for the New Zealand road surfacing industry by:

- testing the assumptions regarding technical, commercial and environmental barriers that are resisting implementation of CRB
- identifying whether there is an economic model that supports sustainable used tyre recycling providing acceptable quality crumb rubber that enables consistent quality crumb rubber manufacture by New Zealand binder suppliers
- investigating the health and safety, environmental, and life cycle costs of CRB versus traditional penetration grade bitumen chipseals to justify the use of CRB.

The key objectives of the research are:

- to conduct a literature review of international examples regarding CRB chipseal technology, usage and performance in Australia and South Africa
- investigate the costs involved in bringing a CRB manufacturing plant to New Zealand
- investigate the costs of sourcing and producing CRB and constructing CRB chipseals back to back with traditional binders on sites in at least three climate zones in New Zealand
- confirm the viability of CRB chipseals using New Zealand manufactured crumb rubber materials, including:
  - local supply of crumb rubber
    - tyre-sorting capability
    - local quality
    - local availability
  - scale of and consistency of feedstock supply
  - likelihood of the binder being able to be emulsified
- identify the construction requirements that may be required to ensure that CRB chipseals are successful in New Zealand conditions, such as:
  - whether pre-coated chips should be used
  - whether blending oils are required
  - whether cutter and/or adhesion agent should be used
  - whether the binder should be emulsified
  - whether the minimum surface temperature of 25 °C and rising, specified for seal construction by Waka Kotahi, is practical for CRB in New Zealand conditions
  - the health and safety implications of potential application temperatures > 200 °C
  - other environmental implications/impacts (eg, odour and smoke).

2 International best practice

2.1 Specifications

2.1.1 Australia

Over 80% of Australia's surfaced road network (~350,000 km) is surfaced with hot bitumen sprayed seals (chipseals). Roughly 25% of the total bitumen market in Australia is modified with polymer (including crumb rubber). The practice of using crumb rubber modified (CRM) seals has been commonplace for the state road authorities in Victoria, New South Wales (NSW) and South Australia since the 1970s. More recently, Queensland and Western Australia have started the practice (Distin & Esnouf, 2018) because of the increasing awareness of the ELT waste problem and the introduction of the voluntary product stewardship scheme in 2014 (Tyre Stewardship Australia, n.d.). For example, in Queensland, MRTS11 *Sprayed Bituminous Surfacing (Excluding Emulsion)* (State of Queensland Department of Transport and Main Roads [TMR], 2019a) has been updated to permit contractors to substitute a CRM binder in many cases where a conventional polymer-modified binder (PMB) is specified. CRM sealing binders can be either field (mobile plant) or terminal (fixed plant) blended products and usually contain approximately 15% crumb rubber. In 2017, it was estimated that 21% of the total bitumen in Australia was modified (12.5% using synthetic polymers and 8.5% using crumb rubber).

CRM binder is classified as a PMB and used to increase flexibility and reduce the impacts of surface cracking. The first national specification for PMBs in Australia was published in December 1992 (Austroads, 1992). Numerous revisions were made in 1997 and 2000, and then a major update combining the specifications for both PMBs and multigrade binders was published by Austroads in 2006 (Austroads, 2006). In 2010, the specification was further updated and published as Austroads test method AGPT/T190 (Austroads, 2019), which was updated again in 2014 with the introduction of a 'consistency 6%' test parameter and the removal of the 'ease of remixing' test. The multigrade binders were also removed from the T190 specification framework because of the duplication in specifying this class of binders in the Australian bitumen specification AS2008 (Standards Australia, 2013). The latest revision as published in 2019 consists of the addition of an alternative method to determine viscosity at 165 °C, addition of a stress ratio binder property, and removal of consistency and elastic recovery binder properties. Other updates to the T190 framework are:

- the replacement of the 'rubber content by analysis' binder property for the class S45R binder with a stipulation that this binder class be manufactured from crumb rubber derived from used vehicle tyres
- the addition of a definition for field-produced CRM binders.

Austroads (2020) published the technical specification ATS3110 *Supply of Polymer Modified Binders*, which sets out the requirements for the supply of PMBs and CRM binders for use in both chipsealing and asphalt applications.

In Australia, the binder classes for PMBs are coded as **S** for Sealing applications or **A** for Asphalt applications, followed by a 2-digit numeral and a polymer code. In the case of S45R, the **R** stands for PMBs that contain crumb rubber derived from mechanically ground recycled vehicle tyres. In addition, the code **RF** is used where the crumb rubber binder is produced in the field. The clear definition is that field-produced CRM binders are simple blends of bitumen and crumb rubber produced close to the application site and are used within a short time frame. S45R (see Table 2.1) is a fixed plant blend, whereas S15RF and S18RF are field-blended (see Table 2.2). Table 2.3, as extracted from the T190 specification framework (Austroads, 2019), summarises the properties of the two grades of crumb rubber available for the CRM sealing binder classes. Crumb rubber must be sourced from waste tyres generated in Australia and processed by a Tyre Stewardship Australia accredited supplier and must be free from cord, wire, fluff and other deleterious material.

Table 2.1 Material test requirement for plant-blended CRM bitumen for sprayed sealing (adapted from Austroads, 2019, p. 6)

Test method	Minimum testing frequency	Binder property	S45R*
AS/NZS 2341.4 or AGPT/T111	Each batch	Viscosity at 165 °C (Pa.s) max.**	4.5
AGPT/T122	Each batch	Torsional recovery at 25 °C, 30 s (%)	25–55
AGPT/T131	Each batch	Softening point (°C)	55–65
AGPT/T125	Monthly	Stress ratio at 10 °C min.	to be reported
AGPT/T121	3-monthly	Consistency 6% at 60 °C (Pa.s) min.***	800
AGPT/T121	3-monthly	Stiffness at 15 °C (kPa) max.	180
AGPT/T132	3-monthly	Compressive limit at 70 °C, 2 kg (mm) min.	0.2
AGPT/T108	3-monthly	Segregation (%) max.	8
AGPT/T112	Annually	Flash point (°C) min.	250
AGPT/T103	Annually	Loss on heating (% mass) max.	0.6

* Class S45R binder shall be manufactured by the incorporation of crumb rubber derived from used vehicle tyres. To assist users in determining the quantity of added cutter oil required for spraying, the manufacturer shall report on the concentration and type of process oil used in the formulation.

** L series Brookfield is recommended together with spindle SC4-31, except in the case of S45R, where spindle SC4-29 is recommended. The shear rate involved in determining viscosity by AS/NZS 2341.4 and AGPT/T111 shall be calculated and recorded. AGPT/T111 has been retained to allow laboratories sufficient time to adopt AS/NZS 2341.4.

*** Consistency 6% at 60 °C shall be tested using mould A (breakpoint of 10 mm and a test speed of 1 mm/s).

Table 2.2 Material test requirement for field-blended CRM bitumen for sprayed sealing (adapted from Austroads, 2019, p. 8)

Property	Method	Minimum testing frequency	S15RF	S18RF
Nominal rubber concentration (%)	–	–	15	18
Rubber content by analysis (%) min.	AGPT/T142*	Weekly**	13	16
Torsional recovery (%) min.	AGPT/T122	Weekly	25	30
Softening point (°C) min.	AGPT/T131	Weekly	55	62
Consistency 6% at 60 °C (Pa.s)	AGPT/T121	Weekly	Report	Report

* A soxhlet extraction using toluene may also be used.

** The weekly sampling is from a sprayer load after digestion but prior to the addition of cutter oil. Samples must be free of diluents for subsequent testing to be meaningful. The agreed digestion period (at mixing temperature) must be completed before sampling.

Table 2.3 Material test requirement for crumb rubber used in bitumen modification (adapted from Austroads, 2019, p. 8)

Test	Method	Size 16	Size 30
Grading	AGPT/T143	–	–
Passing 2.36 mm		100	100
Passing 1.18 mm		80 min.	100
Passing 600 µm		10 max.	60 min.
Passing 300 µm		–	20 max.
Particle length (mm) max.	AGPT/T143	3	3
Bulk density (kg/m^3)	AGPT/T144	Report	Report
Water content (%) max.	AGPT/T143	1	1
Foreign materials – other than iron (%) max.	AGPT/T143	0.1	0.1
Foreign materials – metallic iron (%) max.	AGPT/T143	0.1	0.1

Recent experience has shown that CRM sealing binders can now be successfully transported for extended distances (2,000 km) and still conform at the point of use without segregation problems. This is managed by careful temperature control during storage and transportation as well as advancement in bitumen technology. CRM binders also perform as well as, if not better than, conventional PMBs when stored, handled and used correctly, and can be a lower-cost alternative to some conventional PMBs (see section 3.1.2).

Examples of the S45R products marketed by suppliers in Australia are SAMIseal (SAMI Bitumen Technologies, n.d.) and Olexobit (Puma Energy (Australia) Bitumen Pty Ltd, 2020a). Both of these meet the current Australian specifications (ATS3110 and AGPT/T190).

2.1.2 South Africa

In South Africa, CRM binders are known as ‘bitumen rubber’ and considered a non-homogenous modified binder because they typically consist of rubber crumbs (18–24%) partially dissolved in a bitumen matrix, whereas PMBs (modified with styrene-butadiene-styrene or styrene-butadiene rubber polymers) are classed as homogeneous modified binders (Southern African Bitumen Association [SABITA] 2015). Bitumen rubber in South Africa is largely based on technology imported from Arizona during the 1980s. Generally speaking, the rubber content used in South Africa is slightly higher than that used in Australia, and thus the higher spraying temperatures. However, there are new technologies that reduce the operational temperature significantly – these are discussed in more detail below. From the perspective of binder modification though, the principle is the same as that in Australia – that is, the modification improves the elastic properties of the binder. Additionally, 2–5% of liquid additive (eg, blending oil) is often added to further improve the compatibility and storage stability of the modified binder, which is measured by a standard segregation test. Table 2.4 shows the composition of bitumen rubber typically used in South Africa.

Table 2.4 Typical composition of bitumen rubber (adapted from SABITA, 2015, p. 23)

Component	Percentage by mass
Bitumen	72–82
Extender oil	0–4
Rubber crumb	18–24
High boiling point fluxing agent	0–4

Crumb rubber is also used in hybrid modified binders hot mix asphalt where blends of polymers/warm mix additives are used and the operating temperatures tend to be lower. The typical requirements (Table 2.5) for crumb rubber for modified bitumen in South Africa appears to be comparable to the ambiently ground rubber, Size 30 (Table 2.3), used in Australia.

