LG TRRIP
Local Government Transport Road Research and Innovation Program

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Technical Report: Crumb Rubber Modified Binders in sprayed seal applications on Local Government roads in WA

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About LG TRRIP

The Local Government Road Research and Innovation Program (LG TRRIP) is an initiative between Main Roads Western Australia and the Western Australian Local Government Association.

LG TRRIP has a strategic commitment to the delivery of collaborative research and development that positively contributes to the design, construction and maintenance of safe, sustainable transport infrastructure in Western Australia.

Executive Summary

This report presents the underpinning research for the development of a practitioners' guideline for Western Australian Local Government: *Use of Crumb Rubber-modified Binders in Sprayed Seals*. This research was undertaken by the Western Australian Local Government Association (WALGA) with the support of Main Roads Western Australia (MRWA), under the Local Government Transport and Roads Research and Innovation Program (LG TRRIP).

Addressing the Australian Waste Policy Action Plan, Western Australia (WA) has developed the Waste Avoidance and Resource Recovery Strategy 2030, setting targets for the increased recovery of waste materials as valuable resources. This has contributed to a drive to increase the use of recycled materials in road construction, thus leading to the development of these guidelines to support local government in this endeavour and give confidence to road managers.

This report presents details of a project that sought to define the current state of practice in the use of crumb rubber–modified binders (CRMBs) in sprayed seals in WA. This work included a literature review, a series of stakeholder engagement activities and the identification of gaps in current practice. The work resulted in recommendations regarding material supply, design and selection; challenges and risks; and construction guidance that will be subsequently refined into succinct, practical guidance for local government.

While initial costs for CRMB sprayed seals may be higher than conventional bitumen, road trials that demonstrate longer lifespan and durability could mitigate the high capital cost. CRMB proves to be a versatile and effective option for sprayed seals, particularly in high-stress areas and cracked pavements, offering enhanced performance in terms of temperature resistance, adhesion and elasticity. While it requires careful consideration of surface conditions and proper priming for new constructions, its benefits, including improved waterproofing and the circular economy benefits, make it a valuable material for road projects in WA. However, challenges such as transportation logistics, environmental concerns and site -specific safety measures may need to be further addressed to optimise its use.

In general, CRMBs have increased elasticity, which provides resistance to shear stresses (turning movements), and a higher softening point than conventional bitumen, thus providing reduced susceptibility to flushing in hot climates, increased cohesive and aggregate retention properties and improved crack resistance. Due to the enhanced performance characteristics of CRMBs, it can be selected for use as strain alleviating membranes (SAMs), strain alleviating membrane interlayers (SAMIs), and high-stress seals (HSSs).

The diverse experiences of local governments in implementing CRMB sprayed seals suggest varying levels of familiarity and reliance on contractors, which points to a need for further capacity-building and knowledge-sharing within the local government sector.

The report also highlights the development of field-blended CRMB products, alongside plant-produced options, which offer greater flexibility in meeting specific project requirements. Field blending allows for on-site customisation of CRMB, ensuring the binder meets the necessary performance standards even in challenging conditions. This approach is particularly useful in remote or regional areas where transporting plant-produced CRMB over long distances can be both logistically complex and costly.

However, despite these advancements, the logistical challenges associated with transporting CRMB across WA's vast distances remain a significant barrier to its widespread adoption. Ensuring the consistent quality and availability of CRMB in remote locations requires not only advanced planning and infrastructure but also an evaluation of the most cost-effective and sustainable methods of production and distribution. Addressing these logistical hurdles is crucial for expanding the use of CRMB in road construction projects throughout WA.

List of Abbreviations

AfPA	Australian Flexible Pavement Association
CRMA	Crumb rubber–modified asphalt
CRMB	Crumb rubber–modified binder
EoL	End-of-life
GRS	Geotextile reinforced seal
HSS	High stress seal
IPWEA	Institute of Public Works Engineering Australasia
LG TRRIP	Local Government Transport and Roads Research and Innovation Program
MRWA	Main Roads Western Australia
NTRO	National Transport Research Organisation
PAH	Polycyclic aromatic hydrocarbons
PAV	Pressure ageing vessel
PBD	Polybutadiene
PMB	Polymer modified binder
SAM	Strain alleviating membrane
SAMI	Strain alleviating membrane interlayer
SBS	Styrene-butadiene-styrene
SOP	Standard operating procedures
SWMS	Safe work method statement
TSA	Tyre Stewardship Australia
VOC	Volatile organic compound
WALGA	Western Australian Local Government Association
WARRIP	Western Australian Road Research and Innovation Program
WHS	Work health and safety
XSS	Extreme stress seal

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Definitions

Crumb rubber	Rubber particles manufactured from waste or reclaimed rubber products, such as vehicle tyres, and graded to conform to a specified size range. Used in bitumen to improve binder properties (Austroads 2015a).
High stress seal (HSS)	A bituminous seal or reseal treatment, which may be a single/single (HSS1) or double/double (HSS2) seal, but with a polymer modified binder (PMB) to improve seal performance in areas of high traffic loading and stress (Austroads 2015a).
Polymer modified binder (PMB)	A binder consisting of polymeric materials dispersed in bitumen with enhanced binder performance for particular applications (Austroads 2015a).
Strain alleviating membrane (SAM)	A sprayed seal with the binder containing a relatively large concentration of rubber or polymer modifier. It is used to absorb strains that occur in a road pavement, thereby reducing reflection cracking (Austroads 2015a).
Strain alleviating membrane interlayer (SAMI)	Similar to a SAM but provided as an interlayer before placing an asphalt overlay (Austroads 2015a).

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1 Introduction

1.1 Background

1.1.1 The Project

The Australian Waste Policy Action Plan was prepared by the Australian state and territory governments and the Australian Local Government Association in 2019, and it sets a target of 80% resource recovery by 2030. To achieve this, the development of national standards and specifications that guide the uptake of recycled materials in several areas of construction, prioritising road construction, is required (Department of Climate Change, Energy, the Environment and Water 2019). As a result, Western Australia's (WA's) Waste Avoidance and Resource Recovery has set targets of increased material recovery of 70% by 2025 and 75% by 2030 (Waste Authority 2023). In addition, the State Road Funds to Local Government Agreement (2023–24 to 2027–28) includes a commitment for local governments to increase usage of recycled materials in road construction. During the term of the Agreement, systems and processes to support, monitor and report the use of recycled materials are to be developed (Main Roads Western Australia & WALGA 2023).

Acting towards these targets, the Western Australian Local Government Association (WALGA) with the support of Main Roads Western Australia (MRWA) under the Local Government Transport and Roads Research and Innovation Program (LG TRRIP) has engaged the National Transport Research Organisation (NTRO) to develop a series of documents to guide local government practitioners to the meaningful adoption of recycled materials in road construction. This report follows the *Sustainable Road Construction Practices for Local Government Roads in WA* (Howland et al. 2023), focusing on the use of crumb rubber-modified binders (CRMBs) in sprayed seals. Although crumb rubber in sprayed seals has seen extensive adoption by several authorities across Australia as well as worldwide, local governments in WA would benefit from more targeted guidance on the design, specifications and construction to further increase their uptake.

WA's road network provides an extensive opportunity to meet the targets set for the adoption of recycled materials in road construction with more than 41,199 km of sealed roads being managed by local governments (WALGA 2023). As of 2023, 3,644 km of these are sprayed seals placed in built-up areas, and 24,559 km are sprayed seals outside of built-up areas (WALGA 2023). WA, being the largest Australian state, has been divided into localities, namely metropolitan, regional, remote and very remote, to facilitate the implementation of road construction guidance. Metropolitan WA includes the greater Perth region, regional WA includes the inner and outer regional areas surrounding Perth, remote WA primarily comprises the area surrounding regional WA and includes some isolated remote zones along the coast, while the rest is considered very remote WA (Howland et al. 2023).

1.1.2 Sprayed Seals

A sprayed seal is a road surfacing treatment that, in its most basic form, consists of a single layer of sprayed bitumen, which is covered by a layer of crushed aggregate. Sprayed seals are commonly used in Australia as they provide a low-cost construction and maintenance technique, and due to the vast distances between population centres in Australia, cost-effective road construction techniques are crucial. Sprayed seals offer an economical solution and can effectively serve roads with significant traffic volumes.

Under heavy traffic, the aggregate particles in sprayed seals become densely packed and reorient themselves, predominantly lying flat with their broadest dimension parallel to the road surface. In contrast, under light traffic conditions (typically fewer than about 200 vehicles per lane per day), the aggregate particles maintain a more random arrangement, leaving greater space between them. Consequently, the amount of binder needed to effectively secure the aggregate may be up to twice that required for the same-sized aggregate on a heavily trafficked road. Traffic volume and aggregate size are, therefore, primary factors considered in designing optimal sprayed seal binder application rates.

Bitumen binders to be used in sprayed seals can be enhanced through specific modifications. By incorporating polymers or crumb rubber, the binder's properties are improved. These modifiers enhance the binder's ability to adhere to the aggregate, especially in areas subjected to high stress. Additionally, the modified binder can be used to create thicker and more flexible membranes, providing better protection against water infiltration and minimising the reflection of cracks on the road surface (Austroads 2018).

1.1.3 Crumb Rubber

Crumb rubber is derived from the shredding and crumbing of end-of-life (EoL) tyres. After the removal of other tyre components, such as textile fibres and steel cords, tyres are shredded and crumbed to size. Even though, theoretically, tyres from various sources can be considered (e.g. cars, trucks, and off-the-road), crumb rubber that is derived from truck tyres is most commonly used in road pavements. Depending on the source, crumb rubber may vary in its composition of natural rubber, synthetic rubber, carbon black and fillers (Hall et al. 2022). Further details on CRMBs used for sprayed sealing are included in Section 2.1.

1.2 Scope

This project builds on the LG TRRIP 03 local government guideline on *Sustainable Road Construction Practices for Local Government Roads in WA* (Howland et al. 2023), focusing on the opportunities for incorporation of CRMBs in sprayed seal applications.

In this report, the technology; applications; sources; work, health and safety considerations; specifications; challenges; risks; and mitigation measures for the CRMB incorporation in sprayed seals are explored to understand how their use in local government roads in WA is supported. To deliver these insights, a desktop literature review and targeted stakeholder engagement activities were undertaken. These aimed to better grasp the areas where support and guidance is provided and where it is lacking as well as to better understand current practice.

1.3 Objectives

This report aimed to understand the state of current practice surrounding the incorporation of CRMBs in sprayed seals in Western Australian local government roads. Following the literature review and stakeholder engagement, the gaps in current practice were identified to develop recommendations for design, specification and construction, which has been targeted for applications in WA.

These recommendations are aimed to build upon current guidance provided by local (Western Australian) as well as national (Austroads, Australian Flexible Pavement Association (AfPA), Institute of Public Works Engineering Australasia (IPWEA)) standards and specifications. The main objective was to deliver a practical guideline that will assist local governments to make informed decisions for the use of CRMB in sprayed seal applications.

2 Literature Review

2.1 Product Definitions and Options

Crumb rubber for sprayed sealing applications is incorporated into bitumen using the 'wet' method, where crumb rubber is added to the bitumen at elevated temperatures as a modifier (Hall et al. 2022a). Crumb rubber blended by the wet process has been widely used to construct sprayed seals in Victoria, New South Wales, WA and South Australia for several decades. A 'dry process' can be used in the production of an asphalt mix, where the crumb rubber is blended with other aggregate components (Hunter et al. 2015).

The CRMB available for sprayed seals are split into 2 categories: field-produced and plant-manufactured.

The Austroads Technical Specification ATS 3110 (Austroads 2023) sets out the requirements for the supply of polymer modified binders (PMBs) and CRMB for use in both sprayed sealing and asphalt applications (the requirements of ATS 3110 are discussed in more detail in Section 2.6.1). The CRMB grades specified for use in sprayed seals by ATS 3110 are:

- plant produced – S9R, S15R
- field produced – S9RF, S15RF, S18RF.

