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Literature Review on Passenger Vehicle Tyre Usage in Bitumen

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TRANSPORT FOR VICTORIA

Literature Review on the Use of Passenger Vehicle Tyres in Bitumen

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This study has been undertaken to promote knowledge development in the field of road construction. The study is not intended to make any legal representations and does not commit the Victorian State Government to any future course of action. No-one should rely on the study in making construction, business or investment decisions. The Victorian State Government and its departments and agencies accept no responsibility for any use of this study, including for any loss or detriment resulting from reliance on or application of this work.

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Summary

Victoria is one of the leaders in the use of crumb rubber in Australia, with its use well established in sprayed seals and increasing in asphalt. As the demand for crumb rubber is expected to increase in coming years, it may be necessary to diversify the source of waste tyre rubber to ensure the demand can be met. Victoria's roadworks specifications currently do not prescribe the source of crumb rubber and allow the use of both truck tyres (i.e. tyres from light and heavy vehicles and buses) and passenger vehicle tyres (i.e. cars, motorcycles and caravans). However, crumb rubber suppliers solely use truck tyres to meet the current market demand and rarely process passenger vehicle tyres.

The Australian Road Research Board (ARRB) was engaged to undertake a literature review on the use of passenger vehicle tyres in sprayed seal / asphalt applications. This report is provided as Appendix A.

The main objectives of the literature review were to:

- understand the current specifications of crumb rubber source by other road agencies, both locally and internationally;
- understand the market availability and processing requirements of passenger vehicle tyres, and
- identify the benefits and limitations of using passenger vehicle tyre crumb rubber as a road material in asphalt and sprayed seals.

Key Findings

The key findings of the literature review were:

- In Australia, passenger vehicle tyres contain approximately 16% natural rubber, 30% synthetic rubber, 23% carbon black, 16% metal and 6% textile. Truck tyres contain approximately 30% natural rubber, 13% synthetic rubber and 25% metal.
- No state or territory specifies source of tyre, or synthetic rubber limitations in their roadworks specifications.
- California and Florida have strict requirements, with a specified minimum percentage of natural rubber content required.
- No data from an Australian context has been obtained regarding the performance of solely passenger vehicle tyres as a crumb rubber modifier. Direct comparative research would be needed to confirm the superiority of performance of either rubber type.
- A significant issue associated with utilising passenger vehicle tyres in pavements is the compatibility of synthetic rubber with bitumen. Further research would be required to understand the effect of the compatibility, and to compare performance between non-modified binders, passenger vehicle tyre modified binders and truck tyre modified binders.
- The benefits seen in performance and durability from the minimal international research surrounding passenger vehicle tyres indicates that they may show similar benefits as truck tyre rubber modification.
- At present there is no consistent availability of passenger vehicle tyre crumb rubber from an Australian source.
- The main current limitation for manufacturing passenger vehicle tyre crumb rubber is economic, as specific infrastructure would be required to efficiently process the tyres. However, the required infrastructure can be put in place once the demand for passenger vehicle tyre crumb rubber is high enough to justify the required investment.

The findings of the review will provide supporting information for changes that may need to be made to current roadwork specifications because of the potential increased use of passenger vehicle tyre rubber.

Appendix A – ARRB Literature Review Report

SHAPING OUR TRANSPORT FUTURE

Passenger Vehicle Tyre Usage in Bitumen

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Final Report

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1 INTRODUCTION

Victoria is one of the leaders in the use of crumb rubber in Australia, with its use well established in sprayed seals and its use in asphalt increasing. VicRoads has committed to the re-use of one million tyres in road works annually across country Victoria over the next five years.

With the use of crumb rubber projected to increase in coming years, it may be necessary to diversify the source of waste tyre rubber to ensure the demand can be met. VicRoads specifications currently do not prescribe the source of crumb rubber and allow the use of both truck tyres (i.e. tyres from light and heavy vehicles and buses) and passenger vehicle tyres (i.e. cars, motorcycles and caravans). However, crumb rubber suppliers solely use truck tyres to meet the current market demand and very rarely process passenger vehicle tyres.

This project aimed to assess the viability of using passenger vehicle tyres as a source of crumb rubber for bitumen modification, should the demand for crumb rubber increase, necessitating a diversification of source. The findings of this review will provide supporting information for any changes that may need to be made to current specifications as a result of the increased proportions of passenger vehicle tyre rubber.

1.1 PROJECT OBJECTIVES

The main objectives of this literature review were as follows:

- understanding the current specifications of crumb rubber source by other road agencies, both locally and internationally;
- understanding the market availability and processing requirements of passenger vehicle tyres, and
- identifying the benefits and limitations of using passenger vehicle tyre crumb rubber as a road material in asphalt and spray seals.

1.2 REPORT STRUCTURE

This section of the report outlines the scope and objectives of this project.

Section 2 gives additional background information by providing a general overview of crumb rubber terminology, outlining the current Australian waste tyre issue and the overall benefits of crumb rubber use in road construction.

Section 3 details the composition of truck and passenger vehicle tyres.

The current position of Australian road agencies and international road agencies on specifying the source of crumb rubber is reviewed in Section 4.