Table 2.5 Property requirement for crumb rubber used in bitumen rubber (adapted from SABITA, 2015, p. 23)

Property	Requirement	Test method
Sieve analysis (by % mass) Passing screen 1.0 0.600 0.075	 100 40–70 0–5	MB-14
Fibre length (mm)	6 max	–
Bulk density (kg/m^3)	300–400	MB-16

In conventional bitumen rubber manufacture, crumb rubber and bitumen are blended at temperatures in excess of 180 °C and the process involves the absorption of some of the maltene fraction of the bitumen into the rubber, causing the partial digestion and swelling of rubber and thus a significant increase in the binder viscosity. The reaction time of the rubber is normally at least 45 minutes, but it must also be noted that if the rubber is fully digested, then the desired properties of the CRM binder will be lost (SABITA, 2015). Therefore, careful management of time and temperature is critical to the production of a successful CRM binder.

Studies (SABITA, 2015) have shown that as the CRM binder cools down, the partially digested rubber particles form a rubber network that is filled with bitumen, and it is the rubber network that contributes to the improved cohesion, elasticity, flexibility, re-healing capabilities and strength of the material. The stone retention properties and resistance to bleeding and deformation are also enhanced.

CRM binder in South Africa (SABITA, 2021) is classified as S-R1 and S-R2. **S** as in ‘Spray’ seal, **R** for ‘Rubber’, and **1** as in the level of modification. The higher the number, the higher the softening point value of the binder. The key properties of the CRM binders for surfacing seals are summarised in Table 2.6.

Table 2.6 Material test requirement for different types of CRM sealing binder (adapted from SABITA, 2021, p. 60)

Property		Unit	Test method	S-R1	S-R2
Softening point		°C	MB-17	55–65	65–80
Dynamic viscosity @ 190 °C		dPa.s	MB-13	20–40	–
Dynamic viscosity @ 170 °C					10–40
Compression recovery	5 minutes	%	MB-11	> 70	> 70
	1 hour			> 70	> 70
	24 hours			> 40	> 25
Resilience @ 25 °C		%	MB-10	13–35	10–40
Flow @ 60 °C		mm	MB-12	15–70	0–40

Since the early 2010s, Tosas, a South African bituminous product manufacturer, has promoted New Crumb Rubber Technology in South Africa (Hannes Lambert, Tosas, pers. comm., 24 March 2021). New Crumb Rubber Technology is the tradename for what is essentially a warm mix technology bitumen rubber (WMTBR). This is classed as S-R2 in the South African specification. The fundamental difference between WMTBR and conventional bitumen rubber is similar to the technology advancement in Australia – that is, the WMTBR is much more stable (during transport over distances > 1,500 km) and able to be used at lower temperatures than conventional bitumen rubber. This not only has advantages in terms of health and safety and environmental impact, but also reduced operational risks due to improved stability.

2.1.3 Adoption of overseas specifications to New Zealand

If crumb rubber technology is to be implemented in New Zealand, a test specification for crumb rubber feedstock similar to Table 2.3 or Table 2.5 needs to be introduced. With regard to binder specifications, a performance-based specification (M01-S) for sealing binders is currently under development in New Zealand. In principle, the draft M01-S specification should be able to cover the performance-based properties of CRM binders because the specification is designed to be blind to composition. This needs to be investigated further during the implementation stage of the M01-S specification.

In South Africa, current opinion is that their Performance Grade binder specification is insufficient to properly evaluate binder performance of the newer technologies. Therefore, some practitioners still revert back to earlier empirical tests.

If required, all specified test methods highlighted in the tables in section 2.1 could be easily adopted in New Zealand, except for one specialist test method – ‘Consistency 6%’ test (AGPT/T121) – which requires a unique piece of equipment (Australian Road Research Board elastometer). This instrument is no longer manufactured, and it is understood that there is currently research funded by Austroads to investigate an alternative test method based on the dynamic shear rheometer to replace the elastometer-based test.

2.2 Seal designs

2.2.1 Australia

In Australia, the design of sprayed seal (chipseal) treatments is to be undertaken in accordance with the Austroads *Guide to Pavement Technology Part 4K* (Austroads, 2018) and Austroads Technical Report AP-T310-16 *Selection and Design of Initial Treatments for Sprayed Seal Surfacings* (Patrick, 2016). Exceptions can be made with individual state road authorities. For instance, in Western Australia, *Engineering Road*

Note 15: Sprayed Seal Design (Main Roads Western Australia [MRWA] 2017) provides supplementary guidance on the design of chipseal treatments. In Australia, PMBs are used in the following seal types:

- high-stress seal (HSS)
- extreme-stress seal (XSS)
- strain-alleviating membrane (SAM)
- strain-alleviating membrane interlayer (SAMI)

For example, in Victoria, Standard Specification Section 408 (VicRoads, 2020) identifies that S45R and S15RF are suitable for HSS, XSS and SAM, and S18RF is more appropriate for SAMI applications. Note that bitumen incorporating less than 5% crumb rubber is considered an unmodified bituminous binder.

2.2.2 South Africa

CRM binder (bitumen rubber) has been used in South Africa since the early 1980s and remains the preferred binder to retard crack reflection, extend pavement service life and to prolong high macrotexture. Bitumen rubber is often used in a SAMI and in single-coat seals (with Grade 3 chip) on very high-volume roads (> 4,500 vehicles per lane per day). Double seals (comparable to a two-coat seal in New Zealand) are often used as reseals on high-volume roads with a combination of binders in which S-R1 or S-R2 (see Table 2.6) is used in the tack coat only. The double seal using two layers of bitumen rubber has also been used successfully as a holding action to postpone pavement rehabilitation for several years (Jooste, 2011).

Most practitioners in South Africa recognise the risks associated with specifying bitumen rubber in a double seal. This is due to the risk of flushing and poor skid resistance. As an alternative, the industry has created several split-application double seals consisting of 20 mm and 7 mm aggregate (approximately Grade 2 and Grade 5, NZTA M/06) where the bitumen rubber is used only for the first coat, and the second coat is applied with a diluted PMB emulsion (van Zyl & Fourie, 2018). While this has been proven to reduce risks, such practice would require two sprayers on site and significantly increase the cost of operation in New Zealand. This would need to be carefully considered, especially when the New Zealand industry is changing to emulsion.

The minimum practical hot application rate is 1.8 L/m^2 for S-R1 and 1.6 L/m^2 for S-R2 and winter grade products. It is recommended that due to the contractor's allowance for variation, the minimum application rates should be increased by 5–10% (SABITA, 2021, Tables E6 and E7). For a typical 14 mm single seal using a CRM binder (S-R1), the recommended application rate is between 2.0 and 2.5 L/m^2.

Aggregate spread rates can be found in Table F3 in SABITA Manual 40 (SABITA, 2021). It has been noted that the risk levels associated with the use of bitumen rubber for single and double seals can be 'very high' for inexperienced contractors, even with pre-coated chip. This should be considered when planning for a field trial in New Zealand.

2.2.3 Discussion

The seal design methodologies are well established in both Australia and South Africa, and these can be used as benchmarks for New Zealand. The binder application rate needs to be increased by at least 10–20% when a CRB is used in the seal design. While this directly translates to an increase in cost, the potential life extension could offset the cost increase. This is discussed further in section 3.

2.3 Construction requirements

In 1985, MRWA, in conjunction with VicRoads (Victoria) and Roads & Traffic Authority (NSW), prepared a practical guide for the industry to use CRM binders in both chipsealing and asphalt (MRWA, Roads & Traffic Authority, & VicRoads, 1985). The guide highlighted the compositional variation between passenger car tyres (high in synthetic styrene-butadiene rubber) and truck tyres (high in natural rubber). The guide also highlighted the effect of rubber composition on the property of elastic recovery of the CRM binder.

It has been noted that both natural and synthetic rubber behave satisfactorily during digestion in bitumen and perform well in practice. While natural rubber tends to be incorporated better than synthetic rubber, the conditions required for the digestion process are much more stringent.

It is recognised that CRB manufacturing requires continual assessment and testing. The base bitumen and crumb rubber have a set of chemical properties that need to be tested and evaluated on a continual basis (explaining the frequency of tests specified in both Australian and South African specifications). The chemical composition of the bitumen plays an important role in the formulation and compatibility with the crumb rubber and vice versa. Therefore, adjustments are made via additives to compensate for the variation in grade and source of bitumen.

A key consideration for both the roading industry and the ELT recycling industry is whether or not to sort the ELT waste stream and to set a benchmark of the mix of truck and passenger car tyres. If the composition of crumb rubber (ie, the amount of natural vs synthetic rubber) can be controlled and kept consistent, then the processing and quality of the final modified binders can be less variable.

A series of guides were developed and produced by the Austroads PMB Project Group in the late 1990s and early 2000s (Austroads & Australian Asphalt Pavement Association [AAPA], 2000, 2001, 2015). The series refers to practices specifically for PMBs used in Australia.

A major difference in using PMBs in chipsealing work, compared to unmodified bitumens, is that increased binder consistency and poor wetting characteristics make it more difficult to obtain initial aggregate adhesion. Hence, special attention is required to be paid to:

- condition and pre-coating of aggregate
- use of adhesion agents
- ambient conditions
- cutting procedures
- speed of covering and rolling.

For instance, in Queensland, MRTS18 (TMR, 2020a) specifies that the contractor shall prepare documented procedures for all required processes as defined in Clause 6 of MRTS50 *Specific Quality System Requirements* (TMR, 2021), and be consistent with the requirements of ATS3110 *Supply of Polymer Modified Binders* (Austroads, 2020), MRTS11 *Sprayed Bituminous Treatments* (TMR, 2019a), and the binder manufacturer's recommendations, as appropriate. These procedures must be included in the respective asphalt quality plan or construction procedure specified in MRTS30 *Asphalt Pavements* (TMR, 2020b), or MRTS11 *Sprayed Bituminous Treatments*, as appropriate. For field- or plant-blended CRM binders, the procedures must address the following specific issues:

- the management of crumb rubber blending, digestion, and storage times and temperatures
- the maximum time/temperature conditions that field-produced/plant-blended product can be stored and/or transported without loss of properties
- circulation of the product during transportation and storage

- method for achieving a homogeneous product that can be sprayed to achieve a uniform application of binder across the pavement during sealing operations, free of streaking
- requirements for spraying plant and spraying practices, including adjustments to nozzles (if required).