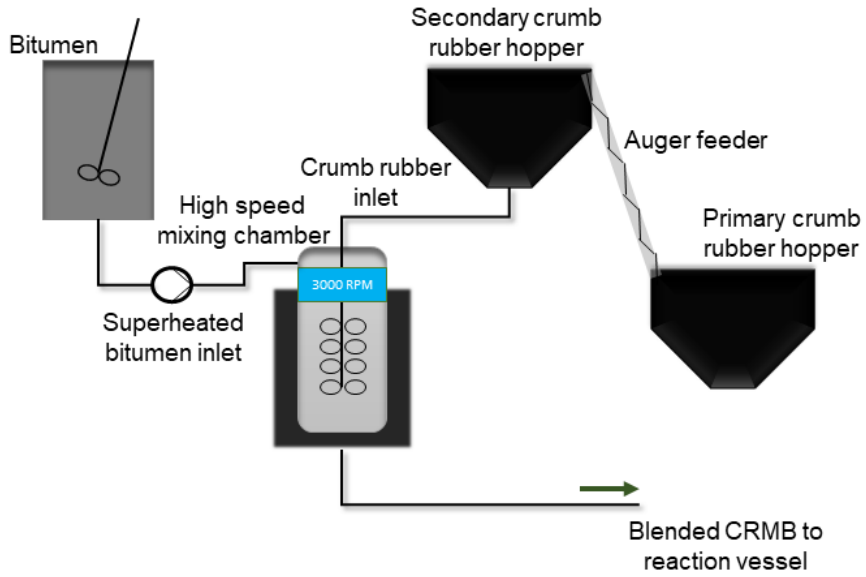
Plant-manufactured CRMBs are blended by a binder supplier remotely from the application site prior to being used in road construction (Austroads 2021). These binders generally combine the bitumen and crumb rubber with additives, such as combining oil.

Field-produced CRMBs are made by blending bitumen and crumb rubber immediately prior to their use in road construction, such that only partial digestion of the rubber occurs. The material is generally prepared close to the application site and used within a short timeframe. Field-production can be undertaken by directly adding the crumb rubber to the bitumen sprayer or using a separate on-site blending and storage unit (Austroads 2017). ATS 3110 further defines field-produced CRMB as 'simple blends of bitumen and crumb rubber' that 'are used within a short time frame (in no case more than 2 hours travelling time from the blend site)'.

A continuous blending system (the original McDonald process) may be employed to prepare CRMBs (Lo Presti et al. 2013). Continuous blending systems consist of a unit of agitators. The process of binder blending continues during the production of the mix or the blends are prepared and stored in storage tanks for later use (Lo Presti 2013). The McDonald method employs a high-speed mixer to blend the crumb rubber in the bitumen at temperatures between 177 and 260 °C for 45 to 60 minutes (McDonald 1976).

For the successful production of compliant binders, the blending facilities need to be able to reliably measure the mass of crumb rubber added to the bitumen. One method to do so is by using a weight hopper. In addition, specialised heated reaction and blending tanks, storage tanks and crumb rubber feeders are required (Lo Presti 2013) to maintain homogeneous blends at uniform temperatures (Heitzman 1992). Figure 2.1 schematically presents a typical high-speed CRMB blender.

Figure 2.1: Schematic of example high-speed crumb rubber modified binder blender



Source: Adapted from Southern African Bitumen Association (2020).

During the blending of crumb rubber with bitumen via the wet method, the crumb rubber undergoes a digestion process, which is essential in order to achieve certain performance benefits offered by this process (Artamendi & Khalid 2006). When crumb rubber is added to bitumen at elevated temperatures, the crumb rubber particles expand as they absorb some of the light components of the bitumen. As blending continues, the rubber turns into a gel followed by an oil (Southern African Bitumen Association 2019). Factors such as blending temperature (Artamendi & Khalid 2006; Gawel et al. 2006; Ghavibazoo & Abdelrahman 2013), digestion time (Airey et al. 2003; Billiter et al. 1997; Cao et al. 2011; Gawel et al. 2006; Ghavibazoo & Abdelrahman 2013; Oliver 1981; Sybhy et al. 2016), bitumen (Airey et al. 2003; Artamendi & Khalid 2006; Billiter et al. 1997; Ghavibazoo & Abdelrahman 2013; Ould-Henia & Dumont 2008), crumb rubber type (Artamendi & Khalid 2006; Ghavibazoo & Abdelrahman 2013), as well as crumb rubber size, gradation, and morphology (Dantas Neto et al. 2011; Gawel et al. 2006; Oliver 1981; Ould-Henia & Dumont 2008; Shen et al. 2009) have been found to affect this process.

2.2 Benefits

2.2.1 Environmental

Presently, it is estimated that 10 billion EoL tyres are generated globally each year (Liang et al. 2020), of which a large proportion are either sent to landfill, lost or burned as a fuel. Tyres sent to landfill take up scarce landfill space, while lost tyres can litter landscapes and waterways (Denneman et al. 2015).

The conversion of EoL tyres into crumb rubber, which can then be used in numerous applications including sprayed seals, results in the diversion of otherwise waste material from landfill. Tyre Stewardship Australia (TSA) (2019) noted that 52% of the 448,000 tonne of EoL tyres produced in Australia during 2018–19 were repurposed for environmentally sound uses; within this number, 4% were recycled back into tyres, 75% were used as an energy source (either as whole or shredded tyres or as a pyrolysis oil derived from tyres) and 21% were used to produce tyre-derived products (including crumb rubber, shredded tyres for use as tyre-derived aggregate, steel and char). The use of tyre-derived products in sprayed seals decreases the demand for virgin materials and, in turn, reduces the environmental impact associated with the production of polymers and petroleum-derived bitumen products (Howland et al. 2023).

In terms of greenhouse gas emissions, the production of crumb rubber has a lower emissions factor compared to the other polymers that are widely used to modify bitumen, including latex, styrene-butadiene-styrene (SBS) and polybutadiene (PBD). Emissions factors of bitumen and polymers sourced from the Australian Life Cycle Assessment Society (ALCAS) AusLCI database (ALCAS 2022) are

listed in Table 2.1. As crumb rubber has lower embodied emissions than C170 bitumen, the addition of crumb rubber to bitumen will have an essentially neutral effect to the embodied emissions of the resultant binders. Conversely, the other polymers have emissions factors much higher than bitumen, which will see an increase in the embodied emissions of the resultant binders.

Table 2.1: Greenhouse gas emissions factors for bitumen and polymers

Material	Emissions factor (tCO_2-e/tonne)	LCI reference (if applicable)
C170 bitumen	0.4001	Bitumen, at refinery/RER U/AusSD U (ALCAS 2022)
Crumb rubber	0.3116	Custom process, modelled as rubber from waste tyres, fine pulverised, crumb rubber (< 0.7 mm)/AU U (ALCAS 2022)
Latex	2.6264	Latex, at plant/RER S/AusSD U (ALCAS 2022)
SBS	5.4794	Polybutadiene, at plant/RER U/AusSD U (ALCAS 2022) Polystyrene, general purpose, GPPS, at plant/RER U/AusSD U (ALCAS 2022) Paraffin, at plant/RER U/AusSD U (ALCAS 2022)
PBD	3.8802	Polybutadiene, at plant/RER U/AusSD U (ALCAS 2022)

A reduction in tyre stockpiles also minimises health risks to communities, as they are known to present risk of vermin, mosquito-borne diseases, toxic fires, a degraded natural environment and lost visual amenity (Tyre Stewardship Australia 2023a; TSA 2023b; Western Australia Local Governments Association 2013).

Further discussion of the environmental impact is included in Section 2.9.

2.2.2 Performance

The predominant reason to use the crumb rubber binders included in the Austroads PMB specification (ATS 3110) instead of unmodified bitumen is to limit the amount of cracking that occurs in sprayed seals (Austroads 2017).

Guidance from Austroads (2018) indicates that the S15R and S15RF grades, which have a nominal crumb rubber content of 15% by mass, are suitable for strain alleviating membrane (SAM) applications that mitigate slow rate environmental cracking propagation, or the traffic-induced cracking propagation at a rapid rate with low cracking severity. These grades are also applicable for extreme stress seal (XSS) applications that accommodate extreme stresses induced by high traffic volumes and percentage of heavy vehicles, or demanding service conditions such as long ascending lanes or tight radius curves.

The S18RF grade, which has a nominal crumb rubber content of 18% by mass, is suitable for strain alleviating membrane interlayer (SAMI) and SAM applications that mitigate rapid rate traffic-induced cracking propagation with high cracking severity.

The S9R grade was added to ATS 3110 in 2023 and is a field-produced mixture of C170 bitumen and nominally 9% crumb rubber by mass. Some Australian jurisdictions use S9R in high stress seal (HSS) applications to assist aggregate retention on roads with high traffic volume; however, formal guidance to its use has not yet been included in the Austroads (2018) guide.

Crumb rubber binders have a higher softening point than unmodified bitumen and, thus, can be applied at a higher binder application rate (Austroads 2018) without causing flushing. Hoffmann and Potgieter (2007) observed that a binder with a higher softening point can lower the amount of aggregate penetration in a sprayed seal, which helps preserve skid resistance of a sprayed seal over time. These researchers also observed that sprayed seals with thicker binder films would be more water-resistant, which would better safeguard the underlying pavement. The thicker binder films that result from crumb rubber addition would thus be expected to better safeguard the underlying pavement than unmodified bitumen.

Austroads (2018) demonstrated that crumb rubber binders harden at a slower rate than unmodified bitumen when samples are aged in the laboratory using a pressure ageing vessel (PAV). South African researchers (Hoffmann & Potgieter 2007; Marais et al. 2017) have also reported that sprayed seals with crumb rubber binders oxidise/harden at a slower rate in the field than unmodified bitumen. These researchers suggest that as crumb rubber binders harden at a slower rate, these types of seals will have higher durability than those constructed with unmodified bitumen and can lead to an increase in service life (TSA 2022a).

2.2.3 Economical

A number of international studies have indicated that the use of crumb rubber may increase the cost of road construction compared with when unmodified bitumen is used, and this increase may limit its use (Lo Presti 2013; Picado-Santos et al. 2020). Increased costs are associated with the general use of higher crumb rubber binder contents in sprayed seals and asphalt, as well as the higher temperatures generally used when roads are constructed with crumb rubber. CRMBs are also typically more expensive than unmodified bitumen. Studies have generally assumed that the initial costs of constructing roads with crumb rubber are likely to be offset by long-term reductions in maintenance costs associated with the better performance of roads which contain crumb rubber.

A South African study (Hoffmann & Potgieter 2007) indicated that crumb rubber binders are typically 30% more expensive than unmodified bitumen, which increases sprayed seal construction costs by about 10%. Although sprayed seals are more expensive to construct when crumb rubber binders are used, these researchers noted that the use of these types of binders can increase seal life by up to 50%, which would be expected to more than offset initial increased construction costs.

2.3 Sources of Crumb Rubber Modified Binders in Western Australia

The production of crumb rubber from EoL tyres typically involves shredding, followed by ambient or cryogenic grinding (Lo Presti 2013). In Australia, crumb rubber is primarily produced by ambient grinding (Harrison et al. 2019). Ambient grinding takes place in ambient or just above ambient temperatures where scrap tyres are mechanically ground using rotating blades (Lo Presti 2013).

Although relevant specifications (ATS 3110 and Specification 511 (MRWA 2023)) allow for the use of crumb rubber for suppliers approved by the Principal Engineer, they recommend the use of suppliers approved by TSA. In WA, these include:

- Tyrecycle in Port Hedland (operational in 2024) (Paten 2023)
- Tyrecycle in O'Connor (City of Fremantle)
- WA Tyre Recovery in Albany
- Elan Energy Matrix Pty Ltd in Welshpool
- Lomwest Enterprises Pty Ltd in Dumbarton (TSA n.d.).

The crumb rubber can then be incorporated in bitumen to produce CRMBs via the methods outlined in Section 2.1. A number of binder manufacturers have the capability to produce CRMBs that meet Western Australian and national specifications including Puma Bitumen, Viva Energy Australia and SAMI Bitumen Technologies.

2.4 Design Guidelines

2.4.1 Western Australia Local Government Association (WALGA)

The WALGA *Sprayed Bituminous Surfacing: Road Building Model Specification* (WALGA 2022) refers to Austroads documentation for undertaking sprayed seal design incorporating crumb rubber, which is discussed in Section 2.4.3.

It should be noted that WALGA (2022) refers to Austroads documents AP-T68 *Update of the Austroads Sprayed Seal Design Method* and AP-T236 *Update of Double/Double Design for Austroads Sprayed Seal Design Method,* which have been superseded by Austroads (2018).

2.4.2 Main Roads Western Australia (MRWA)

MRWA *Engineering Road Note 15* (MRWA 2017) refers to using Austroads documentation for the design of sprayed seals, including those utilising crumb rubber binders, which is discussed in Section 2.4.3.

It should be noted that MRWA (2017) refers to Austroads documents AP-T68 *Update of the Austroads Sprayed Seal Design Method* and AP-T236 *Update of Double/Double Design for Austroads Sprayed Seal Design Method,* which have been superseded by Austroads (2018).

2.4.3 Austroads

The design of sprayed seals in Australia follows the procedures of the *Guide to Pavement Technology Part 4K: Selection and Design of Sprayed Seals* (Austroads 2018).