Sections 5 to 8 look at the availability of passenger vehicle tyre crumb rubber and the differences in processing conditions for truck and passenger vehicle tyre crumb rubber in terms of infrastructure, cost, environment, and Work, Health and Safety. These sections also contain a review of the literature on the compatibility of rubber in bitumen, highlighting the differences between truck and passenger vehicle tyre rubber, and outline Australian and international findings on performance of passenger vehicle tyre crumb rubber.

Sections 9 and 10 provide conclusions and give recommendations outlining further research, specifications and processing.

2 BACKGROUND

It is estimated that more than 56 million equivalent passenger units (EPU's), around 450 000 tonnes of tyres, reach their end of life annually in Australia (Tyre Stewardship Australia (TSA) 2017). In 2015–16, of these 450 000 tonnes, 40% were passenger vehicle tyres, 32% were truck tyres and 28% were off-the-road tyres. Victoria alone contributes 24% of end-of-life tyres, with a breakdown of 43% passenger vehicle tyres, 29% truck tyres and 27% off-the-road tyres.

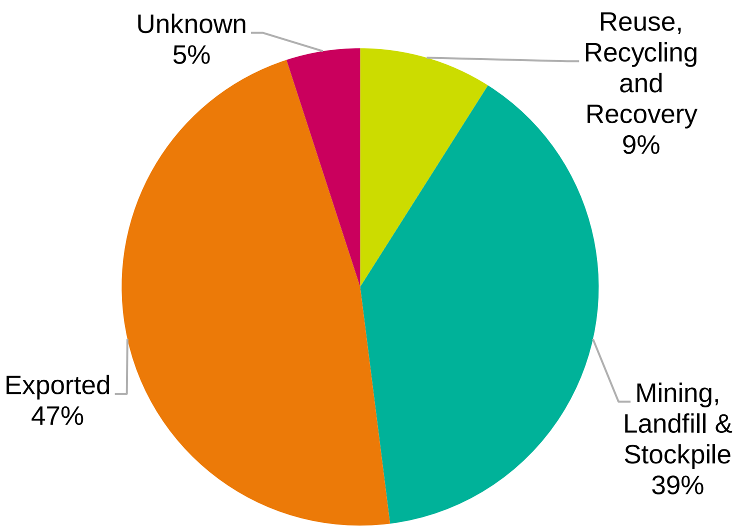
Waste tyres are a most challenging and problematic waste stream, posing health and environmental concerns, acting as a breeding ground for pests and presenting a significant fire hazard. Figure 2.1 shows the different destinations for waste tyres in Australia in 2017–18. Only 9% of waste tyres are currently re-used, recycled or recovered. The majority are either exported (47%) or destined for mining purposes, landfill or stockpiles (39%). With significant environmental and safety risks posed by stockpiled and landfilled tyres, working to increase Australian recycling of this waste stream is crucial.

Tyres are made of durable and resilient materials, which makes them both a challenge to recycle and a valuable resource to repurpose (Lo Presti 2013). It is imperative that viable end markets for recycled waste tyre rubber are developed and maintained. Long-term market projections across Australia estimate opportunity for the use of up to 30 000 tonnes of crumb rubber, incorporated into sprayed seals and over 12 000 tonnes in asphalt by 2026 (TSA 2017), making road construction one such end market deserving of focus.

Crumb rubber provides many benefits as a road material, both economic and environmental. When used as a binder modifier in asphalt pavements, crumb rubber improves rutting and fatigue resistance, oxidative ageing resistance, prevents binder drain down, and produces a more durable pavement (Subhy, Lo Presti & Airey 2015). The improved road performance leads to lower maintenance costs overall, and a reduction in carbon monoxide and methane emissions is often seen compared to alternative asphalts (Wang et al. 2018). Warm mix methods can be employed to mitigate any risk of odorous fumes or emissions from the use of rubber (Lo Presti 2013).

Open graded asphalt containing crumb rubber modified binder has also shown improved noise reduction performance compared to conventional open graded mixes (Denneman et al. 2015). One other benefit of crumb rubber is that it has the potential to be used in tandem with other recycled materials such as recycled polyethylene (Ge et al. 2016).

Figure 2.1 Destination of waste tyres in Australia 2017–18 (TSA 2018)



3 COMPOSITION OF TYRES

The main structural components of tyres are the tread, body, side walls and beads, composed of elastomeric compounds, fabric and steel. Figure 3.1 provides an internal view of the composition of a tyre. The make-up of tyres varies depending on type – truck or passenger vehicle – manufacturer and place of manufacture (i.e. locally or internationally), as can be seen in Table 3.1. Truck tyres generally contain a higher proportion of natural rubber, whereas passenger vehicle tyres generally contain a higher synthetic rubber component in thinner layers, as well as a nylon (textile) component.

Discussions with industry have shown that the use of synthetic rubber has increased in the manufacturing of tyres in recent years due to a spike in natural rubber prices. The percentages provided in Table 3.1 are general guides to the composition, as it can vary between manufacturers and over the course of time.

As the composition of passenger vehicle tyres and truck tyres differ, there is variability in the ways that industry processes these tyres. At present, the majority of crumb rubber in Australia is produced from truck tyres, with challenges arising for the processing of passenger vehicle tyres due to the high textile content. Figure 3.2 shows a sample of truck tyre, which has been shredded and ground, which would then be processed further into a crumb. Figure 3.3 shows shredded passenger vehicle tyre, still containing nylon. Alternative equipment to that which is used for processing truck tyres is required to process passenger vehicle tyres beyond a large shred, due to the requirements of managing the high textile content. This is further discussed in Section 5.