MRWA (2003) provides guidance on the specifications of rubber granules that are added to bitumen to produce a rubberised binder, and the equipment requirements and field procedures for best practice CRM sprayed sealing. Based on the state road authority guides, AN36 or AN27 (formerly known as B8 or B6, respectively) nozzles should be used for spraying S45R binders.

Based on practice in Australia and South Africa, the following subsections cover specific material requirements for successful construction of CRM binder chipseals.

2.3.1 Pre-coating

The prerequisite for chipsealing aggregate in Australia is that the aggregate must be clean, dry, and of good quality. *Pavement Work Tips – No. 27* (Austroads & AAPA, 2001) states that pre-coated aggregate should be used for spraying PMBs in order to maximise adhesion. In Western Australia, it is common practice to pre-coat aggregate with distillate, or if preheated aggregate is used, with bitumen. In NSW, section 8 of *QA Specification R107: Sprayed bituminous surfacing* (Transport for NSW, 2020, p. 12) specifically states to 'use only precoated aggregate'.

In South Africa, according to Chapter 9 of the *South African Pavement Engineering Manual* (South African National Roads Agency Limited, 2014), it is essential to use pre-coated aggregate when bitumen rubber is used. In all instances of hot applied modified binders, it is recommended that the aggregate should be pre-coated using a bitumen-based pre-coating fluid containing at least 0.5% adhesion agent to improve both initial and long-term retention of the aggregate (South African National Roads Agency Limited, 2014). Pre-coating the surfacing aggregate will improve binder–aggregate adhesion by reducing the surface tension between the two interfaces (refer to SABITA (2006) Manual 26 for more information on best practices for pre-coating aggregates). When emulsions or highly cut back binders are used, then pre-coating is not required.

It must be noted that pre-coating is no longer a common practice in New Zealand. Therefore, it would require a change in specification and industry practice to meet both technical and environmental management of such operations. Based on current technology and best practice in Australia and South Africa, pre-coating is hugely beneficial to the adhesion of the modified binder to the aggregate. The practice limits the risk of water-induced stripping and improves early adhesion and wetting of the chip. The use of pre-coated chip is likely to add extra cost to the chipsealing operation. In New Zealand, the chip adhesion concern is normally addressed using cutback or emulsified binder to help chip wetting and coating. Adhesion agent is added to minimise water-induced stripping.

2.3.2 Blending oil (flux oil)

The compatibility of a polymer can be defined as its ability to remain distributed in the bitumen without phase separation occurring. This property is therefore an important attribute during handling and storage of the modified binder. However, the degree of compatibility varies by bitumen and by type and grade of polymer (including crumb rubber) used in the formulation of the PMB.

In a modified bitumen, there is competition between the modifier and the naturally occurring asphaltenes for the available maltene portion (resins and aromatics) of the bitumen. This competition varies with the type and source of both the bitumen and the polymer, and this will affect the compatibility of the final product. Hence, extender oil is sometimes added to the bitumen rubber blend to improve the degree of compatibility. Total incompatibility could cause segregation and even gelling. The oils also can reduce the spraying temperature when used in chipseal binders. This practice is sometimes used for plant-blended products (eg, S45R). Note that when oils are used with the high operating temperatures of modified binders, the combination can result in an increase in fuming.

The segregation or stability test as described in AGPT/T108 (Australia) and MB-6 (South Africa) is used to determine the compatibility of the base bitumen and the polymer in question and to assess the hot storage stability of the material.

As the application of mechanical stirring will inhibit segregation of the different components during storage, the stability test should be used by manufacturers as an indicator of whether stirring of their product is required or not. Also, whenever there is any reason to believe that the chemistry of the base bitumen has changed, the test should be repeated.

This issue is not specific to crumb rubber, it also applies to PMBs, so the New Zealand industry would continue to manage this as it is currently doing.

2.3.3 Cutter/Adhesion agent

As discussed earlier, modification of bitumen with polymers or crumb rubber tends to increase the cohesion of binders, and to render them more elastic at the expense of reducing the binder's ability to 'wet' the aggregate, resulting in the possible reduction of adhesion between the binder and stone. The reduction in adhesion could become critical when constructing a surfacing seal using hot sprayed binder during cooler and wetter weather conditions. It is not uncommon for some modified binder seals to perform adequately in warm and dry conditions but to lose a considerable portion of aggregate during the first cold wet weather if best practice is not followed.

In Australia, based on *Pavement Work Tips – No. 27* (Austroads & AAPA, 2001), adhesion agents should always be added to hot PMBs used in chipsealing work. It is generally added in amounts double the concentration used for unmodified bitumen. In general, the binder must have a sufficiently low viscosity at the time of sealing to achieve adequate initial wetting of aggregate. Where the pavement and/or surface temperature is too low to achieve the necessary viscosity for the particular binder, cutting of the binder may be required to achieve this viscosity (TMR, 2019a). *Pavement Work Tips – No. 14* (Austroads & AAPA, 2010) and *Pavement Work Tips – No. 27* (Austroads & AAPA, 2001) provide guidance on appropriate cutter rates for bitumen and PMBs for applications other than SAMI seals. In addition to the guidance provided in the *Pavement Work Tips*:

- for double/double seal applications, where the second application is applied with little or no trafficking between applications, the proportion of cutter oil in the first application should be reduced to:
  - 0–2 parts for bitumen and PMBs (other than CRM binders)
  - 2–4 parts for CRM binders.
- consider reducing the recommended proportion of cutter oil given in *Pavement Work Tips – No. 14* (Austroads & AAPA, 2010) by up to 2 parts when pavement temperatures are rising (eg, early morning and/or during abnormally cool days in warmer seasons).

In Western Australia, examples of the approved adhesion agents (MRWA, 2020) are:

- Bitumite concentrate
- Diamin TO-L
- Redicote BE
- Rhodoval DA 410
- Aggrebond PC

- Evotherm PC 1770.

A minimum of 1.0% of an approved concentrated adhesion agent should be included in the binder. Cutting oil is also recommended at various percentages for varying road temperatures and binder rubber content. In general, the amount of cutter used would be determined by local weather conditions and Australian state road authority guidelines (MRWA, 2018, 2020).

While the addition of a cutter may solve, or reduce, a potential adhesion problem in the short term, problems have been experienced with respect to bleeding/flushing of the surface during subsequent hot periods, especially in heavy duty applications. Therefore, it is recommended that this practice should only be considered when spraying at the end of the summer season before the onset of winter. In South Africa, kerosene is not used with CRB because the rubber crumb will absorb and retain the kerosene for extended periods. Therefore, only a higher flash point flux oil is used if required.

The addition of adhesion agent in CRB is also not practised in South Africa because most adhesion agents will deteriorate very rapidly at the relatively higher temperatures that the South African CRB (bitumen rubber) is produced at.

The use of cutter and adhesion agent is well established in New Zealand, so this does not pose any technical barrier should the industry adopt any crumb rubber technology. However, the increased dosage level for adhesion agent (1% versus 0.5–0.7% in New Zealand) would increase cost of operation. This would need to be investigated further to determine an optimum level of additives.

The other key issue to be considered here is the industry's move away from cutback bitumen because it would not make sense to promote a product that requires the use of kerosene cutter and high spray temperatures. This could be the main impediment to adoption of crumb rubber in chipsealing practice in New Zealand unless:

- special exemption is made to allow the use of CRM chipseals
- CRB can be emulsified to reduce handling temperatures as well as to eliminate the needs for cutter and potentially other additives.

2.3.4 Emulsification

There is no published work covering emulsified CRM bitumen products available in Australia and South Africa, and there has not been a need for an emulsified CRB product in either of these markets since CRB was implemented. However, this needs to be explored further because New Zealand is now considering moving away from hot cutback bitumen to emulsions.

While it is technically feasible to emulsify CRM binders, emulsification is much more difficult than when using standard binders because of the high temperatures required for handling these binders and their non-homogeneous nature. In South Africa, emulsification of bitumen rubber has been investigated. Due to the non-homogenous nature, the particles tend to precipitate to the bottom after emulsification when the current binder grading is used. Their experience has shown that in order to emulsify a CRB, a lower concentration of crumb rubber is required for the rubber particles to go through the milling system and to be fully digested. As the rubber is fully digested, this product will possess different properties to a conventional bitumen rubber.

As reported by Wu et al. (2015), there are reports of crumb rubber having been successfully incorporated into emulsified binders. The principle behind one technology is to add a solvent-based dispersion of crumb rubber of high concentration (40–50%) into a bitumen emulsion by simple blending (Holleran et al., 1997; Holleran & Reed, 2000).

It has been shown that plant-blended CRB, being of lower viscosity, can be emulsified directly and thus used as conventional bitumen emulsions (Pacific Emulsions Inc, 2009). The caveat is that the percentage of crumb rubber used is no more than 5–10%. This may result in CRM surfacings falling short of the expected full-performance benefits that are typically obtained at 15–20% loadings.

An alternative method for emulsifying CRM binder involves first partially devulcanising the crumb rubber prior to binder modification. The devulcanisation process (Wu et al., 2015) removes some of the sulphur crosslinks and enables crumb rubber to be incorporated into bitumen in a similar manner as virgin SBS polymers, resulting in a homogenous binder with a significantly reduced high-temperature viscosity suitable for emulsification (Subhy et al., 2015; Zanzotto & Svec, 1996). Note that devulcanised rubber modified binder is a different product than conventional CRM binder from vulcanised tyre rubber.

The current initiative by the contracting industry to move away from cutback bitumen poses a critical hold-point for implementation of crumb rubber technology in chipsealing in New Zealand. This drive towards lower temperature emulsion products to minimise the risk of injury means that emulsification may be potentially the only viable path for crumb rubber to be used in chipsealing in New Zealand. Further development and trial of such technology is needed. It should be noted that CRB still has viable markets in other roading applications such as asphalt, but this is not discussed in detail in this study.

2.3.5 Minimum surface temperature

In Australia, Transport and Main Roads Specification MRTS11 (TMR, 2019a) requires that spraying shall not commence until the temperature of the pavement surface is above the temperature given in Clause 6.2 of Annexure MRTS11.1 (TMR, 2019b) or, if not so given, the following pavement surface temperature for at least one hour before spraying commences: 20 °C for treatments containing bitumen (ie, Class 170 and 320 bitumen) that does not contain cutback, multigrade bitumen (ie, M500 bitumen) and crumb rubber binders (ie, S45R, S15RF and S18RF binder classes). In Western Australia, according to *Specification 509: Polymer Modified Bituminous Surfacing* (MRWA, 2018) the minimum temperature for spraying rubberised binder is 20 °C, and various amounts of cutting oil are recommended depending on pavement surface temperature and traffic.