The basis of the design is the procedures for determining binder application rate and aggregate spread rate for single/single sprayed seals with standard bitumen as the binder. For other types of seals, this method is adapted with necessary changes and supplemented with extra details as needed.

For sprayed seals that incorporate crumb rubber binders, the important modification required is in the adjustment of the binder factor. The binder selected for a sprayed seal influences the necessary application rate. This is managed in the design by employing 'binder factors' tailored to the various treatments and binder types. All PMBs, which includes crumb rubbers, are thicker and more flexible than traditional binders and can be applied at higher application rates to enhance performance.

In the sprayed seal design process, the binder factor is used during calculations of the binder application rate and is implemented by multiplying the 'basic binder application rate' by the binder factor to determine the 'modified basic binder application rate'.

The binder factors for single/single seals are listed in Table 2.2, and for double/double seals in Table 2.3. The crumb rubber binders have been identified with bold text in these tables, and the other binders have been retained for information of the reader.

Table 2.2: Binder factors for single/single seals

Treatment type	Binder	Binder factor
Conventional seal	C170, C240, C320	1.0
	M500	1.1
Unmodified emulsion seal	Conventional emulsion (60%)	1.0
	High bitumen content emulsion (≥ 67%)	1.1
Modified emulsion seal	Uses binder factors below for the PMB that has been emulsified	
Aggregate retention (AR)	S35E	1.0
	S10E	1.1
High stress seal (HSS1)	S10E, S15E, S35E	1.0
	S20E, **S45R, S15RF**	1.1
Strain alleviating membrane (SAM)	S10E, S15E, S35E	1.2
	S20E, **S45R, S15RF**	1.3
Strain alleviating membrane interlayer (SAMI)	S25E, **S18RF**	1.6

Source: Austroads (2018).

Table 2.3: Binder factors for double/double seals

Treatment type	Binder	Binder factor[1]
Conventional seal	C170, C240, C320	1.0
	M500	1.1
Unmodified emulsion seal	Conventional emulsion (60%)	1.0
	High bitumen content emulsion (≥ 67%)	1.1
Modified emulsion seal	Uses binder factors below for the PMB that has been emulsified	
High stress seal (HSS2)	S10E, S15E, S35E	1.0
	S20E, **S45R, S15RF**	1.1
Extreme stress seal (XSS)	S20E	1.1
	S45R, S15RF	1.1
Strain alleviating membrane (SAM)	S10E, S15E, S35E, S20E	1.1
	S45R, S15RF	1.1

1. Under very heavy traffic conditions with high percentages of heavy vehicles, these factors may be reduced by 0.1 but should not reduce the binder factor to less than 1.0.

Source: Austroads (2018).

2.5 Selection Guidelines

2.5.1 Western Australia Local Government Association (WALGA)

The WALGA *Sprayed Bituminous Surfacing: Road Building Model Specification* (WALGA 2022) states that S45R is to be used where crumb rubber binders have been selected.

2.5.2 Main Roads Western Australia (MRWA)

Engineering Road Note 15 (MRWA 2017) refers to using Austroads documentation as a general guide to the selection of sprayed seals, including those utilising crumb rubber binders. Austroads sprayed seal selection is discussed in Section 2.5.3.

Specification 503 (MRWA 2018a) states that crumb rubber binders shall be supplied from a bulk mixing facility, thus excluding field blended binders from use on the state network. MRWA allows the use of a blend of 95% w/w C170 bitumen and 5% w/w crumb rubber to be used to construct geotextile reinforced seals (GRS), which is specified in terms of a recipe.

2.5.3 Austroads

Austroads provides preliminary guidance for the selection of sprayed seals in Table 4.7 of Austroads (2018). Based on inputs of total traffic, the proportion of heavy vehicles, climate and stress environment, the table can be used to select an appropriate sprayed seal treatment type for the application. Once the appropriate treatment type has been selected, several binder classes, including crumb rubber binders, are recommended for use with that treatment.

Austroads (2018) considers crumb rubber binders to be part of the larger PMB classification, where PMBs consist of bitumen blended with a synthetic polymer or crumb rubber. Crumb rubber (and other PMBs) is employed to enhance binder performance on heavily trafficked or distressed pavement surfaces, particularly in adverse climatic conditions. These improvements form the basis for their application in SAMs, SAMIs and HSSs.

Bitumen typically exists as a plastic solid at normal ambient temperatures. However, when it is required for use as a sprayed seal, it undergoes liquefaction through processes such as heating, cutting back or emulsification. The viscosity of the binder varies based on the type of binder, the delivery system employed

and the prevailing environmental conditions. When selecting a binder, the anticipated pavement temperature during spraying must be considered. Practical guidelines for minimum pavement temperatures relating to crumb rubber and other materials are outlined in Table 2.4.

Table 2.4: Recommended pavement temperatures for various binders

Binder type	Minimum pavement temperature (°C)	
	with cutter oil	without cutter oil
Hot bitumen	15	35
Polymer modified bitumen[1]	20	45[2]
Crumb rubber bitumen	**20**	**45[2]**
Bitumen emulsion	–	5

1. Does not apply to SAMI seals.
2. This will vary by binder type and could be as high as 65 °C in some cases.

Source: Austroads (2018).

A summary of the guidance from Austroads (2018) regarding treatment types and their applicable crumb rubber binders is provided in Table 2.5. The other binders recommended for those treatment types are included for information.

Table 2.5: Summary of crumb rubber selection options from Austroads (2018) preliminary guide to seal selection

Treatment type	Recommended crumb rubber binders	Other recommended binders
Single/single	Not applicable	C170, C240, C320, M500
Double/double	Not applicable	C170, C240, C320, M500
High stress seal 1 (HSS1)	S45R, S15RF	S10E, S15E, S20E, S35E
High stress seal 2 (HSS2)	S45R, S15RF	S10E, S15E, S20E, S35E
Extreme stress seal (XSS)	S45R, S15RF	S20E
Strain alleviating membrane (SAM)	S45R, S15RF	S10E, S15E, S20E, S35E

Source: Austroads (2018).

2.6 Specifications

2.6.1 National Specifications

The national specifications for the use of crumb rubber binders in sprayed seals are listed in Table 2.6. The properties of crumb rubber and CRMBs for use in sprayed seals are provided in Appendix A.1 and A.2 respectively.

Table 2.6: List of Australian specifications and guidelines on the use of crumb rubber modified binders

Specification/Guideline	Authority	Applications	Reference
ATS 3110 Supply of polymer modified binders	Austroads	• Sprayed sealing binder properties (S9R, S15R, S9RF, S15RF, S18RF)	Austroads (2023)
AGPT04K Guide to Pavement Technology: Selection and design of sprayed seals	Austroads	• Historical background • Operational environments • Selection • Design • Construction procedures	Austroads (2018)

ATS 3110 (Austroads 2023) specifies performance requirements for CRMB for use with sprayed seals: 2 are to be supplied from a bulk mixing facility (S9R and S15R) and 3 are to be field-produced CRMBs (S9RF, S15RF, S18RF). Field-produced CRMBs are defined as binders that are simple blends of bitumen and

crumb rubber that are blended close to the application site and are used within a short timeframe (in no case more than 2 hours travelling time from the blend site). The numerical parts of the grade names represent the nominal percentages by weight of crumb rubber in each binder grade. The properties of CRMB binders are provided in Table A.3 for plant-produced CRMBs and Table A.4 for field-produced crumb rubber binders.

The specification outlines parameters for crumb rubbers of 2 different nominal size gradations (Size 16 and Size 30) and only allows for the incorporation of crumb rubber derived from EoL vehicle tyres generated in Australia. In addition, it specifies that they are sourced by a TSA-accredited supplier or another organisation that is approved by the Principal Engineer. The crumb rubber must be free from deleterious materials including wire, cord and fluff and must meet the properties listed in Table A.1. ATS 3110 (Austroads 2023) also provides a table (Table 9.1 in the specification) outlining the required frequency of testing per property for plant- and field-produced blends.

AGPT04K (Austroads 2018) is a guide to the selection and design of sprayed seals for Australia and also contains background and operational information.

2.6.2 Western Australian Specifications

Specifications from MRWA and WALGA regarding sprayed seals are listed in Table 2.7.

Table 2.7: List of Western Australian specifications on the use of crumb rubber modified binders

Specification	Agency	Applications	Reference
Specification 503, Bituminous surfacing	MRWA	Specifies the supply and application of sprayed bituminous treatments, including primes, primerseals, bitumen and emulsion seals and reseals, geotextile reinforced seals including the use of 5% rubber.	MRWA (2018a)
Specification 509, Polymer modified bituminous surfacing	MRWA	Specifies the supply and application of sprayed polymer modified bituminous treatments including SAM, SAMI, HSS and waterproof bridge deck membranes.	MRWA (2018b)
Specification 511, Materials for bituminous treatments	MRWA	Specifies the supply and use of materials for sprayed bituminous surfacings and asphalt.	MRWA (2023)
Sprayed bituminous surfacing: Road building model specification	WALGA	Specifies the requirements for supply of material and application of sprayed bituminous surfacing including primes, primerseals, bitumen seals and reseals, PMB seals, CRMB seals, geotextile reinforced seals.	WALGA (2022)

Specification 503 (MRWA 2018a) covers sprayed bituminous treatments in general and, specifically for CRMB, specifies:

- CRMB used for geotextile-reinforced seals shall consist of 5 wt.% crumb rubber in C170, each meeting the requirements in Specification 511 (MRWA 2023).
- The rubber binder shall be supplied from a bulk mixing facility. This requires field-produced crumb rubber binders that are used on MRWA works to use a specialised on-site blending and storage unit, rather than ‘in-line’ addition of rubber directly to a bitumen sprayer.

Specification 509 (MRWA 2018b) specifies several construction requirements for CRMB, which are discussed further in Section 2.8.

Specification 511 (MRWA 2023) outlines requirements for crumb rubber to produce CRMB, which are provided in Appendix A.1.2. These requirements are similar to the Austroads requirements but have some differences. It also provides properties for S45R (Table A.3), which are very similar to the Austroads requirements for that binder. Further details with regards to Specifications can be found in **Appendix A.**

The WALGA (2022) road building model specification covers CRMB sprayed sealing. It specifies that CRMBs shall be manufactured using C170 bitumen and recycled rubber from EoL vehicle tyres or other suitable sources that do not contain uncured or devulcanised rubber, foreign material or greater than 20%

elongated particles. Additionally, it specifies that the CRMB shall be dispatched at temperatures not exceeding 195 °C or the manufacturer's recommended maximum temperature, whichever is lower, and the CRMB shall be delivered at a temperature suitable for its immediate use. WALGA (2022) recommends holding CRMB at the lowest practical temperature during transport, and transport vessels shall be equipped with facilities to enable circulation, heating and mixing prior to unloading. The specified properties for the CRMB are equivalent to the MRWA (2023) properties listed in Table A.3, with an additional requirement that the process/combining oil content is reported.

2.7 Challenges, Risks and Mitigation Measures

2.7.1 Segregation and Degradation

Crumb rubber binders for sprayed sealing may be susceptible to segregation of the bitumen and crumb rubber components (where the crumb rubber particles settle at the bottom of a tanker or bitumen sprayer) if they are stored at high temperatures for long periods (Hunter et al. 2015; Lo Presti 2013). Crumb rubber binders can also degrade when stored for extended periods at high temperatures, predominantly due to dissolution of the rubber particles in the bitumen and devulcanisation (a process that reverses the vulcanisation of rubber, which is the cross-linking of rubber molecules with sulphur or other agents to improve its strength and elasticity) of the crumb rubber.

Crumb rubber binder segregation issues can be addressed by equipping storage tanks or trucks with augers or paddles, or piping to circulate the binder, which agitates the blended binder so that the crumb rubber remains dispersed throughout the binder. Degradation can be addressed by limiting the storage time between binder manufacture and use, and/or storing/transporting the binder at the lowest practicable temperature (Lo Presti 2013). When transporting CRMBs over long distances, it is highly important that adequate measures are taken to ensure that segregation does not occur. Suppliers of plant-produced CRMBs are expected to advise on required conditions for agitating the binder during transport to avoid segregation.

2.7.2 Achieving Uniform Binder Distribution

A commonly reported fault with spraying CRMBs has been longitudinal streaking of the sprayed binder, often referred to as 'tramlining', where the sprayed bituminous binder resembles sheets of corrugated iron. Tramlining is thought to be caused by problems with achieving uniform binder distribution (Austroads 2011) due to the relatively high viscosity of the CRMBs. Historically, tramlining has been experienced with other high viscosity PMBs (Neaylon 2007), but the phenomenon has not been fully explained.

