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ACOR
AUSTRALIAN COUNCIL OF RECYCLING

Standards to facilitate the use of recycled material in road construction

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ABOUT STANDARDS AUSTRALIA

Standards Australia is an independent, non-government, not for profit organisation. We are the nation's peak non-government standards development organisation.

The work of Standards Australia and our staff, stakeholders, members and contributors enhances the nation's economic efficiency, international competitiveness and contributes to a safe and sustainable environment for all Australians.

Standards Australia's vision is to be a global leader in trusted solutions that improve life – today and tomorrow.

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Summary

With increasing pressure on natural resources, unprecedented levels of waste and pollution, and the urgent need to address climate change, Australia has begun to explore sustainable solutions to solve these challenges. Rapid economic development and population growth have led to an increasing realisation that the prevalent linear model of "take, make, waste" is financially, socially, and environmentally detrimental. The circular economy model offers a compelling solution to addressing these issues and transforming the way that we value and use resources.

Standards Australia coordinates a Circular Economy Advisory Group (CEAG) comprised of leading industry experts that work to strengthen partnerships and capitalise on opportunities to facilitate Australia's transition to the Circular Economy. This group has identified immediate priority areas in building/infrastructure, textiles, organics, and plastics. As a part of the CEAG's work program and in collaboration with the Australian Council of Recycle (ACOR), this report investigates the use of recycled materials in roads and explores how Standards Australia can assist in overcoming barriers to enable their widespread adoption in road construction.

Key Findings

The benefits of using recycled content in roads: The use of recycled materials in roads and pavements can positively influence triple bottom line performance (i.e., social, economic, and environmental).

Environmental Impact Reduction: Incorporating recycled materials can reduce emissions and conserve natural resources by minimising the need for virgin materials. Depending on the type of recycled materials used, greenhouse gas emissions can be reduced by between 47% and 98% (ARRB 2022).

Improved Performance: Certain recycled materials can enhance both the durability and lifespan of road infrastructure. Researchers at RMIT and the University of South Australia tested asphalt with crumb rubber and found that it could double the durability of roads in hot weather. Crumb rubber has also positive effects on pavements, including through reduced noise and risk of cracking (Jamal, et al., 2022).

Material Cost Saving: The ARRB (2022) estimates that most recycled material applications in road and rail infrastructure can create cost savings between 2% and 83%. The use of reclaimed asphalt pavement (RAP) has the highest economic benefit, with a cost saving of 83%.

Job Creation: Expanding the market for recycled materials can generate additional employment opportunities. A report by Access Economics for the Department of the Environment, Water, Heritage and the Arts found that job creation in the recycling sector is higher than waste disposal with 9.2 jobs created for every 10,000 tonnes of materials recycled, compared with only 2.8 jobs created for sending materials to landfill.

Barrier and challenges: Gaps in procurement policies, lack of evidence demonstrating long-term environmental and performance outcomes, and nascent markets for some materials are several of the barriers that prevent the widespread use of recycled materials in roads. For example, materials such as crushed concrete, reclaimed asphalt pavement, and crumb rubber benefit from established markets with high levels of industry confidence. Other materials such as plastics, however, have less developed markets due to their uncertainty around long term performance and environmental impact. Two of the key barriers that Standards Australia can address include:

- **Inconsistency in local and state specifications and the need for nationally harmonised performance-based standards:** Discrepancies in allowable limits of recycled materials can lead to confusion and practical difficulties that cause reluctance in embracing recycled materials in road construction projects. Research undertaken by Infrastructure Australia (2022) found that prioritisation of the development of national standards and specifications is a key concern to industry stakeholders. The research revealed that an overwhelming 92% of survey respondents considered such standards crucial in supporting business decisions to produce recycled materials for road projects.
- **Lack of guidance and awareness in the use of recycled materials and the enabling standards:** Limited education and practical guidance on the use, performance, safety, and durability of recycled materials can contribute to misconceptions among engineers, contractors, and procurement officers.

Recommendations – at a glance

1. Standards Australia, the Australian Government, and key industry expert participants should collaborate to modify existing and/or create new performance-based Australian Standards that harmonise the inconsistencies in existing specifications.

   Standards should:

   - Support the application of recycled content across jurisdictions
   - Be up to date with current waste streams and the types of recycled materials used in roads

2. Standards Australia, the Australian Government, the construction and recycling sectors, and circular economy leaders must continue to work together to provide practical guidance material for the use of recycled content in roads and the associated enabling standards.