Similarly, SAMIseal's S45R product technical datasheet (SAMI Bitumen Technologies, n.d.) states that the recommended minimum pavement surface temperature is 20 °C for spraying this product when used with cutter, and 45 °C is recommended if the product is used without cutter.

Similarly, in South Africa (SABITA, 2015, 2021), if no cutter is used, then the surface temperature needs to reach 25 °C and continue to rise above 30 °C. Because the maximum surface temperature is likely to be below 25 °C in shaded areas, cutter should be considered. However, in the scenarios where cutters are inappropriate, then there are alternative options:

- increase binder application rate by up to 20%
- start the application in the shaded areas and ensure the distance between the sprayer and chip spreader is kept to a minimum
- use emulsified binder (this applies only with PMBs, see section 2.3.4)

The minimum surface temperature requirements used in Australia and South Africa reinforce the importance of good construction practice, and the role that additives and processes play in reduction of construction risks. In practice, this will inevitably restrict the construction window for CRM chipseals given New Zealand's climate. The ability to lower the working temperatures of crumb rubber binder products will alleviate the risks of applying these products in the cooler conditions.

2.3.6 Spraying temperature

Based on the guidelines from various Australian state road authorities (MRWA, 2018; TMR, 2019a; Transport for NSW, 2020) the spraying temperature window for S45R is 190–200 °C. In South Africa (see Table 2.8), bitumen rubber binders are generally applied at higher temperatures (160–210 °C). Because the spraying temperature is relatively higher than the typical temperature window of PMBs (170–180 °C), unmodified cutback bitumen (140–170 °C), and bitumen emulsions (80–90 °C), appropriate personal protective equipment needs to be worn by the workers who handle the material during production as well as construction. Table 2.7 gives examples of recommended spraying temperatures of some Australian products.

Table 2.7 Examples of recommended temperatures for S45R products

		SAMIseal S45R*	Olexobit S45R**
Recommended spraying temperature range (°C)		190–200	180–190
Maximum storage temperature (°C)	Up to 2 days	185–195	160–175
	Up to 4 days	120–140	145–155
Minimum pumping temperature (°C)		n/a	150

* SAMI Bitumen Technologies (n.d.)
** Puma Energy (Australia) Bitumen Pty Ltd (2020a)

For example, SAMI S45R has a minimum recommended spraying temperature of 190 °C, and the product requires constant circulation to maintain homogeneity. It is highlighted that the product cannot be heated above 200 °C in storage, and in general, storage for prolonged periods at elevated temperatures should be avoided as quality may be adversely affected. That is, this will promote segregation and deterioration of the binder properties. The best practice is that bituminous binders should be stored at the lowest temperature that enables practical use. *AAPA Advisory Note 7* (AAPA, 2019) states that the rate of increase in temperature shall not exceed 15 °C per hour. For products such as SAMIseal S45R, a maximum rate of increase of 10 °C per hour is recommended.

Table 2.8 Recommended time and temperature range for bitumen rubber and WMTBR in South Africa

	Short-term handling		Storage		Spraying/application		
	Max temp (°C)	Max holding time (hrs)	Max temp (°C)	Max holding time (hrs)	Max temp	Min temp	Max holding time (hrs)
S-R1	170	24	150	240	210	190–195	Refer to time/viscosity curve
S-R2	170	24	150	240	190	180	n/a
WMTBR	170	n/a	150	n/a	170	165	n/a

The general spraying and handling temperature of conventional CRM binders is relatively high compared to normal cutback bitumen sealing practice in New Zealand. PMBs are now sprayed as emulsified products, so careful consideration needs to be taken around how the CRB is delivered in New Zealand. As discussed previously, apart from adoption of warm mix technology to reduce handling temperatures of CRB, emulsification of CRB would be the ultimate solution to overcome the relatively high spraying temperatures.

Reduction of handling temperatures would address the health, safety and environmental issues, which are discussed in more detail below.

2.4 Health and safety

There is a comprehensive list of recommended controls to mitigate against safety hazards identified from a typical operation using CRM binder in asphalt wearing courses (SABITA, 2019), most of which are basic requirements for standard, unmodified bitumen operations. For field-blended operations, it is important to avoid any water getting in contact with bitumen and thus creating reactive bitumen foaming and ‘boil over’. Care must be taken to ensure that the rubber crumbs are dry before adding them to the hot bitumen. In addition to the general heat and spill hazards, small quantities of highly aromatic oils are sometimes used as extenders in the manufacture of bitumen rubber. These extender oils can contain high concentrations of potentially harmful polycyclic aromatic compounds, also referred to as polycyclic aromatic hydrocarbons.

Numerous studies in the USA and Europe have been conducted on the health effects of occupational exposure to ‘conventional’ bitumen and modified bitumen, including CRB. Of particular interest is a study published by Burr et al. (2001) for the National Institute for Occupational Safety and Health, titled *Crumb-Rubber Modified Asphalt Paving: Occupational Exposures and Acute Health Effects*. These studies have found that at very high temperatures the presence of additives (ie, extender oils) increases the potential for emission of bitumen fumes during blending and paving operations. The studies found, however, that the measured concentrations of bitumen fumes at recommended processing temperatures were very low, and within the prescribed occupational exposure limits. Diligent temperature control during processing of bitumen rubber is therefore a cardinal rule for quality, health and safety control purposes.

While the measured levels were low and well below the recommended maximum threshold, studies do suggest that worker exposures to CRM binder fumes are potentially higher during paving operations, particularly at job stations near the paver or asphalt delivery trucks. Eye, nose and throat irritation were the symptoms most frequently reported.

The study (Burr et al., 2001) suggested that worker exposure in close proximity to binder distributors/pavers and delivery trucks should be assessed on site and, if necessary, measures must be implemented to minimise exposure to fumes. Chipsealing operations are different to those of asphalt paving and may expose workers to higher risks – for example, when workers are positioned downwind of the bitumen sprayer.

In practice, minimising personal exposure is the only practical way to control the potential ill health effects of CRM binder fumes or, in fact, any bitumen fumes. The following control measures must be given due consideration in blending and application methodology as well as operating procedures:

- Keep a risk register and manage specific tasks where workers are at increased risk of exposure.
- Provide education and training to key personnel, and make sure they understand the safety data sheet for the specific modified bitumen.
- Where practicable, target the lowest operating temperature and follow best practice for handling and application.
- Minimise exposure to fumes by ensuring adequate ventilation and safe work practices at the work site.
- Provide appropriate respiratory protection for any personnel working in areas where fumes are likely to be in their breathing zone at concentrations above the occupational exposure limit.

WorkSafe New Zealand (2020) published the *Workplace Exposure Standards and Biological Exposure Indices* as guidelines for people qualified in occupational health practice to be used as risk criteria for assessment and management purposes.

In addition to emissions, from a safety perspective, the general practice of cutting back hot binders is a hazardous operation because the blending temperature of the binder is well in excess of the cutter's flash point. This is the same for CRM binder production and handling. Therefore, this operation should only be undertaken under controlled conditions such as in a blending plant.

There are specific guides for the control of health, safety and environmental hazards associated with the field production of cutback bitumen in Australia and South Africa. Thus, special care must be taken of all the factors that could affect the performance of the new seal if the modified binder is cut back.

In both Australia and South Africa, there has been no need for the product to be emulsified because engineering measures are put in place to mitigate operational, health and safety risks. However, it is generally recognised that if the handling temperature can be reduced, then the associated health and safety hazard and potential consequences can be further mitigated. The key question remains whether or not the handling temperature of CRB can be reduced adequately via warm mix technology and/or emulsification.

2.5 Environmental impacts

Bitumen is considered a non-ecologically toxic product that does not present any significant danger to plant and aquatic environments. In Australia, S45R is classed as a dangerous good but a non-hazardous chemical as per the Work Health and Safety Regulations and the Australian Dangerous Goods Code.

According to the safety data sheet for the commercially available Puma S45R product (Puma Energy (Australia) Bitumen Pty Ltd, 2020b), the components in its S45R are:

- > 75% road-making bitumen (8052-42-4) or air-blown bitumen (64742-93-4)
- < 25% crumb rubber
- trace amount of hydrogen sulphide (7783-06-4).

  Note that hydrogen sulphide is generated through reaction of the crumb rubber and bitumen during heating of the product and is not added as part of the formulation.

2.5.1 Binder spills

It should always be noted that large spillages of hot liquid bitumen, regardless of the binder composition, could have a devastatingly acute local effect on the natural environment, especially plant life. Spill prevention and recovery measures (secondary containment) should always be a top priority in the design and operation of CRM binder blending, transport and paving facilities.

2.5.2 Air emissions

Since the early 1990s, a number of studies (Albin, 2018; Burr et al., 2001; Environmental Protection Agency, 1995; Gunkel, 1994; Hanley & Miller, 1996) have been conducted in Europe and the USA to evaluate fume emissions from CRM binder and mix manufacturing and paving sites. Conclusions from these studies suggest that:

- stack emissions from the production of CRM binders are not significantly different than those from the production of conventional materials
- odours emanating from CRM binders are not significantly stronger than those from conventional bituminous products. (Noticeable odours were generally confined in close proximity to loaded haul trucks.)

Nevertheless, in South Africa, users are urged to ensure that emission controls required in terms of the Air Quality Act 2004 are properly maintained and carefully monitored to ensure that emission limits are not exceeded. In Australia, WorkSafe Australia has exposure standards for reference. Relevant standards for Australia, South Africa and New Zealand are presented in Table 2.9.