One theory on the cause of sprayed seal 'tramlining' is that the trailing nozzle spray in the overlap acts like a grader blade/broom/squeegee and channelises the binder that has already been placed in front of it by the leading nozzle in the overlap. If the CRMB creates a stronger force to cause this channelisation effect, then it may be a contributing factor to why tramlining problems are sometimes experienced with these binders compared to those experienced with more homogeneous binders. The high viscosity of the crumb rubber binders and the added internal cohesion provided by the rubber particles may also contribute to a lack of self-levelling once the binders have been sprayed onto the pavement surface.

To limit the risk of tramlining occurring with CRMBs, several elements related to binder viscosity should be controlled. Binder viscosity is directly affected by its temperature (viscosity reduces as temperature increases), and cutter oil can be added to temporarily reduce viscosity. The pumps in bitumen sprayers are affected by the bitumen viscosity and have to work harder to pump the viscous CRMBs. Thus, limiting the bitumen sprayers to only spray over single lanes (approximately 4 m) as opposed to 'full width' (approximately 8 m) can be beneficial for achieving adequate pressure and transverse distribution. These items are discussed further in Section 2.8.

The transverse distribution from bitumen sprayers is also affected by the nozzles fitted to the sprayers. The most common nozzles used in Australia are manufactured by Copley, being the A18 (nominal output of

18 L/min), B27 (nominal output of 27 L/min) and B36 (nominal output of 36 L/min). The larger output nozzles are sometimes preferred for use with CRMBs when they are perceived to provide better performance and/or present less risk of blockages due to the larger-sized nozzle outlet. Whereas MRWA specify that CRMBs must be sprayed with A27 or B36 nozzles (MRWA 2018b), other jurisdictions do not specify the type of nozzles that must be used to spray CRMBs. A18 nozzles are commonly used for all binder types, including CRMB, elsewhere in Australia. The ability of a bitumen sprayer to achieve satisfactory transverse distribution is tested as part of the calibration of bitumen sprayers, which is required annually for bitumen sprayers that operate on the Australian state road networks. The bitumen sprayers must be calibrated for each type of nozzle that it will use, and thus, it can be expected that a calibrated bitumen sprayer can achieve satisfactory transverse distributions for whichever nozzle types it is using.

2.8 Construction Guidelines

2.8.1 Requirements for CRMB Sprayed Seal Construction

The Austroads *Bituminous Materials Safety Guide* (Austroads 2015b) outlines safe practices for handling hot bituminous products in sprayed sealing, asphalt and bituminous stabilisation operations. This resource serves as a fundamental reference for training inexperienced personnel and refreshing the knowledge of experienced staff. The guide should be used alongside each company's work health and safety management system, complementing Standard Operating Procedures (SOP) and Safe Work Method Statements (SWMS). It should be used in conjunction with equipment and supplier recommendations when working with bitumen products.

Sprayed seals with CRMB are constructed following similar procedures to those for other binders, with some specific requirements. A brief outline of the principal activities involved in sprayed sealing operations is provided in Section 7 of Austroads (2018). Further details of the construction of sprayed seals are provided in the *Guide to Pavement Technology Part 8: Pavement Constructio*n (Austroads 2019), and Austroads/AfPA *Pavement Work Tips* that are accessible from the Austroads website. Further useful information on the construction of sprayed seals is provided in manuals prepared by road agencies (Roads and Traffic Authority 1997; Transit New Zealand, Road Controlling Authorities & Roading New Zealand 2005; VicRoads and Geopave 2004).

Bitumen sprayers used on Australian state road works are required to be calibrated annually by a facility accredited by NATA for the calibration of bitumen sprayers to the Austroads test methods AGPT-T530, T531, T532 or T533 or T534, and T535. The sprayer must pass the Pump Output and Transverse Distribution tests for the maximum allowable width of the bar and shall have been tested for each type of nozzle to be used by the sprayer.

The pump of the bitumen sprayer is expected to be replaced annually due to wear, which is typically done preceding the annual calibration. To ensure the pump of the bitumen sprayer can cope with the demands of pumping the high viscosity CRMB, the width of the spray may be limited. MRWA (2018b) specifies that spray bar widths are limited to 4.0 m when spraying crumb rubber binder on the MRWA network.

The binder spraying temperature is specified to control binder handling and performance. MRWA (2018b) specifies that crumb rubber binders are sprayed between 190 to 200 °C, noting that manufacturer's instructions on binder temperature shall take precedence, and when cutter oil is to be added, the manufacturer's instructions for spraying temperatures shall be followed.

Cutter oil is added to the CRMB binder to reduce its viscosity to aid the initial wetting of the aggregate. General guidance for the amount of cutter to be added is provided in Pavement Work Tips 14 (Austroads 2010) and 27 (Austroads 2013). It must be noted that these rates are currently under review by Austroads and AfPA as reported experience from practitioners is that the suggested rates are too high; however, any amendments have not yet been published.

Guidance from MRWA (2018a) cutter rates for CRMB is summarised in Table 2.8. Otherwise, MRWA (2018a) specifies that, for double/double seals where both layers are applied on the same day using

CRMB, only 2% medium curing cutting oil should be added to the first layer. For the second coat, the medium curing cutting oil should be added in accordance with Table 2.8 and accompanying notes.

Table 2.8: Percentage of cutting oil to be added

Pavement temperature (°C)	Traffic (vehicle/lane/day based on AADT)	% of cutter for S45R
20 to 25	Less than 1,000	9
	1,000 or more	7 to 8
26 to 32	Less than 1,000	6 to 8
	1,000 or more	6
33 to 38	Less than 1,000	6
	1,000 or more	4 to 6
39 to 45	Less than 1,000	Min 4
	1,000 or more	
Above 45	All	Min 4

Notes:

- Cutter amount is a percentage by volume of the total binder.
- Assessment of pavement temperature should consider shaded areas. Areas significantly shaded should be treated separately from adjacent non-shaded areas. Ambient weather conditions in the days and week following must be considered when deciding on adding cutting oil.
- If manufacturer's instructions differ from Table 2.8, follow the manufacturer's instructions.
- If heavy vehicles exceed 20% of total traffic, reduce the cutter content by 2%.
- When using AN36 nozzles for a single coat seal with a BAR of ≥ 1.5 L/m², no cutter is required above a pavement temperature of 45 °C, and the cutter content below 45 °C is reduced by 2 °C.

Source: MRWA (2018a).

2.8.2 Field Blending CRMB

Field blending is a process where C170 bitumen and crumb rubber are blended to create a CRMB, nearby to the location that it will be used. Historically, before the introduction of plant blends, all CRMB used for sprayed sealing were field blended, and it remains in widespread use across much of Australia. There are several advantages to using field-blended CRMB, including avoiding the need to transport the binder and the risk that it will segregate in a delivery tanker, and the flexibility to blend CRMB of different dosages immediately as they are required.

Field blending generally involves loading crumb rubber from bulk bags into a delivery unit, which will have a hopper to store the rubber and means to weigh the load. Bitumen is transferred from a storage unit, typically a bulk tanker, through a pugmill mixing device which combines the bitumen with the rubber and transfers the combined material into the bitumen sprayer (or other storage device). Additionally, a shear mill may be used between the pugmill and bitumen sprayer to enhance blending. The binder is then circulated for a period in the bitumen sprayer to ensure the binder and crumb rubber are incorporated.

Practitioners undertaking field blending should follow defined processes in a work instruction, or similar type document, that is specific to their equipment and requirements. A general overview of the process for field blending of CRMB is as follows:

1. Crumb rubber is loaded into the delivery unit, typically from 1 tonne bulk bags.
2. C170 bitumen is transported to site and heated to an appropriate temperature for transfer and blending, typically around 200 °C. The bitumen should be circulated through the pipework of the tanker for preheating to minimise the risk of blockages due to loss of heat.
3. The components are connected by transfer hoses. The bitumen tanker is connected to the input of the pugmill mixing device. The output of the mixing device is connected to the bitumen sprayer via the shear mill, if used.
4. Transfer of the bitumen commences. Approximately 500–1,000 L of bitumen should be transferred before crumb rubber is added to heat the components, minimise the risk of blockages and aid mixing.

5. Crumb rubber is introduced from the delivery unit into the delivery chamber of the pugmill. The delivery unit will have means to measure the amount of crumb rubber being introduced. The rate of bitumen and crumb rubber flows can be adjusted by the operator, according to the requirements of the resultant binder and the capabilities of the equipment.
6. The pugmill provides initial mixing of the bitumen and crumb rubber as the binder continues to flow into the bitumen sprayer. If a shear mill is being used, it will provide secondary mixing, which aids incorporation of the crumb rubber into the bitumen before the binder enters the bitumen sprayer.
7. Transfer of the crumb rubber and bitumen is completed. The addition of the crumb rubber should be finished before all the bitumen has been transferred, leaving approximately 500–1,000 L of neat bitumen to clear the transfer lines.
8. The transfer hoses are disconnected.
9. The blended CRMB is circulated or agitated in the bitumen sprayer for a minimum of 20 minutes to complete the incorporation process and provide a homogeneous binder.
10. The binder is heated to the desired spraying temperature in the bitumen sprayer, and additives such as cutter oil or adhesion agents are incorporated to prepare for spraying.

2.9 Work Health and Safety and Environmental Impacts

LG TRRIP 03 local government guideline on *Sustainable Road Construction Practices for Local Government Roads in WA* (Howland et al. 2023) provides a detailed list of relevant legislation surrounding environmental and work health and safety requirements for the use of recycled materials in road construction in WA. The report includes:

- waste legislation
- environmental protection legislation and licensing
- work health and safety legislation
- legislation for the management of local roads.

Waste tyres are considered Inert Waste type 2 due to their propensity for being the source of fires. In addition, tyres are known to contain heavy metals and volatile organic compounds (VOC) as potential contaminants of concern (Howland et al. 2023).

As integrating crumb rubber into bitumen for use in sprayed seals involves heating the mixture, the heating process has the potential to emit fumes and airborne particles because of potential contaminants of concern within the crumb rubber. Emissions of VOC and polycyclic aromatic hydrocarbons (PAH) are known to rise as temperatures increase (Mitchell 2022). According to the TSA Tyre Particle Health, Environment and Safety report (Mitchell 2022), there exists a minor to moderate risk to workers during construction. However, the levels of these pollutants are reported to be well below the Safe Work Australia Standards.

There is little literature on the fuming behaviour of CRMB for sprayed seals; however, several studies have investigated CRMB applications in asphalt. When compared to the fumes, emissions and reported discomfort from workers that is experienced with the laying of conventional asphalt, and relevant exposure standards and limits, crumb rubber modified asphalt (CRMA) is found not to pose any significant risk (Department of Transport 2020; van Aswegen & Latter 2019).

Other environmental risks that may be posed with the use of CRMB include leaching and the generation of microplastics. TSA (2022b) undertook a literature review of surface and groundwater leaching risk, concluding CRMA presented a minor risk to the surrounding environment. While it is noted the research referenced is from ~20 years ago, more recent research indicates a similar trend (TSA 2022b). Zou et al. (2023) investigated the leaching risk of CRMB and reported no significant risk was found under most conditions, excepting a potential risk of toxic metals in certain highly acidic aquatic environments. The results indicating the dominant source of PAHs was the bitumen itself, though these also present low environmental risks (Zou et al. 2023).

TSA (2022b) also discusses the risk of microplastics, though the focus is predominantly on particles generated from the wearing of tyres on vehicles, not from the modified pavement. A knowledge gap exists in this space, in both research methods and accepted exposure limits, and further research is required to form conclusive statements about the microplastics risk of sprayed seals and asphalt incorporating CRMB (TSA 2022b).

3 Stakeholder Engagement

3.1 Purpose and Process

A key objective of this project was to build local government capacity in the use of CRMBs in sprayed seal applications in WA. A stakeholder engagement process was therefore carried out to obtain information relating to:

- sources and constraints
- design guidance, detailing suitability of applications regarding traffic and location, seal design and their suitability
- guidance to assist practitioners to select and motivate adoption of applications including economic and engineering aspects
- specifications
- risks and mitigations
- construction guidance, quality control and supervision
- health and safety considerations.

The targeted stakeholders included local government representatives (through WALGA), material suppliers, AfPA members, MRWA personnel, contractors and consultants. The stakeholder engagement methodology is discussed in Sections 3.1.1 to 3.1.3.

3.1.1 Initial Survey

An online survey was distributed to local councils, industry representatives, asphalt manufacturers and binder suppliers. The survey was intended to source an appropriate contact list and develop an initial understanding of the local usage and awareness of CRMBs and Reclaimed Asphalt Pavements (RAP) in asphalt. As it was delivered in conjunction with LG TRRIP 06 *Use of Crumb Rubber Modified Binders and Reclaimed Asphalt Pavements in Asphalt*, the survey was also used to distinguish between the local councils that primarily use asphalt and those that primarily use sprayed seals, or both.