Figure 3.4 shows the breakdown of tyre types, by material type, that reached their end-of-life in 2015–16 in Australia. As can be seen from this graph, steel, natural rubber and synthetic rubber were in the highest quantities by mass. Synthetic rubber reaches the end of its life in similar quantities to natural rubber; it is therefore important to investigate its potential for use as crumb rubber. With goals in place to utilise increasingly larger amounts of end-of-life tyres, it is important to understand the implications of using increasingly larger amounts of synthetic rubber and its performance as a road making material.

Figure 3.1: Parts of a tyre (Lo Presti 2013)

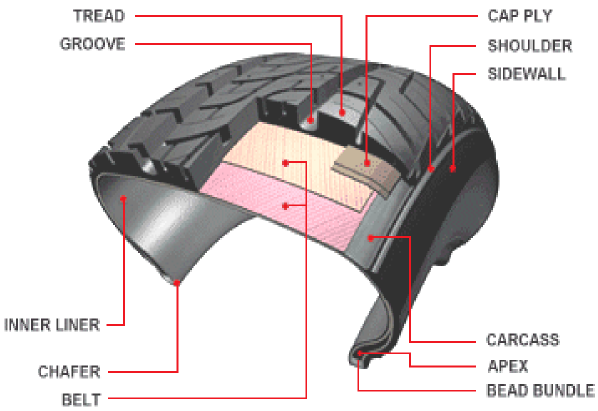


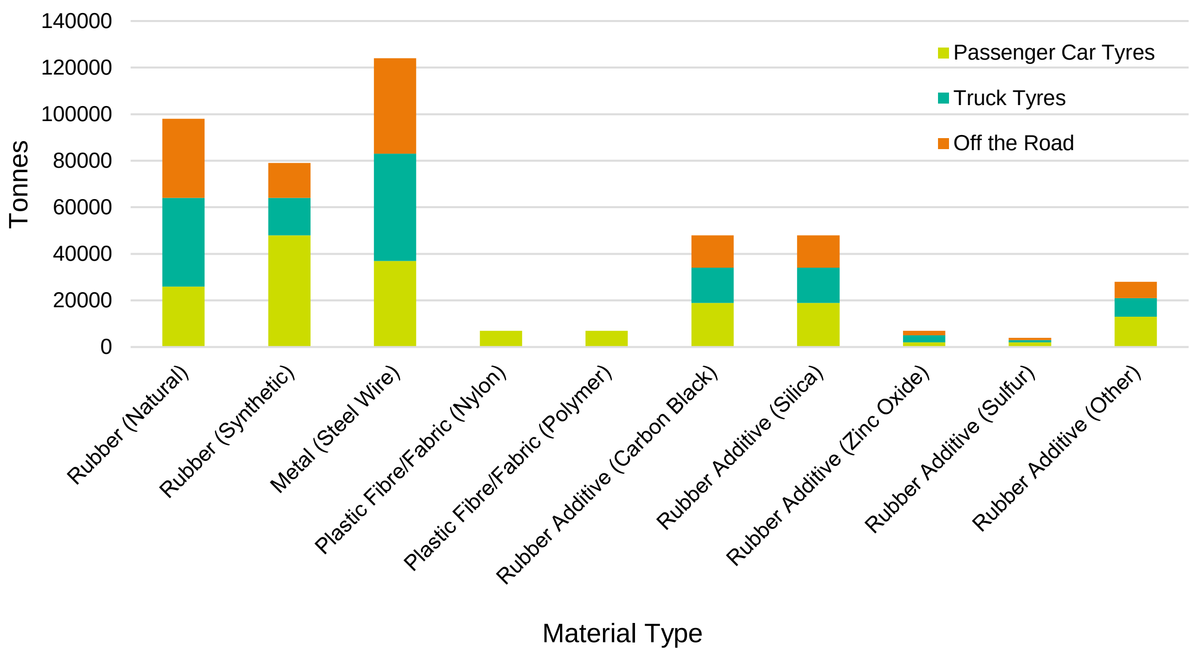
Figure 3.2: Ground truck tyre

Figure 3.3: Shredded passenger vehicle tyre (contains nylon)

Table 3.1: Australian and international composition of truck and passenger vehicle tyres

Material	United Kingdom		USA	Australia	
	Passenger cars	Truck/buses	Basic components of passenger and truck tyres in the USA is roughly the same	Passenger cars	Trucks
Rubber	17% Natural 31% Synthetic	28% Natural 15% Synthetic	14–27% Natural 14–27% Synthetic	16% Natural 29% Synthetic	29% Natural 13% Synthetic
Carbon black	22%	21%	28%	23%	24%
Metal	15%	27%	14–15%	16%	25%
Textile	5%	–		6%	–
Additives	8% (Additives) 1% (Zinc oxide) 1% (Sulphur)	6% (Additives) 2% (Zinc oxide) 1% (Sulphur)	16–17% (Processing Oils)	8% (Additives) 1% (Zinc oxide) 1% (Sulphur)	2% (Zinc oxide) 1% (Sulphur)
References	(Lo Presti 2013, Rahman 2004)		(Federal Highway Administration (FHWA) 2014)	(Genever et al. 2017)	

Figure 3.4: Australian tyres reaching end-of-life in 2015–16 (TSA 2017)



3.1 DETERMINING THE COMPOSITION OF CRUMB RUBBER

One of the concerns arising from the idea of processing passenger vehicle tyres in conjunction with truck tyre rubber is that consumers of crumb rubber may be unaware of the composition of the rubber they receive. Some research has considered tyre source to be a critical element, indicating that switching of source could impact road construction.