Tyre Stewardship Australia has recently funded projects in Victoria and Queensland to investigate environmental impacts of crumb rubber use during manufacture and construction of road surfacings. In late 2020, the Victorian Department of Transport published an emission monitoring report for a CRM asphalt trial. The purpose of the monitoring was to assess the operator exposure to volatile organic compounds/petroleum hydrocarbons, total suspended particulates, polycyclic aromatic hydrocarbons and benzothiazole during laying of the different asphalt products and to qualitatively assess any feedback of symptoms/irritations amongst three crew members. In summary, the levels of volatile organic compounds and total suspended particulates were well below the SafeWork Australia standards. Similarly, for polycyclic aromatic hydrocarbons, none of the detectable compounds are classified as carcinogenic, and the levels were well below the SafeWork Australia workplace exposure standard. The study also did not find any correlation between benzothiazole levels and symptoms reported by the crew members. Finally, in terms of bitumen fumes, the study found that the exposure level was generally higher for the control mixes (without crumb rubber) than for the CRM mixes. The earlier study, conducted in Queensland, showed the addition of warm mix additives was able to reduce the operating temperature by 20 °C and to reduce the amounts of volatile organic compounds and polycyclic aromatic hydrocarbons released into the air to make them comparable to products made from another PMB. The general conclusions of these recent studies indicate that the use of crumb rubber in asphalt can be achieved without generating additional harmful emissions during the road construction process when compared to conventional PMB asphalt.

The majority of these studies have focused on asphalt mix and paving operations with varying outcomes. However, the general principle applies that as temperature increases, the level of emissions of both hazardous compounds and greenhouse gases is likely to increase. Ultimately, efforts must be made to reduce the operating temperature of CRB products for better uptake in New Zealand. Detailed monitoring of air emissions should be included as part of the next phase of investigation.

Table 2.9 Standards for exposure to CRM binder related emissions

	Australia	South Africa	New Zealand
Emission	**Time-weighted average/ Short-term exposure limit**	**Follows American Conference of Industrial Hygienists threshold limit values**	**Time-weighted average/ Short-term exposure limit**
Total suspended particulates	Not available	Not available	**High** (Waka Kotahi, 2019) • 60 µg/m^3 (24-hour rolling average) • 200 ug/m^3 (1-hour average) • 250 ug/m^3 (5-minute average) **Moderate** • 80 µg/m^3 (24-hour rolling average) • 250 ug/m^3 (1-hour average) **Low** • 100 µg/m^3 (24-hour rolling average)

	Australia	South Africa	New Zealand
Polycyclic aromatic hydrocarbons	Naphthalene only 10/15 ppm (52/79 mg/m^3)	Not available	Particulate polycyclic aromatic hydrocarbons 0.2 mg/m^3
Benzothiazole	Not available	Not available	Not available
Bitumen fumes	5 mg/m^3 (time-weighted average)	5 mg/m^3 (time-weighted average)	5 mg/m^3 (time-weighted average)
Rubber fume (as cyclohexane soluble material)	Not available	Not available	0.6 mg/m^3
Volatile organic compounds	Not available	Not available	Not available
Hydrogen sulphide	Not available	14/21 mg/m^3	7/14 mg/m^3

2.5.3 Odour

In Australia, while the use of CRM chipseals is well established, the uptake of CRM binder in asphalt has been slow due to logistics of handling the CRM binder in hot mix plants and the fume/odour associated during manufacture, transport and construction.

As stated in the Waka Kotahi (2019) *Guide to Assessing Air Quality Impacts from State Highway Projects*, odour emissions resulting from state highway construction activities are assessed on a case-by-case basis against guidelines set by the *Good Practice Guide for Assessing and Managing Odour* (Ministry for the Environment, 2016). However, there is a requirement that any odour associated with construction activities will not result in 'odours that are offensive, objectionable or noxious' beyond the boundary of the works (designation). The odour generated from both manufacturing and construction activities needs to be considered and mitigated when practicable.

In New Zealand, odours are typically managed under the Resource Management Act 1991 (RMA), although other legislations such as the Health Act 1956 may also be relevant. Under the RMA, regional councils are responsible for managing discharges of contaminants into the air. Councils are responsible for monitoring compliance with resource consent conditions applied to odour discharges, and for responding to complaints about new and/or offensive odours.

While there are no legislative requirements for the applicant to engage with the stakeholders under the RMA, stakeholders would be consulted as part of the environmental management plan for the project. Given that the plant required to use crumb rubber in bitumen modification will be defined as 'new or modified facilities' in New Zealand, the key requirement is to apply for resource consent as part of the preparation for a field trial. The trial should also be designed to minimise exposure. The key management tools include:

- community consultation (those likely to be impacted after design consideration to minimise exposure)
- experience and knowledge from other sites of a similar nature, scale and location, including consideration of appropriate separation distances (in this case, experienced personnel from Australia)
- site management and contingency plans (inputs from both local and offshore contractors)
- process controls and design, including details of emission controls and engineering risk assessment for system failures
- odour treatment and control as part of the environmental management plan to monitor and assess options during the trial.

In terms of odour treatment options and control, there are numerous technologies to choose from. The majority of the technologies designed for the bitumen industry tend to be scrubbing and adsorption systems. These can be wet-gas scrubbing, gas-to-gas oxidation, or solid-phase systems that can remove or change the chemical composition of odorous contaminants.

It should be noted that some of the reagents, particularly those that are oxidising or reducing, have their own odour and may result in a visible plume, which may be an issue in some areas. With adsorption systems, contaminants attach or condense onto the surface of an adsorbent, which is a porous solid. Carbon, zeolite, bentonite and polymer adsorbents have been used to adsorb volatile organic compounds and other pollutants from relatively dilute discharge concentrations. Other adsorbents used include alumina, activated clay, silica gel and molecular sieves. Some adsorbents can be regenerated by desorption and the media used again. The compounds emitted can sometimes be recovered and reused. For example, Desotec markets activated carbon filters in addition to wet scrubbers to reduce bitumen fumes from air coming from bitumen mixing plant, storage tanks, and production lines.

Another example of an odour suppressant, which was demonstrated in a rubberised asphalt trial in New Zealand in recent years, was a product called Ecosorb from OMI Industries. The particular product type was 606A, which was targeted for standard bitumen. The supplier claims that the dosage can be as little as 1 in 10,000 unit volume to be effective in eliminating odours from bitumen. After direct consultation with the distributor in Australia (Cam Waddell, Odour Management and H2O Management, pers. comm., 24 March 2021), it is understood that there are actually three other product variations targeting different bituminous blends: Ecosorb 206A (heavy PMB), 806A (medium PMB), and 1200A (high sulphur bitumen). It is a proprietary formulation containing different essential oils and food-grade surfactants as a means of odour control. This product can be added at any stage of the manufacture. However, it does have a maximum working temperature of 175 °C, beyond which the effectiveness of the product is compromised.

Based on the safety data sheet provided for Ecosorb 206A, the chemical mixture is not classified as a hazardous chemical under the Globally Harmonised System in Australia. As of 30 April 2021, New Zealand has also adopted the Globally Harmonised System. The product is considered not harmful to aquatic organisms nor to cause long-term adverse effects in the environment, and it contains no harmful volatile organic compounds. The handling requirements are standard for most liquid chemicals. The supplier does offer alternative treatment methods because it may not always be practical to use additives in a fixed plant or other storage facilities, especially with long-term storage tanks that vent foul odours. Therefore, it is possible to collect vent gases and port them to a misting vessel of chemical adsorbent. The mist removes odours before they are released into the atmosphere during tank cleaning.

Based on the consultation with a supplier in Australia, the recommended odour suppression product for CRM bitumen is ECO-206A at the application rate of 5–10 litres per 10,000 litres of binder. Indicative pricing ranges from AU$18 to AU$26 per litre depending on the size of order. Based on the safety data sheet, there is no additional measure required apart from the attention of its relatively low flash point during handling around hot binder.

For a more definitive conclusion on the crumb rubber effect on emission/odour, it is recommended that emission/odour monitoring during production, material handling, transport, and construction are designed as part of a future field trial. A comprehensive environmental assessment should be conducted on any chemical additives incorporated in the CRB product because each would contribute towards the energy consumption and emission output of the product over its lifecycle.

There are engineering measures and chemical additives that are readily available to temporarily address these environmental impacts. However, the general principle is that emission and odour can be significantly reduced as the operating temperature of CRB is lowered. This can be facilitated using warm mix technology.

However, it would be even more effective if the product is emulsified, which seems to be the fundamental question highlighted in this study and previous reports. It must be noted that any of the additional mitigation measures will come at a cost.

2.6 Summary

Table 2.10 Summary of key construction requirements

	Australia	South Africa
Pre-coating	Yes	Yes
Blending oil–bitumen compatibility	Yes	Yes
Cutter/adhesion agent	Yes	Conditional
Emulsification	No	No
Minimum surface temperatures	20 °C	25 °C
Health and safety	Additional measures	Additional measures
Environmental impacts (emissions and odour)	• Emission control/monitoring; odour monitoring/suppressant • Devulcanisation or warm mix additives to lower operating temperature	

3 Viability in New Zealand

3.1 Economics

3.1.1 Crumb rubber production

As mentioned in the introduction, it is estimated that about 120,000 tonnes of bitumen is used in chipseals in New Zealand each year. Hypothetically speaking, if 15% crumb rubber is used to modify all of the chipseals constructed, there is an opportunity to use 17,000 tonnes per year of crumb rubber from the waste stream. In a more conservative approach, given that CRB chipseals are used predominantly in high-stress sites in Australia, then the immediate application for CRB chipseals in New Zealand would be in the market that is currently serviced by polymer-modified emulsions. According to the Waka Kotahi T10 specification (skid resistance management), approximately 20% of the state highway network is categorised as high-stress sites (Cenek et al., 2011). Assuming the same percentage applies to the local road networks, then it is estimated that about 2,500 tonnes of crumb rubber would be required (at 15% modification level) to replace the imported polymer modifiers. Note that while this study only focuses on chipseal applications, for the crumb rubber manufacturing to be viable in New Zealand, it would require a wider application range, including its use in asphalt products.

In recent years, there has been only one crumb rubber supplier in New Zealand with a track record of producing and supplying products that meet the Australian specification for roading use from tyre buffing from retread operations. Rubber Solutions in Upper Hutt has a processing facility for rubber buffings from truck tyre retread operations and converts them into products such as rubber granules for horse arenas, rubber powder, and 25–28 mesh crumb rubber. However, there is a capacity limitation at about 1,500 tonnes per annum. While Waste Management NZ has an operation for processing ELTs into tyre-derived fuel, expanding its operations into crumb rubber production has not been the focus of its business operation.

Entities appear to be gearing up in anticipation of Tyrewise – a regulated product stewardship scheme for ELTs in New Zealand, which has been submitted for accreditation. The purpose of Tyrewise is to incentivise the industry to enable a circular economic approach to deal with tyres. Central to the scheme is an advanced disposal fee, under regulation, which will help fund collection, transport, and processing of tyres across the country. It is envisaged that Tyrewise will be approved in the second half of 2021. The expectation is that part of the fee collected from Tyrewise will go towards processors to subsidise the cost of manufacturing related products.