3.1.2 Local Government Workshop

To understand what local governments in WA know and have experienced with crumb rubber spray seals, the LG TRRIP organised an online workshop. This workshop aimed to gather insights from local government representatives through an invitation to join and share their thoughts and experience both on the project and crumb rubber spray seals.

3.1.3 Interviews with Industry

Between 20 and 28 May 2024, interviews were conducted with industry. One MRWA representative, as well as one consultant were consulted. These interviews were seeking insight regarding:

- current usage, including types of projects where CRMB are employed in sprayed seals, specifications used, technologies used
- barriers and challenges to adopting these materials
- experience with local governments and barriers to engaging local governments as clients.

3.2 Outcomes of Stakeholder Engagement

3.2.1 Workshop

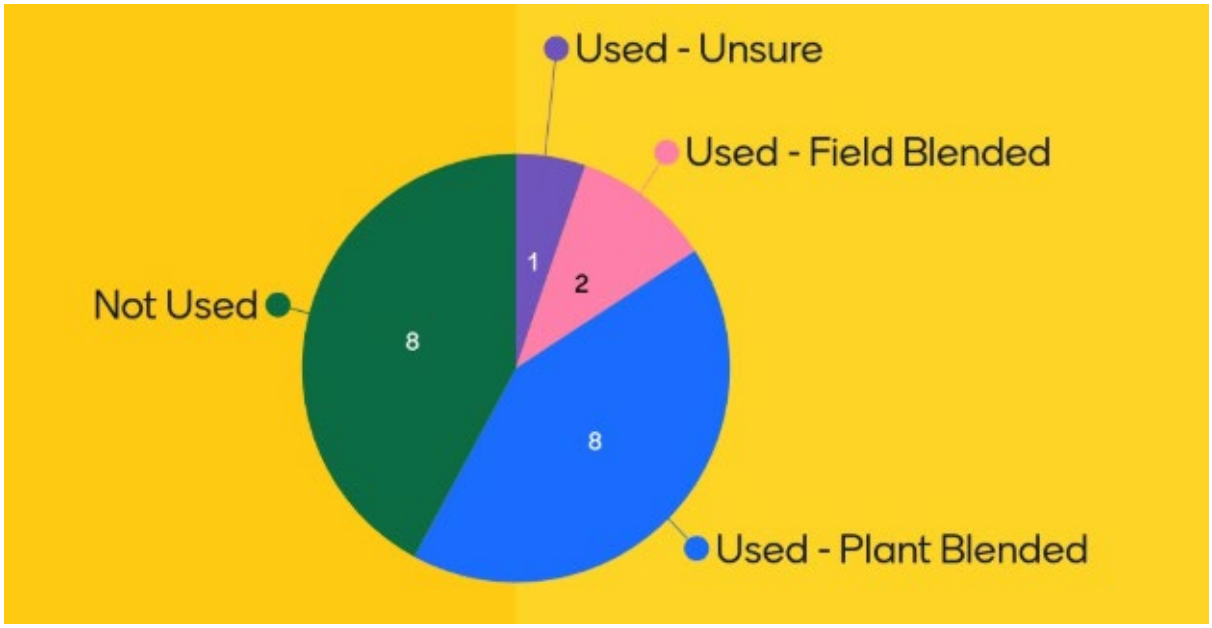
The workshop was advertised through the WALGA newsletter to reach a wide range of local government audience throughout WA and approximately 50 participants attended the workshop thorough Microsoft Teams. During the workshop, the organisers used a tool called Mentimeter to collect responses and facilitate discussions.

The session started with an introduction to crumb rubber, explaining the benefits, performance, properties and characteristics when applied in the spray sealing process and mixes. The goal was to give participants a clear understanding and gather their perspectives on crumb rubber. The discussion also focused on practical aspects of using crumb rubber sprayed seals, providing real-world context. The workshop aimed to engage both industry professionals and local government project managers to gather diverse viewpoints and feedback for the technical report and guidelines for practitioners on the following topics:

- Responsibility for spray seal designs within local governments
  - contractors
  - designers
  - in-house
- Current experience with crumb rubber spray seals
  - field blended
  - plant blended
  - not used previously
- Familiarity with current crumb rubber specifications in WA
  - WALGA sprayed bituminous surfacing specifications
  - MRWA CRMB Specification 509
  - Austroads CRMB specification
- Significant barriers to implementing spray seals and efforts to overcome them (rating out of 10)
  - supply
  - logistics
  - equipment capacity
  - specifications
  - expertise
  - work health and safety
  - lack of guidance
- Expected project outcomes and desired guidance for successful crumb rubber spray seal implementation
  - discussion
- Current CRMB contractors for spray seal.

The findings from the workshop showed that experiences with crumb rubber spray seals among participants were quite diverse, as displayed in Figure 3.1. A majority, about 60%, relied on contractors to implement designs of spray seals, while the remaining 40% were split evenly between consultant and in-house design teams. Regarding actual experience, around 60% of participants reported having some level of experience with CRMB sprayed seals, primarily with plant-blended varieties.

Figure 3.1: Current experience with crumb rubber sprayed seals

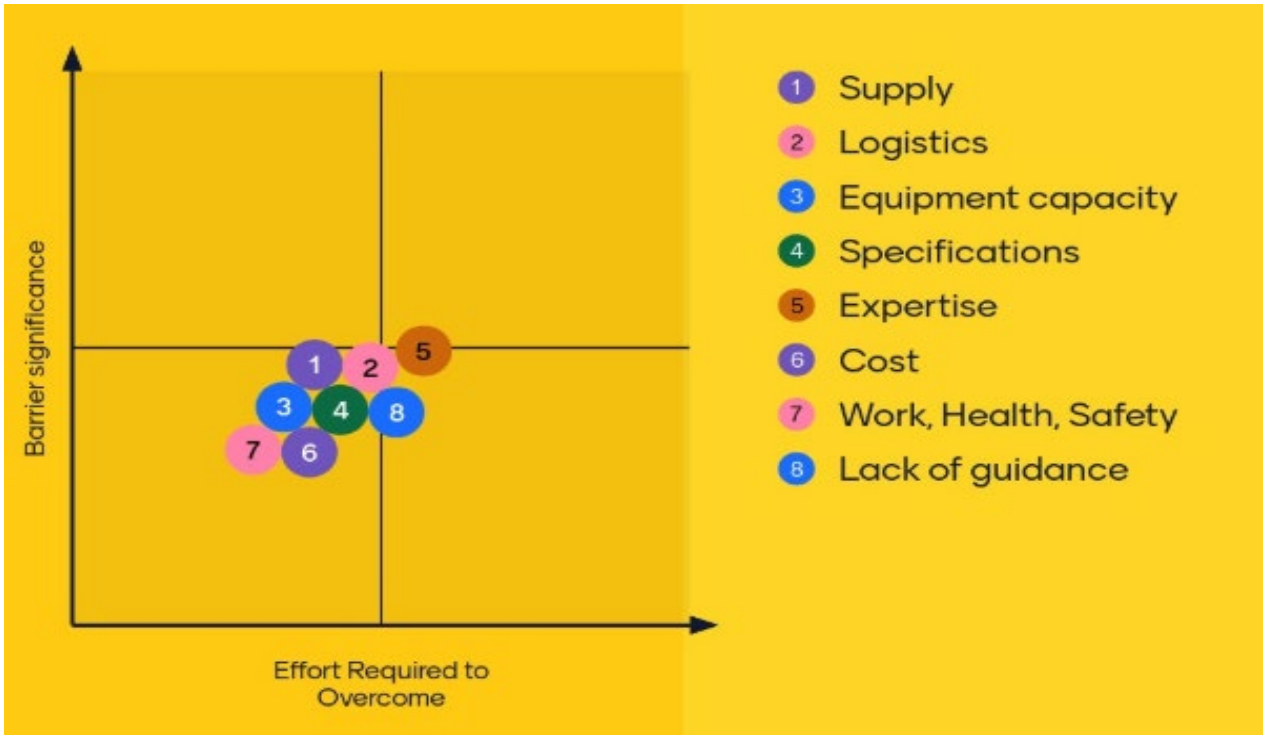


Participants indicated a modest familiarity with crumb rubber specifications, giving an average rating of 3 out of 10, as displayed in Figure 3.2. Among these specifications, the MRWA specification was slightly more familiar than the rest, scoring 3.3 out of 10.

Figure 3.2: Familiarity with current CRMB specifications

The workshop identified several key barriers hindering the adoption of CRMB spray seals. These included a perceived lack of expertise, issues with supply chain and logistics, and insufficient guidance for implementation. A matrix illustrating these barriers, as voted on by workshop participants, was presented to visually represent the collective feedback and concerns, as displayed in Figure 3.3. These findings underscore the need for more support and clearer guidelines to enhance the implementation of CRMB spray seals in local government.

Figure 3.3: Resultant matrix for key barriers for CRMB implementation



The workshop generated several suggestions and comments aimed at advancing the implementation of CRMB spray seals:

- Participants emphasised the need for case studies and previous performance evaluations of similar products to inform decision-making.
- To develop further guidance on CRMB specifications and comparisons of costs associated with CRMB spray seals.
- Suggestions were made for developing performance-based specifications tailored to CRMB spray seals.
- Encouragement was voiced for suppliers to incorporate CRMB into asphalt mixes, potentially boosting its usage.
- Participants highlighted the importance of considering heavy vehicles and traffic volume when applying CRMB spray seals for resurfacing.
- It was noted that CRMB spray sealing in metropolitan areas is relatively underutilised, suggesting a need for industry-wide support to standardise its application.

Alongside the local government industry workshop, individual meetings with suppliers and contractors were conducted, and to ensure a comprehensive identification of CRMB suppliers, participants were asked to identify any of their current suppliers or contractors for CRMB spray seal. The identified CRMB contractors/suppliers were:

- PUMA
- Downer
- Colas
- Bitutek
- Fulton Hogan.

The workshop shed light on the status of CRMB spray seals in WA, indicating an opportunity to delve deeper into differing perspectives between regional and metropolitan councils. However, due to the anonymity provided by Mentimeter during voting sessions, specific council perspectives could not be distinguished.

Overall, the workshop provided valuable insights and set a foundation for further exploration and collaboration to enhance the adoption and effectiveness of CRMB spray seals in local government projects across WA.

The full workshop presentation and survey results can be found on the WALGA website.

3.2.2 Interviews

Road agencies

One MRWA representative, as well as one consultant with extensive experience representing road agencies for sprayed sealing in WA were interviewed privately to discuss CRMB in sprayed sealing for WA local government.

Both MRWA and the consultant identified that sprayed seals are a priority for utilising CRMB in road building applications for local government, with good potential for expansion of its use. The high proportions of rubber used, and the existing established use make sprayed sealing a good candidate for CRMB. It was noted that crumb rubber is widely available, and the availability of CRMB is developing. MRWA and the consultant noted that those already undertaking sprayed sealing with CRMB were typically doing so successfully and had good understanding of the required quality management, yet at times, issues occur due to lack of adherence to specification requirements and application guidance, or general understanding of the engineering needs of CRMB.

As presently S45R/S15R is the only CRMB binder specified for use by MRWA and WALGA specifications, representatives were asked about the potential to expand that range into the S9R as specified by Austroads (2023), or 5% blends commonly used in other states of Australia. MRWA indicated a general intention to limit the number of different binders used so as to retain a focus on strong binder management and quality principles for the available binders. It was thought the 5% CRMB was unlikely to find further use in WA, as the engineering benefits typically sought from CRMB were not present with the smaller amount of rubber, but the S9R binder was more likely to be used in certain applications such as geotextile reinforced seals. The consultant identified that changes to MRWA specifications would be required to implement other binders and noted the WALGA specification required an update to address some inadequacies in guidance and outdated requirements.

The potential for more widespread use of field-blended CRMB binders was discussed. MRWA indicated there was potential for this to occur, focused on areas where long transport distances of plant-blended binders would otherwise be required. MRWA noted a preference for specialised mobile plant such as the ‘rubber ducky’ as already used by some suppliers in WA and commonly in other areas of Australia to blend CRMB. The consultant noted that economies of scale will need to be considered for specialised equipment, as the smaller local government sealed road networks may not justify mobilising the specialised equipment for a small volume of works, and instead, it would be more cost efficient to pursue long-distance haulage of plant-blended CRMB. The consultant noted that smaller-scale ‘in line’ rubber blending is available and could be feasible. This process has been used extensively in Victoria for several decades and requires minimal other equipment and conducts the binder blending in the bitumen sprayer.