The general perception is that the source of rubber used for laboratory testing and specifications should match with the source that is then utilised in the coinciding project (Gursel, Akca & Sen 2018). This suggests it may be suitable to use passenger vehicle tyre rubber as a road material; however, processing conditions, amounts and intended uses may need to be established for passenger vehicle tyre rubber independently of the current processes and uses for truck tyres. At the very least, it will be crucial that crumb rubber manufacturers maintain their current awareness of the source of the tyres they are processing and providing to industry. Furthermore, industry should be aware of the source and type of tyre crumb they are receiving to ensure that long-term performance data is accurate.

Current requirements for crumb rubber manufacture in Australia do not include any information on the natural rubber/synthetic rubber composition. This testing could be introduced; however, the ability to manage the ratio is limited by the feedstock and the composition of the tyres being recycled.

As can be seen in Table 4.2, the California and Florida state road agencies require a minimum limit of natural rubber to be present in crumb rubber employed as a road material additive. Both road agencies cite the methodology ASTM-D297 Rubber Chemical Analysis methodology as their specified standard for assessing the composition of crumb rubber. The standard outlines an assessment of natural rubber content by oxidation of the rubber in chromic acid, after which the acetic acid formed is distilled and determined quantitatively via titration. This chemical test provides the quantity of natural rubber content in a crumb rubber blend, with commonly employed solvents and techniques.

4 ROAD AGENCY SPECIFICATIONS

4.1 AUSTRALIAN ROAD AGENCY SPECIFICATIONS

At present, VicRoads do not specify source of crumb rubber to be used as a binder modifier, allowing for the use of both truck and passenger vehicle tyres. This section provides an overview of current Australian and international specifications, outlining where Victoria stands in comparison to the rest of the world.

Table 4.1 provides a summary of the specifications used by each Australian road agency for the use of crumb rubber asphalt and/or crumb rubber modified binders in sprayed seals.

As Table 4.1 indicates, all State and Territories are very similar to Victoria in terms of crumb rubber specifications. Most road agencies allow both natural and synthetic rubber, without any limitation placed on composition, enabling both truck and passenger vehicle tyres to be utilised. Some States specify that the crumb rubber must be free of contaminants, and Victoria and Tasmania are the only States requiring products to be sourced from Tyre Stewardship Australia approved manufacturers.

Table 4.1: Summary of specifications used by each Australian road agency

Road agency	Specification	Source requirements				Synthetic or natural limits
		TSA approved manufacturer	Natural	Synthetic	Free from contaminants	
VicRoads (VIC) Department of State Growth (TAS)	Section 421 Bitumen Crumb Rubber Asphalt Section 408 Sprayed Bituminous Surfacings	✓	✓	✓	✓	Not specified
Department of Infrastructure, Planning and Logistics (NT)	Standard Specification for Roadworks 2017					Not specified
Roads and Maritime Services (NSW) Canberra (ACT)	QA Specification 3256 Crumb Rubber		✓	✓		Not specified
Main Roads (WA)	Specifications 511 Materials for Bituminous Treatments		✓	✓	✓	Not specified
Transport and Main Roads (QLD)	MRTS18 Polymer Modified Binder (including Crumb Rubber)		✓	✓		Not specified
Department of Planning, Transport and Infrastructure (SA)	Part R25 Supply of Bituminous Materials				✓	Not specified

4.2 INTERNATIONAL ROAD AGENCY SPECIFICATIONS

Table 4.2 provides a summary of the specifications used by a collection of international road agencies for the use of crumb rubber asphalt and/or crumb rubber modified binders in sprayed seals.

Much like Australian road agencies, most international specifications evaluated in this review lack strict regulations. Most agencies require the crumb rubber to be free from contaminants and to be ambiently ground. Some agencies have more specific requirements, for example Florida requires the product to be sourced from a State-approved manufacturer, and Massachusetts and Ontario utilise only vulcanised rubber products. In terms of differences between passenger vehicle tyres and truck tyres, California and Florida have requirements placed on the composition of the crumb rubber permitted, specifying a minimum and maximum natural rubber content. Referring to Table 3.1, this content is more in line with Australia's truck tyre composition.