In 2018–19, a company called Treadlite entered the New Zealand market supplying processed ELT products for horse arena use. Treadlite is equipped to process whole ELTs from both truck and passenger car classifications (Brad Pierce, pers. comm., 18 March 2021), including separating steel and textile components from the tyre. It is understood that approximately 99% of the rubber can be fully recovered from their processing steps. The remaining < 1% of rubber is typically attached to the metal. This can be reduced further through process enhancements. Treadlite's main product line is 1.5–8 mm rubber granules for horse arenas, but Treadlite will have capability to produce rubber crumb below 1.5 mm. The increase in production capacity will certainly provide a more secure supply of crumb rubber derived from the local ELT stream. However, this needs to be supported by a sustainable demand from the roading market.

Based on the recent Tyrewise report (3R Group Ltd, 2020), there were approximately 43,000 tonnes of used on-road passenger vehicle (including cars, motorbikes, light commercial/industrial) tyres in New Zealand in 2019, of which approximately 31,000 tonnes are rubber. The remaining weight is steel and textile components. In addition, there were approximately 33,000 tonnes of used on-road bus/truck (including trucks, buses, forestry vehicles, tractors, construction/industrial) tyres in New Zealand, of which about 22,000 tonnes are rubber. A smaller portion (5,000 tonnes) of the ELT stream comes from off-road vehicles, with a similar percentage of rubber (~70%) available for further processing. Once the product stewardship scheme is in place, with a regulated system to control and track the flow of tyres, there will be sufficient supply of ELT rubber on an annual basis to support crumb rubber use in roading applications.

Another source of ELTs is legacy and orphan tyres. In Tyrewise 1.0 (3R Group Ltd, 2020), it was estimated that there were 3.5 million tyres across these two categories, most of which are scattered across the country, often on private land. Although it is much more challenging to maintain quality, it is entirely possible to utilise this resource, provided there is capacity to sort and process it on-site. In this case, its use in roading is not necessarily the most appropriate end-application.

The consistency of the stock supply comes down to the decision on whether to target truck tyres that are typically high in natural rubber or to deliberately use a mixed stream of passenger car (high in synthetic rubber) and truck tyres. The latter case does not pose insurmountable problems, but it would require more stringent quality control at the production stage of crumb rubber. In the long run, this would ensure better quality control further downstream at the CRB production step.

Currently in Australia, the price of crumb rubber ranges from AU$500 per tonne where it is competitive in urban areas, to AU$800–$900 per tonne in more remote areas like Western Australia (Liam O'Keefe, pers. comm., 24 March 2021). For cost–benefit analysis, Tyrewise 2.0 has used a mid-level figure of NZ$695 per tonne as an indicative price of crumb rubber for the New Zealand market (3R Group Ltd, 2020).

Table 3.1 provides a summary of indicative plant operating costs for producing various tyre-derived products from an overseas supplier specialising in crumb rubber products.

Table 3.1 Indicative plant costs for different end-product type and production rate (Julian Lim, Maxlink, pers. comm., 11 February 2021)

	Metric tonnes per year	Plant costs (USD)	Plant costs (USD/tonne)	Notes
Tyre-derived fuel (50 mm pieces)	19,200	$265,000	$13.80	Tyre-derived fuel is currently used by Golden Bay Cement to fuel its cement kiln.
Crumb rubber	4,800	$748,500	$155.94	This is the product currently used in Australia and South Africa.
	20,480	$1,292,500	$63.11	
Devulcanised crumb rubber	4,600	$2,000,000	$434.78	This is the crumb rubber product after devulcanisation.
	13,800	$3,300,000	$239.13	
Pelletised bitumen modifier*	4,600	$2,760,000	$600.00	This is a proprietary product that contains devulcanised crumb rubber as well as other additives.
	13,800	$5,300,000	$384.06	

* Devulcanised rubber with proprietary additives to improve dispersion in bitumen

3.1.2 CRB production

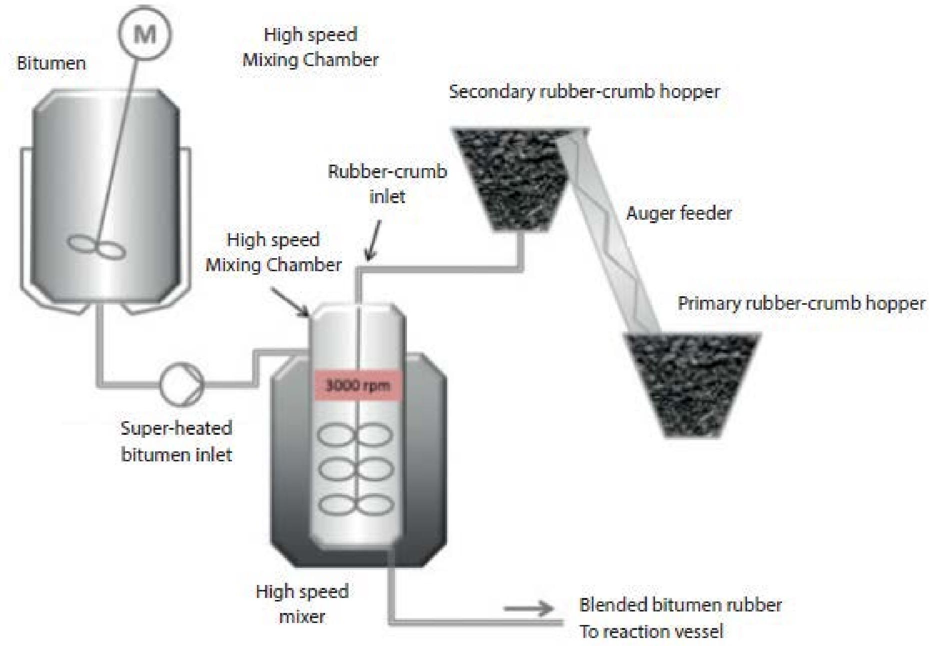
The production process for CRB is shown schematically in Figure 3.1. In Australia, C170 (which is similar to penetration grade (PEN) 60–80 bitumen) is used as the base bitumen for crumb rubber modification. In South Africa, a PEN 70–100 bitumen is used. In principle, a softer binder is preferred for modification. The decision is often made on the chemical composition and balance of the properties of the base binder itself. For New Zealand, it would make sense to use the sealing grade binders, which are typically 80–100, 130–

150 or 180–200 penetration. However, as previously stated, additives such as blending oil would have to be determined locally by suppliers depending on the base bitumen source and composition.

The key plant requirement for CRB production consists of:

- mixing – high shear mixer
- digestion – tank with agitator.

Figure 3.1 Schematic diagram of a typical high-speed bitumen rubber blender (reprinted from Marais et al., 2017, Figure 2)



Once the CRB is produced then it goes straight to a specialised sprayer (field blended) that can cope with the high viscosity of the CRB. For fixed plant blended products, the CRB goes into a storage tank but is used within the maximum storage time. Note that in the USA, terminal blend can mean ‘fully digested’ crumb rubber binder. However, this would have vastly different rheological properties, as described earlier.

Without knowing the exact path the New Zealand industry is choosing to go, it is difficult to estimate the capital investment required for the CRB production. The exercise of determining actual costs of manufacturing CRB in New Zealand will need to be conducted by the binder suppliers as the preliminary step of the field trial. It should be noted that anecdotal feedback from previous trials indicates that crumb rubber technology is no exception when it comes to economy of scale.

For comparison purposes, Tables 3.2 to 3.4 provide indicative costs of CRB in Australia in relation to unmodified bitumen and SBS-modified binders purely from a material supply cost perspective. Note that the binder application rates used in Australia may not apply in New Zealand, which could change the economics of CRB versus PMB. Nevertheless, the figures show why CRB is economically viable in Australia.

Table 3.2 Indicative cost (AUD) of SBS-modified binder for different seal treatments in Australia

Treatment	% bitumen in binder	Price per tonne bitumen	Cost bitumen component	% SBS in binder	Price per tonne SBS	SBS modifier cost	Cost per tonne SBS binder
HSS	97	$850	$825	3	$4,000	$120	$945
XSS	96	$850	$816	4	$4,000	$160	$976
SAM	95	$850	$808	5	$4,000	$200	$1,008
SAMI	94	$850	$799	6	$4,000	$240	$1,039

Table 3.3 Indicative cost (AUD) of CRM binder for different seal treatments in Australia

Treatment	% bitumen in binder	Price per tonne bitumen	Cost bitumen component	% crumb rubber in binder	Price per tonne crumb rubber	Crumb rubber modifier cost	Cost per tonne crumb rubber binder
HSS	95	$850	$808	5	$680	$34	$842
HSS/XSS	90	$850	$765	10	$680	$68	$833
XSS/SAM	85	$850	$723	15	$680	$102	$825
SAMI	80	$850	$680	20	$680	$136	$816

Table 3.4 Indicative cost savings (AUD) of CRB over standard bitumen and SBS-modified binder for different seal treatments in Australia

Treatment	Application L/m² bitumen	Bitumen $/m²	Application L/m² SBS binder	SBS binder $/m²	Application L/m² crumb rubber binder	Crumb rubber binder $/m²	Saving in binder cost (crumb rubber vs bitumen)	Saving in binder cost (crumb rubber vs SBS)
HSS	1.10	$0.97	1.30	$1.26	1.40	$1.24	−27.8%	2.2%
XSS	1.20	$1.06	1.50	$1.51	1.60	$1.40	−32.6%	7.2%
SAM	n/a	n/a	1.60	$1.66	1.80	$1.56	n/a	6.1%
SAMI	n/a	n/a	2.00	$2.14	2.20	$1.88	n/a	11.9%

The general rule is that CRB is cheaper than PMB, but more expensive than unmodified binders. This is supported by information from South Africa. Table 3.5 shows indicative cost ratios of different binder types from Johannesburg, South Africa. Actual costs will depend on the exact proprietary formulation, blending, handling complexities, and material price variations.