   Guidance materials should:

   - Clearly communicate the benefits and applications of these materials in roads
   - Highlight the enabling standards and relevant use cases that govern the use of recycled materials
   - Provide the necessary knowledge to dispel misconceptions around recycled materials and the associated Australian Standards

Background

Australian Council of Recycling

The Australian Council of Recycling (ACOR) is the peak industry body for resource recovery, recycling, and remanufacturing in Australia, representing a sector that contributes almost $19 billion in economic value, while delivering broad social, economic and environmental benefits.

ACOR's membership operates across the recycling value chain, and includes leading organisations in advanced chemical recycling processes, CDS operations, kerbside recycling, recovered metal, glass, plastics, paper, textiles and e-product reprocessing and remanufacturing, road recycling and construction and demolition recovery.

The recycling industry operates across our homes, businesses, factories and construction sites. It collects, sorts and reprocesses material, and makes new products with recycled content, creating more jobs for Australians and supporting a circular economy.

Standards Australia

Standards Australia is Australia's peak non-government, not-for-profit standards organisation. We work with Australian industry, government, academia, consumer groups, and the community to help address the challenges and opportunities facing the nation. Standards Australia also represents Australia at the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), and specialises in the development and adoption of internationally aligned standards.

Standards Australia's vision is to be a global leader in trusted solutions that improve life – today and tomorrow. This vision has taken on a renewed importance as we face unprecedented biodiversity loss, climate change, and resource depletion. We work with industry, government, academia, consumer groups, and the community to help address the environmental challenges facing the nation.

Standards Australia is responsible for coordinating the attendance of Australian experts in the development of international standards and meetings at ISO and the IEC. Australian participation allows industry, academic, and government experts to shape trajectories and advance Australian values and interests on the international stage.

The role of standards in the transition to a circular economy

Standards play a crucial role in facilitating the transition to a circular economy by establishing common definitions, measurements, and guidelines for industry, government, and consumers. Standards can provide guidance on issues such as energy and material efficiency, life cycle assessments, greenhouse gas emissions, traceability, and recycling practices. Standards can also encourage industry to design products with end-of-life in mind, so that they are more easily repairable, reusable, and recyclable.

By providing clear and verifiable criteria for evaluating environmental claims, standards can also combat greenwashing. This can deter businesses from making unsubstantiated claims about their products and help empower consumers to make informed decisions about the products they buy.