Table 4.2: Summary of specifications used by each international road agency

Road agency	Specification	Source requirements				Synthetic or natural limits	Other
		Ambiently ground	Natural	Synthetic	Free from contaminants		
Texas Department of Transport (USA)	TxDOT Item 300 Asphalts, Oils and Emulsions	✓	✓	✓	✓	Not specified	
Ministry of Transportation Ontario (Canada)	OPSS 313 Hot Mix Pavements (as cited in Hicks 2012)	✓	✓	✓		Not specified	Must be dry, free flowing and vulcanised. Also allow cryogenic grinding.
Arizona Department of Transport (USA)	Section 1009 Asphalt Rubber Material					Not specified	US-owned tyres.
Massachusetts Department of Transport (USA)	Section 466 SAMI	✓				Not specified	Must be vulcanised.
New Jersey Department of Transport (USA)	Section 902 Asphalt				✓	Not specified	US-owned tyres.
South Africa	Technical Guidelines 1, TG1, 2015				✓	Not specified	Must meet grading.
Florida Department of Transport (USA)	FDOT Section 919 Ground Tire Rubber	✓			✓	16 to 45% natural rubber	Must be provided by a State-approved manufacturer.
Caltrans (California, USA)	Specification Section 37-2.05B Crumb Rubber Modifier	✓	✓	✓	✓	22 to 39% natural rubber	Can be tyre rubber and high natural crumb rubber. Must meet grading.

5 AVAILABILITY OF PASSENGER VECHICLE TYRES

At present, the main limitations for manufacturers acquiring and utilising the suitable equipment to process passenger vehicle tyres are economic and environmental. Discussions with a key crumb rubber manufacturer, Tyrecycle, have provided insight to the current situation surrounding processing of passenger vehicle tyres. The information discussed in this section is based on that which Tyrecycle have provided.

There is currently no reliable supply of passenger vehicle tyre crumb rubber in Australia. As the composition of passenger vehicle tyres differs to truck tyres, as discussed in Section 3, there are differing requirements for equipment to process the tyres. Whilst some of the appropriate equipment exists in Australia, it is not being utilised due to a lack of demand for passenger vehicle tyre crumb rubber. It is possible for manufacturers to process and provide it, however it would be dependent on a long-term, reliable market demand.

Industry currently do not typically process passenger vehicle tyres into crumb rubber. On occasion, it has been required for certain manufacturers to process passenger vehicle tyres to satisfy product demands; however, this situation has not been extensively evaluated in this report. It is generally understood by industry that truck tyres satisfy the market demand and provide the desired performance enhancing benefits.

5.1 INFRASTRUCTURE COSTS

Passenger vehicle tyres require specific equipment to process due to their high fabric content.

The current cost to set up a truck tyre processing facility is between $1.5 to $12 million depending on size of the plant and where the equipment is sourced from.

Tyrecycle would likely invest between $6 to 8 million for a fibre separation plant to process passenger vehicle tyres should crumb rubber demand increase beyond its current level and have a sustainable commercial future.

The processing of passenger vehicle tyres is less costly from an equipment maintenance perspective. However, this cost saving is replaced with the disposal cost of the fibre which has been separated from the rubber and the decreased income derived from the steel volume reduction associated with passenger vehicle tyres as a percentage of total weight.

5.2 DEMAND

Tyrecycle estimates it collects approximately 30% of the rubber imported into Australia each year; this includes commercial vehicle tyres, passenger vehicle tyres, large off-the-road tyres and conveyor belting.

Currently, demand in Australia for crumb rubber in roads is much less than the manufacturing capacity. Should the existing capacity be exceeded, then industry, including Tyrecycle, would have to begin processing passenger vehicle tyres to meet demand.

Specifications for crumb rubber hold the key to managing growth of the industry.

5.3 ENVIRONMENT AND WORK HEALTH AND SAFETY

ResourceCo and Tyrecycle currently present the only domestic non-landfill option for disposal of the fibre (fluff) by-product from processing passenger vehicle tyres. The alternative fuel platform can consume this material in its current form.

Another critical reason for increasing demand is the avoided environmental cost of not providing a market for crumb rubber. This typically manifests with the cost associated with stockpiles, dumping and activities that harm both human health and the environment both domestically and abroad.

Tyrecycle noted no discernible changes from the current Work Health and Safety (WHS) concerns/procedures already in place across their organisation for passenger vehicle tyre processing.

6 COMPATIBILITY WITH BITUMEN

The interaction between bitumen and rubber is material-specific and depends on a number of factors including:

- processing variables: temperature, time and mixing process (applied shear stress)
- base binder properties: bitumen source, use of oil extenders, grade, chemical composition or molecular weight distribution (Ghavibazoo 2014)
- recycled tyre rubber properties: processing methods, particle size, natural and synthetic content.

The chemical complexity of crumb rubber and bitumen dictates that a purely chemical approach to designing crumb rubber paving materials is not possible. Proposed modified binder designs must be assessed for compatibility and physical properties (Caltrans & CIWMB Partnered Research 2005).

One of the main concerns associated with using passenger vehicle tyres, or rubber containing a higher synthetic content, is the compatibility of the rubber with bitumen. Research indicates natural rubber has better compatibility with bitumen; however, it is unclear what impact this improved compatibility actually has on performance properties, relative to synthetic rubber.

6.1 COMPATIBILITY OF NATURAL VS SYNTHETIC RUBBER

Generally, literature that distinguishes between synthetic rubber and natural rubber indicates that natural rubber is more compatible with bitumen as it digests more readily; however, there is a lack of data to support this claim. A similar attitude, though not supported with comprehensive chemical or physical property research, has been noted through discussion with industry.