Table 3.5 Relative cost of binders ex-depot in Johannesburg, South Africa

Binder type	Binder cost ratio (ex-depot)
Unmodified 70–100	1
PMB (S-E1)	1.30
CRB (S-R1)	1.09
CRB (S-R2)	1.24

Apart from the physical plant and equipment required for CRB production, the health and safety concerns for workers and the neighbourhoods surrounding the plant and the work site must be addressed. This is an area to focus on during the field trial, to ensure that any additional risk can be mitigated. Warm mix technologies have been adopted in both Australia and South Africa to address the issues associated with typically high operating temperatures of CRB. They have been shown to reduce handling and application temperatures and thus reduce the potential of emissions and odour. While emulsification would also greatly alleviate the health and safety risks, this is an area which requires further research and development because the technology is currently not available in New Zealand, Australia or South Africa.

3.1.3 CRB chipseal construction

Publications from both Australian and South African road authorities (eg, MRWA, 2018, section 509.33) provide comprehensive descriptions of the plant and equipment requirement for CRB seal construction. Table 3.6 shows the relative seal construction cost ratio (including pre-seal treatment costs) for a single-coat seal with nominal 14 mm aggregate in South Africa (SABITA, 2021). This takes into account the difference in binder cost, application rate, and operational cost of specialist plant and equipment.

Table 3.6 Relative seal construction cost ratio for a single-coat seal with 14 mm chip

Binder type	Seal cost ratio
Unmodified 70–100	1
Emulsion (Cat 65%)	1.11
PMB (S-E1)	1.25
CRB (S-R1)	1.49

For crumb rubber sealing technology to be economically viable in New Zealand the unit cost rate must be of the same order of magnitude relative to standard seals as those in Australia and South Africa (after the initial capital investment). In order to be cost-effective in New Zealand, CRB needs to be competitive against current PMB products and have additional life extensions.

3.2 Sustainability

3.2.1 Crumb rubber supply

The economics of supply is discussed in section 3.1.1. The sustainability of ELT supply for roading applications in New Zealand should not be an issue unless new competing applications or ELT products arise. At the moment, the only end-use that would demand a large portion of the ELT waste stream is Golden Bay Cement's HOTDISC combustion device, which runs on tyre-derived fuel.

3.2.2 Recycling of CRM surfacings

Recycling of chipseals is not currently undertaken because chipseal surfacing is normally resealed over, milled for disposal, or incorporated into the pavement. In principle, chipseal recycling should be very similar to asphalt mix recycling to produce reclaimed asphalt pavement, which is a standard resource that the roading industry utilises for the construction of new asphalt pavements. In practice, however, there are technological challenges to chipseal recycling that still need to be overcome.

As reported by Wu et al. (2015), CRM asphalt mix has been successfully recycled in the USA, although only a limited number of cases have been reported. Studies conducted by Caltrans (California Department of

Transportation) indicate that full-depth pavement reclamation has the highest feasibility, followed by hot plant recycling, cold in-place recycling and hot in-place recycling. Test results from a trial in the City of Los Angeles showed that the recycled asphalt rubber mix reclaimed met Caltrans specifications, passed all tests, and was recyclable using either microwave technology or conventional mixed design technology. Air quality testing found that employee exposure to air contaminants was well below Occupational Safety and Health Administration (OSHA) permissible exposure limits and, in most cases, also below the detection limit. Recommendations from the Caltrans study were to focus on full-depth reclamation and hot plant recycling while continuing to develop solutions for both cold and hot in-place recycling. For the recycled crumb rubber mixture, volatile organic compound emissions were lower than the range for standard hot mix asphalt. The report pointed out that air quality did not seem to be any more severe of a problem than it was with conventional asphalt. The issue was predominantly odour.

It is also important to note that while traditional recycling of CRM reclaimed asphalt pavement requires higher production temperatures (> 160 °C), it is possible to incorporate lower quantities of CRM reclaimed asphalt pavement (< 30%) at temperatures similar to conventional hot mixes. As part of the Western Australian Road Research and Innovation Program, Rice (2019) reported on a feasibility study at which there were no technical issues encountered during reclamation of CRM asphalt from the ground and during production of CRM reclaimed asphalt pavement when using conventional equipment used for standard reclaimed asphalt pavement. It was noted that there was no noticeable odour during the works. The CRM reclaimed asphalt pavement was stockpiled and then successfully incorporated into a new asphalt mix at a dosage of 10% through a batch-style asphalt plant, and the manufactured asphalt material was subsequently paved with no issues. The overall outcome of the study was positive, with no barriers identified.

This would suggest that at a relatively low level, CRM chipseal could be recycled back into some form of asphalt, although the extensive heat treatment would likely reduce the ‘effectiveness’ of the crumb rubber as a binder modifier. As mentioned earlier, the use of warm mix technologies would be an effective solution to reduce mixing and compaction temperatures.

This needs further investigation and may be considered as part of a wider monitoring exercise to assess emission from handling of CRM materials.

3.3 Life cycle assessment

3.3.1 Seal lifetimes

In Australia, based on feedback from key personnel from MRWA (Skantzos et al., pers. comm., 30 March 2021), there has been no quantification of the life of CRM seals against unmodified or PMB seals. For recent CRM seals, the sites are not sufficiently aged to provide meaningful life estimates. In South Africa, data collected from a provincial road authorities’ opinion survey in 1994 (Table 3.7) indicate a definite extension of life for seals constructed using CRB.

FC Rust from the Council for Scientific and Industrial Research (CSIR) South Africa (van Zyl et al., pers. comm., 15 April 2021) studied the retardation of crack and concluded effectiveness ratios when compared to conventional PEN 70–100 bitumen as follows:

- PMB (S-E1) = 2:1
- bitumen rubber (S-R1) = 3:1.

Another study in the Western Cape region (van Zyl et al., pers. comm., 15 April 2021) on the long-term performance of seal sections also showed significantly superior performance of S-R1 bitumen rubber (ratio of

5.25) when compared against S-E1 PMB (ratio of 1.31) and the conventional PEN 70–100 (ratio of 1) bitumen seals. Such performance enhancement would offset the higher seal costs associated with CRB.

Local studies in South Africa have shown that PMB (S-E1) provides approximately 25% and the CRB (S-R1) more than 70% additional service life when compared to conventional binders. This is supported by macrotexture data where, over a five-year period, a CRB seal showed a much slower loss in macrotexture when compared to single seals with unmodified binder (PEN 70–100) (SABITA, 2021). The South African experience has shown that bitumen rubber (CRB) has the ability to retard crack reflection 70–200% longer than conventional binders. Table 3.7 provides the indicative effective life of a single-coat seal in reseals on a sound base. The average life expectancy was calculated based on a provincial road authorities' opinion survey conducted in 1994.

Table 3.7 Indicative seal lives of a single-coat seal (reseal on a sound base) (adapted from SABITA, 2021, Table D34)

Seal type	Traffic (equivalent light vehicles per lane per day)	Unmodified (years)	PMB (years)	CRB (bitumen rubber) (years)
Single 14 mm	< 2,000	12	14	16
	2,000–10,000	9	10	13
	> 10,000	6	8	10

3.3.2 Greenhouse gas emissions

While there has been no specific life cycle assessment (LCA) reported on the effect of CRM chipsealing on energy consumption or other environmental measures, there is some published work available on production of crumb rubber itself (Table 3.8) and CRM asphalt mixtures.

Results obtained from an LCA analysis described by Farina et al. (2014) show that use of asphalt wearing courses containing CRB produced by means of the 'wet' technology can lead to significant benefits in terms of energy saving, environmental impact, human health, preservation of ecosystems and resource efficiency. However, these advantages are guaranteed only if mixtures are properly designed and laid, with the corresponding possibility of reducing surface course thickness and maintenance frequency.

In the case of the so-called 'dry' technology, incorporation of crumb rubber from ELTs in the wearing course mixture does not necessarily produce the same benefits. In fact, for the case study considered in the paper, the environmental impact of the corresponding pavement was found to be approximately equivalent to that of a standard unmodified wearing course.

At the same LCA conference in the USA, a study in China was presented by Zhu et al. (2014) investigating energy consumption of material production and pavement construction using different binders. The most significant result is that the energy consumption of field-blended asphalt rubber (CRM bitumen) mixture was 5.75% lower than an SBS-modified asphalt mixture, and the plant-blended asphalt rubber mixture was 13.66% lower. The authors concluded that the technology has a significant advantage in terms of energy conservation over the conventional SBS polymer-modified asphalt. The study, however, also showed that the asphalt rubber technology in general produced more greenhouse gases when compared to conventional SBS-modified asphalt. This is largely due to the higher temperatures associated with the production and construction of rubber asphalt mixes.

Table 3.8 Examples of the energy consumption and greenhouse gas emissions of rubber powder production in China and the USA

Raw materials	Energy consumption (MJ per kg)	Greenhouse gas emission (kg CO_2 eq per kg)
Rubber powder (China)	3.59	0.97
Rubber powder (USA)	4.27	1.15
Extender oil used in CRM asphalt production (USA)	54.1	3.61

As mentioned earlier, warm mix technologies have been implemented to reduce temperatures required to produce and handle conventional asphalt as well as CRM materials. Wu and Qian (2014) conducted a comparative LCA of warm mix asphalt and hot mix asphalt pavement. The LCA showed that, as expected, warm mix additives technology leads to lower fuel consumption and emissions because of its lower mixing temperature in comparison to hot mix asphalt. However, there is a caveat in the use of warm mix additives technology: the emulsifying agent and other materials required contribute to a slight increase of the energy consumption and emission outputs, which potentially offsets the environmental gains from temperature reduction. The authors warned that when conducting LCA comparisons, the environmental impact due to the addition of new materials should not be overlooked.

This research highlights the fact that LCA results can be extremely sensitive to how the parameters and boundaries are set. It is also important to note that the energy consumption and emission output of a manufacturing process can be vastly different based on the type of fuel used to generate the electricity/energy required. This would make a significant difference in the outcome of a comparative LCA. Maulina et al. (2015) demonstrated through an LCA of two virgin crumb rubber processing factories in Indonesia that different technologies and plant configurations have very different efficiencies and energy requirements, and thus very different environmental impacts.

As mentioned earlier, there is the possibility to devulcanise the crumb rubber in order to address some of the issues around high production and handling temperatures. Similarly, the rubber could potentially be emulsified (Wu et al., 2015). Li et al. (2014) conducted an LCA case study of ground rubber production from scrap tyres in China and found that the devulcanisation process counts for the majority of energy consumption and greenhouse gas emissions produced because of China's reliance on coal combustion for electricity generation. In New Zealand's case, the situation would be very different because electricity generation is largely from renewable resources. This mirrors the authors' comment that the utilisation of energy-efficient equipment could be an effective approach to reduce environmental impacts of the process.