The consultant noted that the upfront costs of sprayed seals with CRMB may be higher than conventional bitumen, and road trials to generate evidence of longer achievable lifespans would alleviate the adoption barrier of cost.

MRWA noted that Austroads (2018) guidance around the use of sprayed seals is partially adequate at the moment, but it is expected to improve with future updates that are presently being pursued. MRWA plans to discontinue MRWA (2017) once the Austroads guidance is closer aligned and updated to reflect modern products and guidance.

Contractor

A major WA sprayed sealing contractor was interviewed regarding their experiences with sprayed sealing for WA local government. The contractor reported they have been using CRMB extensively across WA for both state and local government projects and, in general, are happy utilising CRMB sprayed sealing. The contractor noted CRMB is a well-performing product, is less sensitive to small issues and is generally a more forgiving product compared to conventional bitumen. Alongside the benefits, the contractor did note that some challenges with its usage do exist.

Alongside the use of plant-produced products, which have been predominantly S15R/S45R, they have developed capabilities to field-produce crumb rubber binders that meet the properties as required by the specifications. The field products are produced with specialised blending equipment, which is transported to site and is supplemented with ancillary equipment such as a mobile laboratory, lighting towers and forklifts to manoeuvre crumbed rubber. The need to transport and establish this amount of plant and the transport efforts to deliver the base bitumen and crumb rubber mean that the projects must be of a significant enough scale to justify the expense. The contractor reported that local government projects are rarely large enough to qualify as suitable candidates for field blending as standalone projects.

When field blending is not viable, plant-blended products are transported from the Perth area when it is feasible. The feasibility of managing the logistics and economics of crumb rubber binder supply was identified as the most significant barrier to the use of crumb rubber. There are fewer issues with shorter transport distances up to around 1,500 km, but the very large size of WA presents significant issues when transporting. Transport distances of 3,000 km will, for example, take up to 4 days to arrive on site, which can lead to significant risk of segregation of the binder and crumb rubber. This segregation will result in products not meeting specification requirements and can result in clumped rubber residue forming at the bottom of the bitumen sprayer tank. This residue reduces the capacity of the tankers and increases the tare mass of the vehicles and can contaminate subsequent loads of binder, which is undesirable from the contractor's perspective. The contractor manages this risk by using specialised trailers that are suitable for the high viscosity crumb rubber binders and making strong efforts to educate their staff around the requirements of managing crumb rubber binders, particularly around the requirements for frequent binder circulation, temperature management and suitable transfer procedures during delivery.

A further issue identified with crumb rubber was the appropriateness, or lack thereof, of the binders for all applications. The contractor does not prefer to use crumb rubber as an initial seal binder applied directly to a pavement surface, which introduces the need to prime the pavement before the crumb rubber seal is applied. This is not always possible due to the logistics required to keep traffic off the primed surface, where many works are required to be quickly opened to traffic. It is not typically practical or economical to manage and use 2 different binders for sprayed seal projects.

The contractor noted that they perceive there is a somewhat limited knowledge of the CRMB-related specifications for sprayed sealing within WA local governments and how they are understood and implemented. In some respects, this does not present problems, as certain topics such as handling the binders and bitumen sprayers are able to be managed by competent contractors and are no different to working with other binder types. More pertinent are the practical requirements and limitations presented within the desired CRMB sprayed seal types. For instance, the direction from MRWA to only use larger capacity nozzles for CRMB sprayed sealing on state works is carried over to local government works, and this limits the capability to successfully deliver lower binder application rate sprayed seals, for example in the top layer of double/double or intersection/tapered areas. Thus, at times the contractor is unable to deliver works that may be requested to a satisfactory quality.

Additionally, the contractor reported limited understanding within local governments of the performance capabilities and limits of CRMB. Whilst they feel there is reasonable understanding of why CRMB should be used, there is lesser understanding of where it is most appropriate to use them. Whilst the major purpose of utilising CRMB is to enhance resistance against stress and guard against potential cracking, the contractor has noted frequent requests to use CRMB sprayed sealing for lesser stress and crack-risk environments where it is perhaps not needed. The impact of this is the extra expense being wasted on a binder where it

could instead be used to undertake greater amounts of sprayed sealing coverage with a lesser grade, but cheaper, binder.

3.2.3 Case Study – Wheatbelt Secondary Freight Network

The Wheatbelt Secondary Freight Network (WSFN) is a jointly funded program between the Australian Federal Government, State Governments and 42 Wheatbelt local governments aiming to strategically improve the regional road freight safety and efficiency across 4,400 km of key transport routes that support the region's major industries. WSFN has commenced the adoption of an S45R binder, along with other rubber percentage binders, as part of its sealing specifications. The growing support for S45R stems from the challenges encountered with their existing use of C170 binder. In the Wheatbelt region, a significant number of roads were not originally designed to accommodate the increased size and mass of vehicles required by industry to maintain competitiveness. Local government has identified key routes for upgrading on their roads, which will enhance transport efficiency for these larger vehicles.

In an October 2023 submission to the WSFN steering committee proposing the widespread adoption of S45R as a sprayed sealing binder, the purpose, benefits and potential issues, as identified by the WSFN Technical Committee, were discussed. The major issues faced by WSFN with their existing use of C170 bitumen as a sprayed seal binder were:

1. Procuring C170 to required specification requirements has become more difficult as bitumen is now imported, rather than refined in Australia.
2. C170 sprayed seals were often being designed and implemented with conservatively low binder application rates to avoid bleeding and flushing, which may reduce the lifespan before resealing.
3. C170 were bleeding 2 to 3 years after application, even if they initially performed well during a summer season.

The following benefits of adopting S45R as a sprayed seal binder were identified by WSFN:

- utilises recycled material, improving sustainability
- enhances resistance to aggregate stripping
- provides less risk of flushing/bleeding.
- has a longer lifespan (aiming at 20+ years) before resealing is required
- has improved capability for use in double/double seals compared to C170
- is useful as a SAM to resist cracking.

The following potential issues with utilising S45R as a sprayed seal binder were identified by WSFN:

- cannot be sprayed in small quantities (minimum batch size is 20,000 L), however with an understanding that this limitation may decrease with wider industry adoption of S45R
- has a higher cost compared to C170
- is less forgiving during application
- its application direct to pavement is considered risky by WSFN, so an eco-prime or emulsion prime with no volatiles is recommended
- requires a clean surface and stone
- requires maintaining correct spray temperatures (for both pavement surface and binder), which is critical.

An interview was conducted with the WSFN Project Manager to gather further details of this initiative. The primary inspiration for using S45R was to extend the life of sprayed seals compared to what was achieved with C170. Due to limited budgets, opportunities to reseal roads are limited, and thus, methods to extend life and improve freight costs and safety are critically important, with an aspirational goal of achieving a 20-year life without resealing. CRMB was selected over other PMB binders due to perceptions of its comparatively forgiving nature and economic competitiveness.

The initiative to move to S45R has already been adopted willingly by some shires; however, the increased price has limited the capability of other shires to immediately adopt. Those that have adopted S45R have required some adaptation of processes and approach to sealing, which has been helped by the guidance of an expert consultant who has assisted with field issues. The consultant provided technical guidance to the steering committee in February 2024, and the rollout of CRMB sealing commenced promptly after this. So far, 20 km of CRMB sealing was conducted in the summer of 2024, with individual projects between 4 and 8 km being completed.

The shires have reported that the increased costs are balanced by the benefits achieved so far. Asphalt is not used for intersections in the region, and 'farm gate' entries to roads are common, so the increased shear strength of CRMB has been advantageous in these circumstances. This project is in its early stages, so long-term performance benefits are not able to be observed yet. There have been minimal reports of bleeding, which was a developing issue with C170 sealing. It has been found that there is enhanced need for a well-prepared, clean and precoated aggregate to achieve adhesion compared to when using C170. The consultant has encouraged the use of experienced contractors and the use of a 2-year defects liability period, which has worked well so far for those shires that have adopted it.

As there has been expanded use of CRMB by MRWA, the local contractors are experienced with CRMB, and there is good availability of products. Initial reports indicate improvements in sealing outcomes and have allowed further use of double/double seals, which were previously found to be problematic when using C170. It had been common practice to delay the application of the second layer of a double/double for 12 months when using C170, as it was thought a double layer sprayed seal with C170 was unstable; however, no such restrictions are felt necessary with the CRMB.

The MRWA (2018b) Specification 509 is being used and maintains that if the processes described by this specification are followed, then outcomes are expected to be good. However, there is an understanding that some shires lack knowledge about the specification and how to enforce it, and limited supervision of works leads to a reliance on the contractor's ability to adhere to it. The MRWA (2018b) specification is preferred to the WALGA (2022) specification as it is considered to be more robust, and whilst Austroads guidance is available and wide ranging, the breadth of scope covered within them can be difficult for shire staff to interpret and prioritise, especially considering there is often a high turnover rate of staff.

The S45R binders procured have so far been transported up to 4 hours without issue, and sealing contractors are often aligned with preferred binder suppliers, so the responsibility for selecting particular suppliers does not lie with the shires. It has been recommended by the consultant that S9R binders are considered for use in circumstances where performance requirements are not as high, as S9R is considered more forgiving and easier to work with during construction, but this has not occurred yet. Field-blended binders are not considered a viable option at this stage due to the limited volume of binder required and the ease of supply of the plant-produced binders. The WSFN steering committee are looking into additives such as Sripath PGXpand polymer, which is designed to enhance high temperature performance of bitumen without impacting low temperature properties, to facilitate achieving high standard CRMB sprayed seals.

Considering the outcomes so far, WSFN have observed a general improvement in sealing outcomes and appreciate the expanded capabilities achievable with CRMB, considering options to use other PMBs are limited in WA at the low volumes required by the shires. WSFN are aware that the true results of the program may not be evident until 15–20 years have passed and the final performance of these seals can be judged, yet early results have generated generally optimistic expectations.

4 Implementation Opportunities

4.1 Western Australian Local Government Landscape

The literature review and consultations with local and state government practitioners and industry experts has found that CRMB sprayed sealing is actively being used in WA, and its use can be expected to expand over time.

The CRMB products and their component materials are available throughout WA and are subject to existing specifications and design and selection guidance (as discussed in Section 2.6). Product supply across WA is mainly sourced from the Perth metropolitan area for plant-produced products, which presents issues related to maintaining the integrity of the product across the long travel distances to many regional council areas in the state. Field-blended CRMB products are available also; however, the major issue for local governments with these products is the economic scale of the projects to justify establishing remote blending facilities.

Overall, there is a recognition that CRMB sprayed sealing can be beneficial to local governments in WA and that enhanced understanding of the products and procedures available to implement them (further discussed in Sections 4.2 through 4.5) would be beneficial for local governments to achieve desirable outcomes.

4.2 Specifications

As discussed in Section 2.6, specifications for CRMBs are detailed in ATS 3110 (Austroads 2023) MRWA Specification 511:2023 and AGPT04K (Austroads 2018). Specification 503 (MRWA 2018a) covers sprayed bituminous treatments in general and Specification 509 specifies several construction requirements for CRMB. The WALGA (2022) road building model specification is also available for CRMB sprayed sealing.

The industry consultation revealed there was generally limited understanding of the available CRMB sealing specifications and guidance documents, and enhanced use of the existing documentation would assist with understanding and implementing the practical requirements and limitations presented with CRMB sprayed seals.

4.3 Design Guidance

Sprayed seals with CRMB are designed with the same procedures as for other binders as discussed in section 2.4. The design of sprayed seals in Australia follows the procedures of the *Guide to Pavement Technology Part 4K: Selection and Design of Sprayed Seals* (Austroads 2018). *Engineering Road Note 15* (MRWA 2017) and the WALGA *Sprayed Bituminous Surfacing: Road Building Model Specification* (WALGA 2022) both refer to the Austroads procedures for sprayed seal design. Further detail was provided in section 2.4 above.

The industry consultations revealed that in most cases, the sprayed seal designs are completed by the contractor or a specialist consultant.

4.4 Construction Guidance

Sprayed seals with CRMB are constructed following similar procedures to those for other binders, with some specific requirements. Practitioners can refer to following guidelines for construction specifications: Section 7 of Austroads (2018), *Guide to Pavement Technology Part 8: Pavement Construction* (Austroads 2019) and Austroads/AfPA *Pavement Work Tips*. These guidelines are further discussed in section 2.8.

Further guidance on the addition of cutter oil is contained in Section 2.8.1. Practitioners undertaking field-blending should follow defined processes in a work instruction, or similar type document, that is specific to their equipment and requirements. A typical process for field blending CRMB is provided in Section 2.8.2.