This higher compatibility of natural rubber has been attributed to polymer chain flexibility. This flexibility creates free volume which affects the amount of swelling during digestion (Artamendi & Khalid 2006). Compatibility with bitumen is controlled by the nature of the polymer, number and distribution of cross-links between rubber polymer chains, presence of fillers like carbon black, and temperature (Artamendi & Khalid 2006). Synthetic rubber can be expected to be more variable than natural rubber, posing a greater challenge of maintaining consistency of supply when using tyres with higher synthetic rubber contents (Kibuuka et al. 2008).

Artamendi and Khalid (2006) state that the initial uptake of bitumen occurs faster with natural crumb rubber; however, the crumb rubber also degrades sooner after equilibrium swelling has been reached. Natural rubber is more susceptible to time and temperature in the mixing process (Artamendi & Khalid 2006), whereas synthetic rubber is found to be more stable (Jensen & Abdelrahman 2006). Off-the-road tyres (machinery, mining tyres etc.) with an even higher natural rubber content digest more readily in bitumen, whereas passenger vehicle tyres require higher mixing temperatures (Gursel, Akca & Sen 2018).

If overheating during the digestion process occurs, truck tyre rubber is more rapidly degraded than passenger vehicle tyre rubber. The time and temperature of digestion are interdependent variables and the same difficulty can arise from extended digestion times at normal spray temperatures (Oliver 1981). It should be noted that these findings were based on the composition of tyres in 1981, which may differ to current compositions.

Scanning electron microscopy analysis can be used as a method to identify the interaction between crumb rubber and bitumen to define the proper digestion time for the crumb rubber modified binder (Thives et al. 2013). It would be crucial to develop optimum mixing time and temperature data for crumb rubber containing different proportions of natural and synthetic rubber, should passenger vehicle tyre rubber begin to be utilised consistently. Current processes used to produce crumb rubber modified binders may or may not be suitable for passenger vehicle tyre crumb rubber blends, and data in an Australian context would be required to assess this.

7 PERFORMANCE

There is no comprehensive research in an Australian context for performance properties of crumb rubber binders produced using passenger vehicle tyres. There is a small amount of international research that has shown improved properties of passenger vehicle tyre crumb rubber modified binder compared to a base bitumen. No direct comparisons between the performance of truck and passenger vehicle tyre rubber binders could be found; however, Table 7.1 outlines the performance, durability, application and aggregate retention data currently available for passenger vehicle and truck tyres.

It is important to note that many of the improvements seen from research into passenger vehicle tyre rubber modifications are very similar to the improvements seen in research and the many real-world applications of truck tyre rubber as a binder modifier. It would be imperative to compare passenger vehicle tyre and truck tyre crumb rubber directly for an improved understanding of the performance, durability and application characteristics of the two tyre sources.

Table 7.1: In-service performance of passenger vehicle and truck tyre crumb rubber modified binders and asphalt

	Passenger vehicle tyres	Truck tyres
Vulcanisation	• Vulcanised synthetic rubber known to demonstrate better weather resistance and heat resistance compared to non-vulcanised rubber (Lo Presti, Airey & Partal 2012).	• N/A
Performance and durability	• Wide temperature service range and good low temperature performance when compared to unmodified bitumen (Kibuuka et al. 2008). • Improved resistance to low temperature cracking and wheel tracking rutting, compared to unmodified bitumen (Kibuuka et al. 2008). • Low susceptibility to water durability issues, compared to unmodified bitumen (Kibuuka et al. 2008).	• Natural rubber found to be superior to synthetic rubber for elastic properties (Jensen & Abdelrahman 2006). • Truck tyre rubber has been reported to perform better in initial permeability and porosity tests, in asphalt, than passenger vehicle tyre rubber (Xie & Shen 2015). • Truck tyre crumb rubber improves rutting and fatigue resistance, oxidative ageing resistance and produces a more durable pavement (Subhy, Lo Presti & Airey 2015). • Crumb rubber modified binders have shown improved reduction in noise when used in open graded asphalt (Denneman et al. 2015).
Application	• Low binder drain down compared to unmodified bitumen (Kibuuka et al. 2008).	• Provided stable long-term drain down results compared to passenger vehicle tyre rubber (Xie & Shen 2015).
Aggregate retention	• Improved particle retention, compared to unmodified bitumen (Kibuuka et al. 2008).	• Natural rubber has been seen to improve the adhesion of aggregates in sprayed seals (Wu, Herrington & Neaylon 2015).

8 CASE STUDY: ‘RUBBERISED ASPHALT TESTING TO UK STANDARDS’

Kibuuka et al. (2008) conducted research in the United Kingdom, separately assessing the performance and materials properties of truck tyre rubber and passenger vehicle tyre rubber, processed both ambiently and cryogenically. As this research is international, it may serve as only a guide, further considering that the composition of the tyres employed for this study is not provided. As in Australia, the UK incorporates more synthetic rubber in passenger vehicle tyres than truck tyres. While this composition varies depending on size and brand, an estimated recoverable rubber composition from scrapped tyres is 35% natural, 65% synthetic for passenger vehicle tyres and 65% natural, 35% synthetic for truck tyres (Rahman 2004).