In summary, these LCA studies have alluded to the fact that the results need to be treated carefully as indicative information since calculations are often based on assumptions and estimates. It is envisioned that in future studies these problems will be overcome by directly monitoring production and construction activities, and this will likely fill the gaps of life cycle inventory data (Eurobitume, 2020), which are an essential component of LCA. This supports the recommendation that a detailed assessment of the energy consumption and greenhouse gas emissions should be part of the New Zealand field trial of CRM chipseals. It would also be valuable to conduct a comparative LCA between conventional CRM chipseals and devulcanised rubber modified chipseals.

4 Conclusions

CRM chipseal is a proven technology in both Australia and South Africa. However, the New Zealand industry's move towards a safer binder delivery system – that is, emulsions over hot cutback bitumen – is a fundamental barrier that will require consideration of alternative solutions before further progress can be made in the use of crumb rubber in chipsealing in New Zealand. It must be noted that crumb rubber still has viable markets in other roading applications such as asphalt, but this is not discussed in detail in this study. For a crumb rubber technology to be implemented in chipsealing operations in New Zealand, a number of factors need to be taken into account:

4.1 Health, safety and environment

First and foremost, the general spraying and handling temperature of conventional CRM binders is relatively high compared to normal chipsealing practice in New Zealand. PMBs are now sprayed as emulsified products to mitigate health and safety hazards and potential consequences associated with the handling of hot binders. As discussed, apart from adoption of warm mix technology to reduce handling temperatures of CRB, emulsification of CRB would be the ultimate solution to overcome the relative high spraying temperature.

There are also engineering measures and chemical additives that are readily available to temporarily address environmental impacts such as emissions and odour, but the general principle is that emissions and odour can be significantly reduced as the operating temperature of CRB is lowered. This can be facilitated using warm mix technology. However, it would be even more effective if the product is emulsified, which seems to be the fundamental question highlighted in this study and previous reports.

4.2 Construction requirements

The minimum surface temperature requirements used in Australia and South Africa reinforce the importance of good construction practice and the role that additives and processes play in reduction of construction risks. In practice, this will inevitably narrow the construction window for conventional CRM chipseals, given New Zealand's climate.

Research has shown that based on current technology and best practice, pre-coating is hugely beneficial to the adhesion of the modified binder to the aggregate. This is likely to incur additional cost to the chipsealing operation. In New Zealand, potential chip adhesion problems are normally overcome using emulsified binder or cutback with added adhesion agent. Pre-coating is no longer a common practice in New Zealand. A change to specifications and industry practice would be needed to meet the technical and environmental management issues of pre-coating operations.

Given that the move towards emulsified and safer products seems inevitable, the only practical way to reuse crumb rubber in the chipsealing application in New Zealand is to emulsify CRB. This would reduce the handling temperatures as well as largely eliminate the need for cutter.

Technologies for CRB emulsions are being developed internationally, but they have yet to be widely proven or adopted. Assuming a viable emulsion product is developed in which crumb rubber or its derivatives can be incorporated, then it would be appropriate to consider the following aspects when implementing the technology in New Zealand.

4.2.1 Specifications

Based on the industry practices in Australia and South Africa, there must be specifications for both the rubber (crumb rubber) material and the subsequent modified binder material. A specification for crumb rubber feedstock needs to be in place in order to maintain consistency and quality in the rubber modifier. Otherwise, the variation in the ELT waste stream can cause problems downstream during binder production. This is likely to be equally important for the emulsified product. For the CRM binder, the performance-based specification for sealing binders (M01-S) that is currently under development should, in principle, cover the relevant properties of chipsealing binder because the specification is designed to be composition-blind. This needs to be verified further during the implementation stage of the M01-S specification.

4.2.2 Seal design

Seal design methodologies are well established in both Australia and South Africa, and these can be used as benchmarks for New Zealand. Generally speaking, the binder application rate needs to be increased by at least 10–20% when a CRB is used in the seal design. While this directly translates to an increase in cost, the potential life extension could offset the cost increase. This would have to be investigated further when CRB is in an emulsified form, but one would assume that the product would have similar properties to a polymer-modified emulsion.

4.2.3 Crumb rubber supply

A key consideration for both the roading industry and the ELT recycling industry is whether to sort the ELT waste stream and to set a benchmark of the mix of truck and passenger car tyres. If the composition of crumb rubber (ie, the amount of natural vs synthetic rubber) can be controlled and kept consistent, then the downstream processing and quality of the modified binders can be less variable.

4.2.4 Economics

For the technology to be economically viable in New Zealand, the unit cost rate must be of the same order of magnitude relative to conventional seals to those in Australia and South Africa (after the initial capital investment). In order to be cost effective in New Zealand, the emulsified CRB needs to be competitive compared to current polymer-modified emulsion products and achieve extended seal lives.

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Glossary

Terminology/Abbreviation	Description
AAPA	Australian Asphalt Pavement Association (now Australian Flexible Pavement Association)
Adsorption	Adhesion of atoms, ions or molecules from a gas to a surface
Aggregate	Coarse to medium-grained particulate material used in construction
Air-blown	A process in which bitumen is treated by blowing air through it at elevated temperatures to produce physical properties required for the final product
Asphalt	Mix of bitumen, aggregate, and fillers
Asphaltenes	A molecular substance found in crude oil
Binder	A substance that binds aggregate in road construction
Bitumen rubber	Term used in South Africa for crumb rubber modified bitumen
Bleeding	Also called ‘flushing’, it is the shiny black surface film of bitumen on road surface, which often leads to low surface texture
Buffing	Residue rubber from tyre retread operation
Chipseal	A type of road surfacing that typically consists of at least a layer of aggregate held together by a layer of bitumen or binder
CRB	Crumb rubber bitumen
CRM	Crumb rubber modified
Crosslinks	In chemistry, these are bonds that link polymer chains together
Crumb rubber	Ground rubber powder from end-of-life tyres
Cutback	Substance diluted with a cutter with the intention to reduce viscosity
Cutter	Typically a liquid substance added to other liquids to reduce viscosity
Desorption	A phenomenon where a substance is released from or through a surface; opposite of adsorption or absorption
Devulcanised	Processed by devulcanisation where crosslinks in rubber, for instance, are broken through mechanical, thermal, chemical, or a combination of processes
Digestion	Refers to the process where crumb rubber interacts with bitumen
Distillate	Liquid product condensed from vapour during distillation process
Double seal	Similar to a two-coat seal in New Zealand
‘Dry’ technology	Refers to an asphalt technology where crumb rubber is incorporated in hot mix asphalt as partial substitute of aggregate fines
Dynamic shear rheometer	An instrument for measuring rheological properties of viscoelastic materials
Elastic	Ability of a material to return to its original form after a load has been applied and then removed
Elastomers	A class of polymeric materials with viscoelasticity
Elastometer	An instrument developed by the Australian Road Research Board to measure bitumen properties
ELTs	End-of-life tyres
Emulsification	A process to create a liquid containing fine droplets of another liquid; bitumen emulsions are typically bitumen droplets in water
Extender oil	A process or softening oil that is added to bitumen to improve process ability

Factory blended	Products blended in a fixed plant
Field blended	Products blended in a mobile plant, typically on-site
Flash point	The lowest temperature at which a volatile material ignites if given an ignition source
Flushing	See ‘Bleeding’
Fluxing agent	Used in road construction to lower the viscosity of bitumen
Gelling	A process where a liquid or semi-liquid substance sets or becomes more solid
Healing	The road surface’s ability to recover from damage (eg, cracking)
Homogenous	A material composed of a single, uniform physical phase
HSS	High-stress seal
Hydrocarbon	Organic compounds with hydrogen and carbon
LCA	Life cycle assessment
Macrotexture	Road surface texture in the 0.5 mm to 50 mm range
Maltene	Another component of bitumen; lower molecular weight than asphaltene
MRWA	Main Roads Western Australia
Multigrade bitumen	Chemically modified bitumen which has properties that span multiple grades
Non-homogenous	Opposite of homogenous, refers to multi-phase materials
NSW	New South Wales
Pavement rehabilitation	The restoration of pavement to mitigate distresses such as rutting and cracking
PEN	Penetration grade
Penetration grade bitumen	A grading system that gauges the softness of bitumen (the higher the number, the softer it is)
Phase separation	Segregation of a normally evenly distributed multi-phase substance
Plant blended	See ‘Factory blended’
PMB	Polymer-modified binder
PME	Polymer-modified emulsion
Polycyclic aromatic compounds	Also known as polycyclic aromatic hydrocarbons
Polycyclic aromatic hydrocarbons	Chemical compounds composed of multiple condensed aromatic rings
Polymer	A material consisting of large molecules, composed of many repeating subunits
QA	Quality assurance
Reclaimed asphalt pavement	Asphalt millings from existing asphalt pavement that can be reutilised in new pavement construction
Retread	A process whereby used tyres have been given new tread or remoulded
Rheological	Refers to rheology, which is the science of the deformation and flow of materials
RMA	Resource Management Act 1991
SABITA	Southern African Bitumen Association
SAM	Strain-alleviating membrane
SAMI	Strain-alleviating membrane interlayer
SBS	Styrene-butadiene-styrene; a polymer used in the modification of bitumen
Scrubbing	The process of using water or other liquids to remove impurities from gas or vapour

Segregation	See ‘Phase separation’
Tack coat	A thin layer of bitumen to ensure bonding between old and new seal layers
TMR	State of Queensland Department of Transport and Main Roads
Total suspended particulates	Total amount of small solid matter released, documented and/or otherwise observed in the atmosphere
Tyre-derived fuel	Tyre rubber granules used as a fuel
Viscosity	The resistance of a fluid to flow
Volatile organic compounds	Organic chemicals that have a high vapour pressure at room temperature
Warm mix additives	Additives such as wax used to reduce operating temperature of bitumen and asphalt
Warm mix technology	Technology that uses warm mix additive to reduce operating temperature of bitumen and asphalt
Wearing course	The top road surface layer, which is typically thin asphalt or chipseal
Wet	To coat and adhere to a surface
‘Wet’ technology	Crumb rubber incorporated in hot bitumen by partial digestion
Wetting characteristic	Ability of binder to wet/adhere to the aggregate surface
WMTBR	Warm mix technology bitumen rubber
XSS	Extreme-stress seal