4.5 Material Supply

As discussed in Section 2.3, crumb rubber is readily available in WA with various suppliers having the capacity to provide crumb rubber that meets the requirements of Specification 511 and ATS 3110. Crumb rubber supplied for MRWA must be provided by a TSA-approved supplier and meet the requirements of Table A.2.

A number of binder manufacturers have the capability to produce CRMBs in the plant that meet WA and national specifications. Specification 511 (MRWA 2023) outlines requirements for crumb rubber to produce CRMB, which are provided in Appendix A.1.2. These requirements are similar to the Austroads requirements but also provides properties for S45R (Table A.3).Field-produced CRMB can be utilised if specialised on-site mixing and storage facilities are employed.

The availability and feasibility of CRMBs for sprayed sealing varies depending on the site location. The main challenge for plant-produced CRMB is transporting from the metropolitan area of Perth, over potentially long distances, without the crumb rubber segregating from suspension in the bitumen. For field-produced binders, the main challenge for local government applications is having projects of a scale that economically justifies the establishment of the on-site blending and ancillary equipment. It is therefore recommended that sourcing is considered case by case.

The industry consultations noted that CRMB is typically more expensive than unmodified bitumen but is expected to have extended life and enhanced performance when compared to unmodified bitumen, yet the evidence to support this, or to define the exact benefit, is challenging to obtain and would benefit from further road trials and case studies. The increased costs of CRMBs are due to the additional processing in manufacturing rather than material costs, as often the price of crumb rubber is lower than that of bitumen. Therefore, it is recommended that relevant costs are considered on a case-by-case basis.

5 Conclusion and Recommendations

This project aimed to enhance the capacity of local governments in WA to effectively use CRMBs in sprayed seal applications. Through a literature review and stakeholder engagement, the project gained valuable insights into the current practices and challenges associated with CRMB spray seal integration into local government road projects. The report underscores the potential of sprayed seals as a priority area for CRMB, given the high availability of crumb rubber and the existing practices in place.

While initial costs for CRMB sprayed seals may be higher than conventional bitumen, road trials demonstrate that the longer lifespan and durability could mitigate the high capital cost. CRMB proves to be a versatile and effective option for sprayed seals with the ability to handle moderate to high traffic volumes. CRMBs have increased elasticity, providing resistance to shear stresses (turning movements) and a higher softening point than conventional bitumen, thus providing reduced susceptibility to flushing in hot climates, increased cohesive and aggregate retention properties and improved crack resistance. Particularly in high-stress areas and cracked pavements, CRMB offers enhanced performance and waterproofing.

Practitioners must consider the surface conditions and proper priming for new constructions. Using CRMBs also enhances our circular economy, making it a valuable material for road projects in WA. However, to optimise its use, challenges such as transportation logistics, environmental concerns, and site-specific safety measures should be addressed. CRMB's recycling benefits and ability to handle moderate to high traffic volumes underscore its reuse and practical advantages; however, the potential for fumes and odours and the need for additional cutter in high-viscosity mixes highlight areas for improvement.

As local governments look to expand CRMB seal usage, these factors must be considered to ensure successful implementation and long-term sustainability in road infrastructure projects.

In general, CRMBs have increased elasticity, providing resistance to shear stresses (turning movements) and a higher softening point than conventional bitumen, thus providing reduced susceptibility to flushing in hot climates, increased cohesive and aggregate retention properties and improved crack resistance. The selection chart for sprayed seals is detailed in *Part 4K: Table 4.7 Preliminary Guide to Seal Selection*, and the selection of CRMB binders are generally appropriate for the following criteria:

- cracked pavements
- medium- to high-temperature locations with low-volume traffic, < 200 vehicles per lane per day (v/l/d) where equivalent heavy vehicles (EHVs) are > 45%
- locations with low to mid volume traffic, < 750 v/l/d, on high stress locations including: grades > 5%, curves, turning lanes and intersections, where EHVs are > 26%
- all temperature locations where traffic volumes are > 750 v/l/d
- high-stress locations > 200 and < 5,000 v/l/d and all EHVs
- locations with pavement grades > 5% with traffic volumes up to 15,000 v/l/d.
- For traffic volumes > 2,000 v/l/d and EHVs > 26%, or for steep grades the performance of CRMB seals may be unsatisfactory, and alternative treatments, such as asphalt, should be considered.

The traffic type and pavement condition will influence the grade of CRMB that is appropriate for use on the location to be sealed. Generally, S15R (formerly S45R) or S15RF binders which contain 15 wt.% crumb rubber are the standard sealing grade binders used. Lower modifications, such as S9R CRMB, may be suitable for low traffic, low stress locations and will still provide some of the improved properties and performance benefits of CRMB modified binder. Specification 503 (MRWA 2018a) also refers to the use of CRMB in geotextile reinforced seals, consisting of 5 wt.% crumb rubber in C170, meeting the requirements in Specification 511 (MRWA 2023).

The use of CRMB in sprayed seals poses some environmental risks including fumes and odours during application and . CRMB's higher viscosity, compared to standard bitumen, often necessitates the use of additional cutter.

Another environmental consideration is the risk of leaching, which may impact surrounding ecosystems. Although the TSA suggest that the risk is minor, it remains a factor that must be monitored. The continued development of CRMB technologies and adoption of low-viscosity CRMB could help mitigate some of these environmental risks by reducing the use of cutter and the need for additional chemicals.

The diverse experiences of local governments in implementing CRMB sprayed seals suggest varying levels of familiarity and reliance on contractors, which points to a need for further capacity building and knowledge sharing within the local government sector.

The logistical challenges associated with transporting CRMB across WA's vast distances remain a significant barrier to its widespread adoption. Ensuring the consistent quality and availability of CRMB in remote locations requires advanced planning and infrastructure and the use of cost-effective and sustainable production and distribution methods. The development of field-blended CRMB products, which offers greater flexibility by allowing for on-site customisation of CRMB. This approach is particularly useful in remote or regional areas where transporting plant-produced CRMB over long distances can be both logistically complex and costly.

Despite the challenges, CRMB offers significant performance benefits over standard bitumen, including increased elasticity and resistance to shear stresses, higher softening point reducing susceptibility to flushing in hot climates, improved cohesion and aggregate retention for enhanced road durability and improved crack resistance, and supports circular economy outcomes.

References

Airey, GD, Rahman, MM & Collop, AC 2003, 'Absorption of bitumen into crumb rubber using the basket drainage method', *The International Journal of Pavement Engineering*,vol. 4, no. 2, 105-19, doi:10.1080/1029843032000158879.

Artamendi, I & Khalid, HA 2006, 'Diffusion kinetics of bitumen into waste tyre rubber', *Asphalt Paving Technology: Association of Asphalt Paving Technologists-Proceedings of the Technical Sessions, January 2006*, vol.

Australian Life Cycle Assessment Society 2022, *Australian Life Cycle Inventory (AusLCI) datasets,* version 1.40*,* database*,* ALCAS, Melbourne, Vic, <https://www.auslci.com.au/index.php/Datasets>

Austroads 2010, *Sprayed seal cutting practice,* AP-PWT14-10, Austroads, Sydney, NSW.

Austroads 2011, *Review of primes and primerseal design*, AP-T179-11, Austroads, Sydney, NSW.

Austroads 2013, *Sprayed sealing – cutting back of polymer modified binders,* AP-PWT27-14, Austroads, Sydney, NSW.

Austroads 2015a, *Austroads glossary of terms*, 6.0 edn, AP-C87-15, Austroads, Sydney, NSW.

Austroads 2015b, *Bituminous materials safety guide*, AP-G41-15, Austroads, Sydney, NSW.

Austroads 2017, *Guide to pavement technology part 4F: bituminous binders*, 2nd edn, AGPT04F-17, Austroads, Sydney, NSW.

Austroads 2018, *Guide to pavement technology part 4K: selection and design of sprayed seals*, edn 1.3 2019, AGPT04K-18, Austroads, Sydney, NSW.

Austroads 2019, *Guide to pavement technology part 8: pavement construction*, edn. 2 AGPT08-19, Austroads, Sydney, NSW.

Austroads 2021, *National specification for crumb rubber binders in asphalt and seals,* AP-T359-21, Austroads, Sydney, NSW.

Austroads 2023, Supply of polymer modified binders, ATS 3110, Austroads, Sydney, NSW.

Billiter, TC, Chun, JS, Davison, RR, Glover, CJ & CBullin, JA 1997, 'Investigation of the curing variables of asphalt-rubber binder', *Petroleum Science and Technology*,vol. 15, no. 5-6, 445-69, doi:10.1080/10916469708949669.

Cao, WD, Liu, ST, Cui, XZ & Yu, XQ 2011, 'Effect of crumb rubber particle size and content on properties of crumb rubber modified (CRM) asphalt', *Applied Mechanics and Materials*,vol. 99-100, no. 955-59, doi:10.4028/www.scientific.net/AMM.99-100.955.

Dantas-Neto, SA, Farias, MM, Pais, JC & Pereira, PAA 2011, 'Dense graded hot mixes using asphalt-rubber binders with high rubber contents', *Road materials and pavement design*,vol. 7, no. 1, 29-46, doi:10.1080/14680629.2006.9690025.

Denneman, E, Lee, J, Raymond, C, Choi, Y, Khoo, KY & Dias, M 2015, P31 and P32: optimising the use of crumb rubber modified bitumen in seals and asphalt (year 1 – 2014/15), contract report 009176 &

009177, prepared for Queensland Department of Transport and Main Roads under the NACoE program, ARRB, Port Melbourne, Vic.

Department of Climate Change, Energy, the Environment and Water 2019, *National waste policy: action plan*, DCCEEW, Canberra, ACT, accessed 30 September 2024, <https://www.dcceew.gov.au/environment/protection/waste/publications/national-waste-policy-action-plan>.

Department of Transport 2020, *East Boundary road crumb rubber asphalt trial emissions monitoring report*, Vistoria State Government, Victoria, Australia, viewed 21 February 2024, <https://www.vicroads.vic.gov.au/-/media/files/technical-documents-new/technical-reports-and-bulletins/technical-report-tr-220-east-boundary-road-crumb-rubber-asphalt-trial-emissions-monitoring-report.ashx>.

Gawel, I, Stepkowski, R & Czechowski, F 2006, 'Molecular interactions between rubber and asphalt', *Industrial & Engineering Chemistry Research*,vol. 45, no. 9, 3044-49, doi:10.1021/ie050905r.

Ghavibazoo, A & Abdelrahman, M 2013, 'Composition analysis of crumb rubber during interaction with asphalt and effect on properties of binder', *International Journal of Pavement Engineering*,vol. 14, no. 5, 517-30, doi:10.1080/10298436.2012.721548.

Hall, B, Grenfell, J, Pandelidi, C, Yaghoubi, J, Chaudhry, U, Lyons, M, O'Connor, G, Harrison, J & Feigen, D 2022, *Best practice expert advice on the use of recycled materials in road and rail infrastructure: Part A technical review and assessment*, ARRB, Australia, viewed 1 August 2022,

Harrison, J, Lyons, M, O'Connor, G & Thomas, L 2019, *Literature review on passenger vehicle tyre usage in bitumen*, TR 216, VicRoads, Melbourne, Vic.

Heitzman, M 1992, 'Design and construction of asphalt paving materials with crumb rubber modifier', *Transportation Research Record*,vol. no. 1339, 1-8, <https://trid.trb.org/view/370637>.

Hoffmann, P & Potgieter, CJ 2007, ‘Bitumen rubber chip and spray seals in South Africa’, Southern African transport conference, 26th, 2007, Pretoria, South Africa, Southern African Transport Conference, Pretoria, South Africa, pp. 225–38.

Howland, C, Feigen, D, Bartlett, D & Grenfell, J 2023, *Technical report: Sustainable road construction practices for Local Government roads in WA*, LG TRRIP, Perth, WA, viewed 3 January 2024,

Hunter, RN, Self, A & Read, J 2015, The Shell bitumen handbook, 6th edn, ICE Publishing, London, UK

Liang, M, Sun, C, Yao, Z, Jiang, H, Zhang, J & Ren, S 2020, ‘Utilization of wax residue as compatibilizer for asphalt with ground tire rubber/recycled polyethylene blends’, Construction and Building Materials, vol. 230, article no. 116966, 12 pp.

Lo Presti, D 2013, 'Recycled tyre rubber modified bitumens for road asphalt mixtures: A literature review', *Construction and Building Materials*,vol. 49, no. 863-81, doi:10.1016/j.conbuildmat.2013.09.007.

Main Roads Western Australia 2017, *Engineering Road Note 15*, Australia, MRW, Australia.

Main Roads Western Australia 2018a, *Specification 503: Bituminous surfacing*, Australia, MRWA, Australia.

Main Roads Western Australia 2018b, *Specification 509: Polymer modified bituminous surfacing*, Australia, MRWA, Australia.