Kibuuka et al. (2008) assessed rubber blends of 100% cryogenically processed passenger vehicle tyre rubber and 100% ambiently processed passenger vehicle tyre rubber, finding very similar results for both blends. Viscosity, penetration and softening point results are shown below in Table 8.1 compared to a 50% passenger vehicle/truck tyre blend, all incorporating 18.5 wt% rubber in a 40/60 grade bitumen sourced from Venezuela. A 40/60 grade bitumen is similar to C320 bitumen used in Australia.

The 50/50% ambiently ground passenger vehicle tyre and truck tyre blend was more viscous than the relevant UK specification limit after 120 minutes of blending and was therefore discarded from any further analysis. Blends containing 100% truck tyre rubber were also not researched extensively during the study. As such, this study does provide comparative data between passenger vehicle tyre rubber and truck tyre rubber, as would be ideal, but focuses on the difference between ambient and cryogenic passenger vehicle tyre blends.

The results obtained in the research found that both ambient and cryogenic passenger vehicle tyre blends exhibited suitable softening points, viscosity, aging index, resilience and low temperature properties. The plasticity ranges indicated that the modified binders would be suitable for use at a wide range of service temperatures. When compared to non-modified binders, improved cohesion characteristics were seen, indicating an improved ability to retain aggregate. The crumb rubber binders were found to separate to some extent when subjected to hot storage stability tests and had lower flashpoints than the control bitumen sample (which indicates that they were more flammable), although these were noted not to be any worse than a typical polymer modified binder.

Kibuuka et al. (2008) also assessed their 100% passenger vehicle tyre crumb rubbers in porous asphalt and stone mastic asphalt mixes. This research found the asphalts to be resistant to water-related durability issues during service. They also exhibited better workability in terms of required mixing torque. Most samples exhibited a low risk of binder drainage and improved resistance to particle loss. The porous asphalt mixes showed improved resistance to rutting and mostly showed improved resistance to low temperature cracking. The stone mastic asphalt blends also showed improved resistance to low temperature cracking.

While this research must be understood as an example, due to the differences in UK standards and current Australian practice, this study demonstrates that an increased use of passenger vehicle tyres has the potential to provide suitable performance parameters. It is also important to consider that these benefits were compared to a non-modified bitumen. Comparisons were not made with the performance of truck tyre modified binders.

Table 8.1: Material properties of crumb rubber modified binder blends

	Brookfield viscosity at 177°C (cP)				Penetration at 25°C (dmm)	Ring and ball softening point (°C)
Blending time (minutes)	30	60	120	180	180	180
Ambient passenger vehicle tyre	2 140	2 341	3 827	4 630	30	70
50/50% Ambient passenger/truck tyre	2 240	2 320	9 167	10 450	31	72
Cryogenic passenger vehicle tyre	1 485	4 190	4 480	4 510	30	70.2

9 SUMMARY OF FINDINGS

9.1 ROAD AGENCY DOCUMENTS

An investigation of Australian road agency documents has indicated that majority of Australian States and Territories currently employ crumb rubber as a road making material in some capacity; however, no State or Territory specifies source of tyre, or synthetic rubber limitations. Most Australian specifications include mention of ensuring avoidance of contamination from textile, steel or moisture ingress in crumb rubber; however, the limitations are not overly specific. Victoria and Tasmania require rubber to be sourced from Tyre Stewardship Australia approved sources.

International specifications from the USA, Canada and South Africa tend to present similarly unclear specifications. California and Florida have the strictest requirements, with a specified minimum percentage of natural rubber content required.

9.2 AVAILABILITY AND EASE OF USE OF PASSENGER VEHICLE TYRE CRUMB RUBBER

At present there is no consistent availability of passenger vehicle tyre crumb rubber from an Australian source. Australian manufacturers have been known to process passenger vehicle tyres in times of tyre resource shortages; however, there is no intentional market for the product.

The main limitation for manufacturing passenger vehicle tyre crumb rubber is economic, as specific infrastructure would be required to efficiently process the tyres.

The main processing challenge for passenger vehicle tyres is the textile content, as specialised equipment is needed to manage it and an end market would be required for the waste nylon fibre generated during processing. For industry, the issue is more one of market demand and economics; at present there is not enough demand for product for a large investment to be worthwhile. However, should demand exceed existing manufacturing capacity, industry would begin to process passenger vehicle tyres.

9.3 COMPARATIVE REVIEW OF PASSENGER VEHICLE TYRE AND TRUCK TYRE DERIVED CRUMB RUBBER

In Australia, passenger vehicle tyres contain approximately 16% natural rubber, 30% synthetic rubber, 23% carbon black, 16% metal and 6% textile. Truck tyres contain approximately 30% natural rubber, 13% synthetic rubber and 25% metal.

The main limitation associated with utilising passenger vehicle tyres in pavements is the compatibility of synthetic rubber with bitumen; it is understood that due to greater polymer chain flexibility, natural rubber swells more during the digestion interaction with bitumen than synthetic rubber. However, this is not supported by extensive research and it is unclear whether the lower compatibility of synthetic rubber is to such an extent that the rubber is not a viable material. Significant data in an Australian context has not been obtained to support this.

9.4 EFFECT OF THE PERFORMANCE OF CRUMB RUBBER BINDERS

It is unclear how important this improved compatibility effect is on the performance of a crumb rubber modified binder as there is a lack of comparative performance data. Further research would be required to understand the effect of the compatibility, and to compare performance between non-modified binders, passenger vehicle tyre modified binders and truck tyre modified binders.