Main Roads Western Australia 2023, *Specification 511: Materials for bituminous treatments*, Australia, MRWA, Australia.

Main Roads Western Australia & WALGA 2023, *State Road Funds to Local Government Agreement*, D23#417931, MRWA, Western Australia, viewed 5 January 2024,

Marais, HIJ, Botha, C, Hofsink, W, Muller, J & van Heerden, J 2017, 'Latest developments in crumb rubber modified bitumen for use in asphalt and seals: the South African experience', AAPA international flexible pavements conference, 17th, 2017, Melbourne, Vic., Australian Asphalt Pavement Association, Port Melbourne, Vic, 17 pp.

McDonald, CH 1976, *Low viscosity asphalt-rubber paving material*, edn, 754,446, USA.

Mitchell, L 2022, Tyre particle health, environment and safety report, version 2, Tyre Stewardship Australia.

Neaylon, K 2007, 'Spray seal stripping in the Wide Bay District', QEAHDMR-11/2007, ARRB Group, Vermont South, Vic.

Ould-Henia, M & Dumont, A-G 2008, 'Effect of base bitumen composition on asphalt rubber binder properties', *International Symposium on Asphalt Pavements and Environment (ISAP)*, *Zurich*, Dubendorf, EMPA, vol. 21-30.

Oliver, JWH 1981, 'Modification of paving asphalts by digestion with scrap rubber', *60th Annual Meeting of the Transportation Research Board*, *12-16 January 2981*, *Washington District of Columbia, US*, Transportation Research Record, vol. 821, 37 - 44.

Paten, S 2023, *Tyrecycle takes on offroad tyre processing*, webpage, Waste Management Review, viewed 21 February 2024, <https://wastemanagementreview.com.au/tyrecycle-takes-on-offroad-tyre-processing/>.

Picado-Santos, LG, Capitão, SD & Neves, JMC 2020, 'Crumb rubber asphalt mixtures: a literature review', Construction and Building Materials, vol. 247, article no. 118577, 13 pp.

Roads and Traffic Authority 1997, Sprayed sealing guide, 2nd edn, document no. TP-GDL-001, RTA, Milsons Point, NSW.

Shen, J, Amirkhanian, S, Xiao, F & Tang, B 2009, 'Influence of surface area and size of crumb rubber on high temperature properties of crumb rubber modified binders', *Construction and Building Materials*,vol. 23, no. 1, 304-10, doi:10.1016/j.conbuildmat.2007.12.005.

Southern African Bitumen Association 2019, *Guidelines for the design, manufacture and cosntruction of bitumen-rubber asphalt wearing courses*, Manual 19, SABITA, South Africa, viewed 23 December 2022, <https://www.sabita.co.za/wp-content/uploads/2022/02/sabita-manual-19-at-sep-2019.pdf>.

Southern African Bitumen Association 2020, *Technical guideline: The use of modified bituminous binders in road construction*, Sabita, South Africa, viewed 7 July 2023, <http://www.sabita.co.za/wp-content/uploads/2020/11/tg1-as-at-nov-2020.pdf>.

Sybhy, A, Lo Presti, D & Airey, GD 2016, 'Rubberised bitumen manufacturing assested by rheological measurements', *Road materials and pavement design*,vol. 17, no. 2, 290-310, doi:10.1080/14680629.2015.1079549.

Transit New Zealand, Road Controlling Authorities & Roading New Zealand 2005, Chipsealing in New Zealand, Transit New Zealand, Wellington, NZ.

Tyre Stewardship Australia n.d., *Find accredited recyclers & collectors*, webpage, viewed 5 February 2024, <https://www.tyrestewardship.org.au/accreditation/find-accredited-recyclers-collectors/>.

Tyre Stewardship Australia 2019, *Annual report 2018/2019*, TSA, Richmond, Vic.

Tyre Stewardship Australia 2022a, *The benefits of surfacing roads with tyre derived crumb rubber: findings and facts*, TSA, viewed 21 February 2024, <https://www.tyrestewardship.org.au/wp-content/uploads/2022/03/TSA0117-Crumb-Rubber-Roads-Fact-Sheet.pdf>.

Tyre Stewardship Australia 2022b, *Tyre particle health, environment and safety report*, TSA, viewed 21 February 2024, <https://www.tyrestewardship.org.au/wp-content/uploads/2022/11/TSA-Tyre-Particle-Safety-Report.pdf>.

Tyre Stewardship Australia 2023a, *New data reveals a worrying trend*, webpage, TSA, viewed 21 February 2024, <https://www.tyrestewardship.org.au/news/media-release-new-data-reveals-a-worrying-trend/>.

Tyre Stewardship Australia 2023b, *Tipping the balance: The business case for circular economy for Australia's off-the-road tyres, conveyors, and tracks*, viewed 21 July 2023,

van Aswegen, E & Latter, L 2019, *Transfer of appropriate crumb rubber modified bitumen technology to WA*, contract report PRP16016, prepared by ARRB for WARRIP, prepared by ARRB for WARRIP, WARRIP, Perth, WA.

VicRoads & Geopave 2004, Bituminous sprayed surfacing manual, technical bulletin no. 45, VicRoads, Kew, Vic.

Waste Authority 2023, *Action plan 2022-2023: Waste avoidance and resource recovery strategy 2030*, Government of Western Australia, Western Australia, viewed 27 June 2023, <https://www.wasteauthority.wa.gov.au/about/view/strategic-direction>.

Western Australia Local Governments Association 2013, *End-of-life tyre management in Australia*, WALGA, Western Australia, viewed 21 February 2024, <https://www.wastenet.net.au/Assets/Documents/Content/Information/Endorsed_Tyre_Research_Paper_20.02.13.pdf>.

Western Australia Local Governments Association 2022, *Sprayed bituminous surfacing: road building model specification*, WALGA, Perth, WA, viewed 13 February 2024,

Western Australia Local Governments Association 2023, Report on Local Government road assets and expenditure (2022-2023), WA, viewed 16 September 2024, <https://walga.asn.au/policy-advocacy/our-policy-areas/infrastructure/roads/report-on-local-government-road-assets-and-expendi>.

Zou, F, Leng, Z, Li, D, Zhang, S, Yaphary, YL & Lu, G 2023, 'Leaching potential of metals and PAHs of asphalt rubber paving materials', *Transportation Research Part D: Transport and Environment*,vol. 125, no. 103984, doi:10.1016/j.trd.2023.103984.

Australian Standards

AS/NZS 2341.4 *Methods of testing bitumen and related roadmaking products Determination of dynamic viscosity by rotational viscometer*

AS 2341.18:2020, *Methods of testing bitumen and related roadmaking products, Method 18: determination of softening point (ring and ball method)*

Austroads Test Methods

AGPT/T101: *Method of Sampling Polymer Modified Binders, Polymers and Crumb Rubber*

AGPT/T108: *Segregation of Polymer Modified Binders*

AGPT/T121: *Shear Properties of Polymer Modified Binders*

AGPT/T125: *Stress Ratio of Bituminous Binders using the Dynamic Shear Rheometer*

AGPT/T142: *Rubber Content of Crumb Rubber Modified Bitumen: Soxhlet Method*

AGPT/T143: *Particle Size and Properties of Crumb Rubber*

AGPT/T144: *Morphology of Crumb Rubber - Bulk Density Test*

AGPT/T530: *Calibration of Bitumen Sprayers: General Introduction and List of Methods*

AGPT/T531: *Calibration of Bitumen Sprayers: Volumetric Calibration of Bitumen Pumping Systems*

AGPT/T532: *Calibration of Bitumen Sprayers: Transverse Distribution by Fixed Pit Facility*

AGPT/T533: *Calibration of Bitumen Sprayers: Transverse Distribution by Field Mat*

AGPT/T534: *Calibration of Bitumen Sprayers: Transverse Distribution by Portable Trough*

AGPT/T535: *Road Speed and Distance Calibration*

ATM-103: *Mass Change or Loss on Heating of Polymer Modified Binders after Rolling Thin Film Oven (RTFO) Treatment*

ATM-111: *Handling Viscosity of Polymer Modified Binders (Brookfield Thermosel)*

ATM-112: *Flash Point of Polymer Modified Binders*

ATM-122: *Torsional Recovery of Polymer Modified Binders*

ATM-132: *Compressive Limit of Polymer Modified Binders*

Main Roads Western Australia Test Methods

WA 201.1: *Sampling and Preparation of Granulated Rubber*

WA 235.1: *Bulk Density of Granulated Rubber*

WA 236.1: *Particle Size Distribution of Granulated Rubber*

WA 237.1: *Steel Content of Granulated Rubber*

Appendix A Specifications for Crumb Rubber Modified Binders for Sprayed Sealing

A.1 Crumb Rubber Requirements

A.1.1 Austroads

Austroads (2023) specifies that crumb rubber used for the manufacture of crumb rubber binders must be:

1. processed from waste tyres generated in Australia
2. processed by a supplier accredited with TSA or another organisation approved by the Principal
3. free from cord, wire, fluff and other deleterious material
4. meet the properties included in Table A.1.

Table A.1: Summary of Austroads crumb rubber requirements for the production of crumb rubber modified binders

Property	Test method	Austroads	
		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		–	30 max.
Particle length (max, mm)	AGPT/T143	3	3
Bulk density (kg/m^3)	AGPT/T144	TBR	TBR
Water content (max, %)	AGPT/T143	1	1
Foreign materials – metallic iron (max, %)	AGPT/T143	0.1	0.1

Source: Austroads (2023).

A.1.2 MRWA

MRWA (2023) specifies that crumb rubber used for the manufacture of crumb rubber binders shall:

1. consist of rubber processed from EoL tyres or other suitable rubber products
   Uncured or devulcanised rubber shall not be used as a source material.
2. be sourced from a TSA-accredited tyre recycler or an MRWA-approved supplier
3. be supplied in a dry condition, protected against moisture ingress and stored undercover to ensure the product remains dry
4. be sampled and prepared for testing in accordance with AGPT/T101, AGPT/T143 and WA 201.1.
5. meet the requirements shown in Table A.2.
   Crumb rubber shall not contain any foreign material such as sand, fibres or aggregate. Crumb rubber shall not contain more than 20% of elongated particles. An elongated particle is one where the length of the major axis of the particle is more than double the length of the minor axis.

Table A.2: Summary of MRWA crumb rubber requirements for CRMB production

Property	Test method	Requirement
Grading	AGPT/T143 or WA 236.1	
Passing 2.36 mm		100
Passing 1.18 mm		100
Passing 0.60 mm		60–100
Passing 0.30 mm		0–22
Passing 0.075 mm		0–2
Particle shape (mm)	AGPT/T143	Mean of measured particles Maximum 3 mm
Bulk density (kg/m^3)	AGPT/T144 or WA 235.1	< 350
Moisture content (max, %)	AGPT/T143	1
Iron or steel content (max, %)	AGPT/T143 Or WA 237.1	≤ 0.1% by mass

Source: MRWA (2023).

A.2 Crumb Rubber Modified Binder Requirements

Table A.3: Summary of plant-produced CRMB property requirements for sprayed seal applications

Property	Test method	Austroads[1]		MRWA[2]
		S9R	S15R	S45R
Viscosity at 165 °C (max, Pa.s)	AS/NZS 2341.4 or ATM-111	1.5	4.5	4.5
Torsional recovery at 25 °C, 30 s (%)	ATM-122	15–45	25–55	25–55
Softening point (min, °C)	AS 2341.18	50–60	55–65	55–65
Stress ratio at 10 °C	AGPT/T125	TBR	TBR	TBR
Consistency 6% at 60 °C (min, Pa.s)	AGPT/T121	400	800	800
Stiffness at 15 °C (max, kPa)	AGPT/T121	NA	180	TBR
Compressive limit at 70 °C, 2 kg (min, mm)	ATM-132	0.1	0.2	0.2
Segregation (max, %)	AGPT/T108	−8 to +8	−8 to +8	−8 to +8
Flash point (min, °C)	ATM-112	250	250	250
Mass change (%)	ATM-103	−0.6 to +0.6	−0.6 to +0.6	–

Source:

1. Austroads (2023).
2. MRWA (2023).

Table A.4: Properties of field-produced crumb rubber binders

Property	Test method	S9RF	S15RF	S18RF
Nominal rubber concentration (%)	–	9	15	18
Rubber content by analysis (%) min.	AGPT/T142	7	13	16
Torsional recovery (%) min.	ATM-122	15	25	30
Softening point (°C) min.	AS 2341.18	50	55	62
Consistency 6% at 60 °C (Pa.s)	AGPT/T121	TBR	TBR	TBR

Source: Austroads (2023).

Perth, Western Australia