No data from an Australian context has been obtained regarding the performance of solely passenger vehicle tyres as a crumb rubber modifier. The benefits seen in performance and durability from the minimal international research surrounding passenger vehicle tyres indicates that they may show similar benefits as truck tyre rubber modification. Direct comparative research would be needed to confirm the superiority of performance of either rubber type.

10 RECOMMENDATIONS

10.1 PROCESSING ASSESSMENTS

It is recommended that a further assessment of the economic and infrastructure requirements for passenger vehicle tyre crumb rubber processing be carried out to understand cost and equipment logistics. Work, Health and Safety assessments for fuming, temperature, flash point and workability differentiation between truck tyre crumb rubber and passenger vehicle tyre crumb rubber usage would also be needed to understand the implications for any future processing of passenger vehicle tyres.

10.2 FURTHER RESEARCH

Comments regarding natural or synthetic rubber performance in asphalt and sprayed seals are usually generic and unclear, with no substantial evidence provided. This is an area that would require significant research to develop comprehensive knowledge. Further research would be required to determine if natural rubber compatibility with bitumen is drastically greater than synthetic rubber, and if this benefit is hugely important for performance or if the impact is limited to affecting mixing volumes, temperature and shear properties.

It would also be valuable to carry out laboratory analysis of passenger vehicle tyre crumb rubber modified bitumen in asphalt, compared to truck tyre, assessing:

- workability
- resistance to permanent deformation
- resistance to fatigue and low temperature cracking
- aggregate retention.

As comprehensive research does not yet exist, it is recommended laboratory testing for use of passenger vehicle tyre rubber be carried out in an Australian context to obtain optimum mixing amounts, and that shear and temperature trials and field trials be carried out to assess in-service performance factors.

10.3 CRUMB RUBBER SPECIFICATIONS

As a short-term mitigation strategy based on a conservative approach, specification of natural rubber content and source (i.e. Australian truck tyres) is an option, similar to California and Florida, despite the lack of evidence, aside from anecdotal, associated with this. Discussion with industry indicates there is no significant likelihood that passenger vehicle tyres will suddenly begin to be supplied in Victoria; however, this strategy would help to ensure the supply remains consistent. Furthermore, crumb rubber specifications regarding source, processing, sizing and contaminants, would enhance consistency of supply.

It would be beneficial to evaluate the use of a similar methodology to US standard ASTM-D297 to test composition of crumb rubber used to modify binders. The standard employs a method of assessing natural rubber content through oxidation of rubber in chromic acid, after which the acetic acid formed is distilled and determined quantitatively via titration.

10.4 STAKEHOLDER ENGAGEMENT

As two key players in the crumb rubber industry, engagement with the California and Florida road agencies would be beneficial. There could be potential for further understanding the reasoning behind their current specifications outlining natural rubber content, as discussed in Section 4.2.

California has begun to consider a policy requiring 3 to 5% crumb rubber as a component of all hot mix asphalts across the entire state (Jones, Liang & Harvey 2017). Investigating the progress on implementation and success of this policy or assessing a similar approach for a Victorian context is desirable. If a minimum content of rubber is specified, the demand for crumb rubber would increase and the source of this rubber would need to be managed.

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APPENDIX A GLOSSARY OF TERMS

Terminology	Definition
Ambient Grinding	Scrap tyres are mechanically ground at or above room temperature. This method produces irregularly shaped particles with large surface areas; most commonly used and cost-effective method (Lo Presti 2013).
Cryogenic Grinding	Scrap tyres are frozen via liquid nitrogen to typically –87 °C to –198 °C and subsequently shattered into typically smooth particles with a lower surface area (compared to ambient grinding) (Lo Presti 2013).
Digestion	Digestion of crumb rubber refers to the behaviour of the crumb rubber particles when mixed with bitumen. The digestion of rubber occurs as the light aromatic oil components of bitumen are absorbed by the rubber particles. It is a physical, not chemical, interaction.
Equivalent Passenger Unit (EPU)	Standard passenger vehicle tyre; new passenger vehicle tyre standardised at 9.5 kg and end-of-life tyre at 8 kg. Truck tyres are approximately 5 EPU's (TSA 2019).
Natural Rubber	Polyisoprene sourced from the latex of Hevea Brasiliensis; composed of long polymer chains; sticky and easily deformed in its natural state (Lo Presti 2013).
Off-the-road (OTR) Tyres	Tyres from industrial, agricultural and mining uses.
Passenger Vehicle Tyres	Tyres typically from cars, motorcycles and caravans.
Synthetic Rubber	Composed of petroleum products and other minerals. They are produced via the polymerisation of monomers. Various types of synthetic rubbers exist, including styrene-butadiene (Rahman 2004).
Truck Tyres	Tyres typically from light and heavy vehicles, and buses.
Vulcanisation	The addition of agents, usually sulphur, to transform natural rubber to a product capable of ensuring performance and durability. The process involves the formation of cross-links between long polymer chains restricting independent movement. Vulcanised natural rubber will deform when a stress is applied but returns to its original state upon removal of the stress (i.e. it is elastic) (Lo Presti 2013).

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