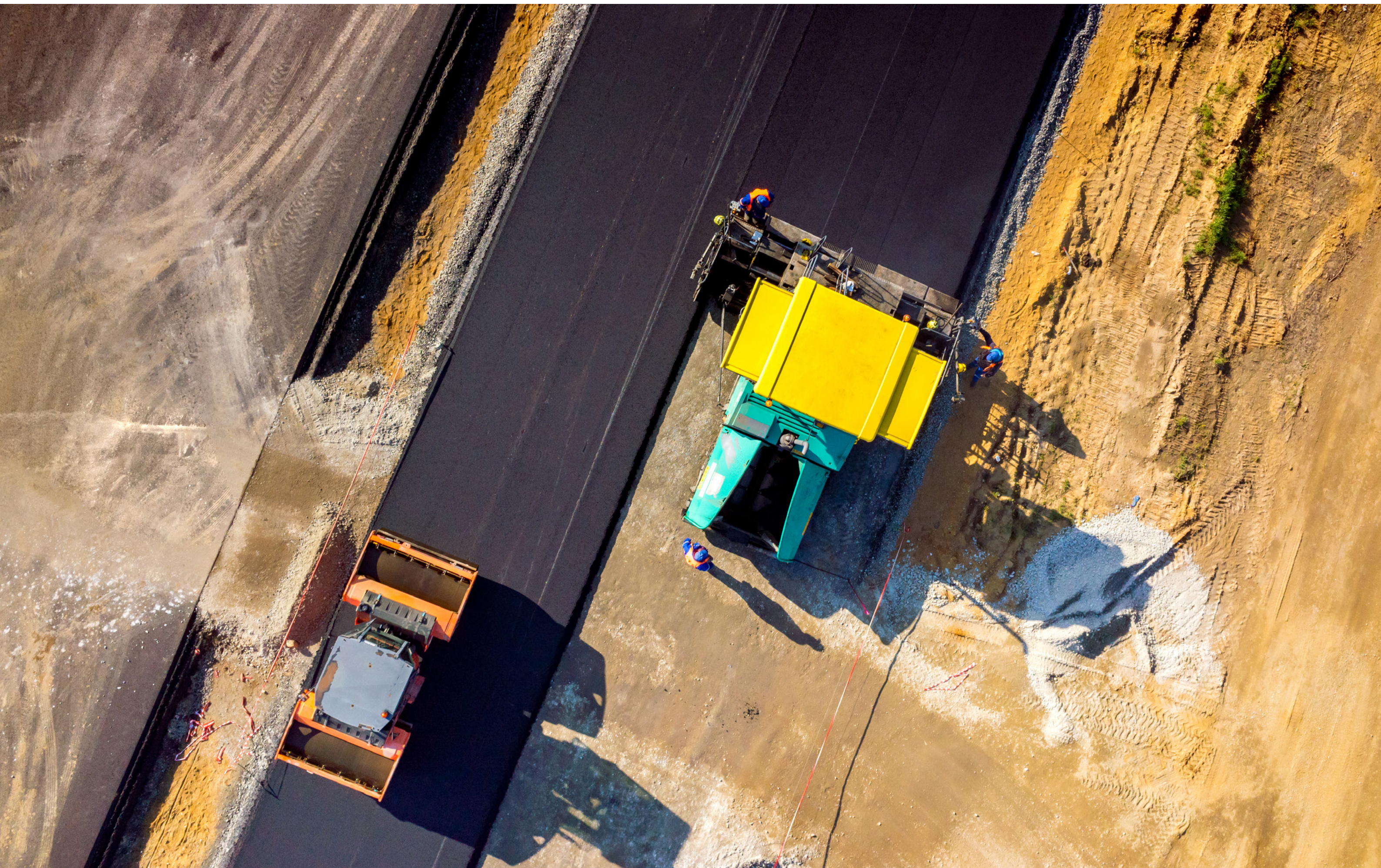
1. Introduction

This report is based on initial research conducted by Standards Australia to investigate if standards inhibit the use of recycled materials in roads, urban furniture, and food containers. We reviewed more than thirty International and Australian Standards that can be applied to the sampling, testing, or determination of the characteristics and quality of asphalt, pavement, and aggregates and found that existing Australian Standards are performance based and do not inhibit use of recycled materials in road and pavement constructions.

The previous research recommends:

1. to provide education opportunities for construction sector stakeholders to improve their understanding of the existing standards requirements,
2. where possible, promote the use of recycled materials in roads.

This report aims to extend the previous research by exploring the areas where Australian Standards can facilitate the transition to a circular economy by addressing some of the barriers associated with the use of recycled materials in road construction. Building upon the findings of the Australian Road Research Board (ARRB) and Infrastructure Australia, this report provides recommendations and areas of action to overcome barriers and increase the use of recycled content in road construction.



2. Policies and Drivers for the Use of Recycled Materials

2.1. National Waste Policy and Action Plan

The Australian Government's 2018 National Waste Policy: Less Waste, More Resources establishes a framework for waste and resource recovery. This policy identifies the following five principles that underpin waste management in a circular economy:

- Avoid waste
- Improve resource recovery
- Increase use of recycled material and build demand and markets for recycled products
- Better manage material flows to benefit human health, the environment and the economy
- Improve information to support innovation, guide investment, and enable informed consumer decisions.

The National Waste Policy Action Plan (2019) included actions to deliver on seven national targets:

1. Ban the export of waste plastic, paper, glass and tyres
2. Reduce total waste generated by 10% per person by 2030
3. Recover 80% of all waste by 2030
4. Significantly increase the use of recycled content by governments and industry
5. Phase out problematic and unnecessary plastics by 2025
6. Halve the amount of organic waste sent to landfill by 2030
7. Provide data to support better decisions

To enable the transition to a circular economy, governments and industry are working to reduce waste generation and improve reuse and recycling of valuable materials. This transition will bring long-term environmental, social and economic benefits to the Australian economy.

In alignment with the National Waste Policy, government and industry have increased the use of recycled materials in their projects including in road infrastructure. Considering the variety of recycled materials that can be used in road construction, this sector can contribute significantly to achieving the resource recovery targets. However, the National Waste Policy specifies few quantifiable targets for the use of recycled content by governments or industry.

2.2. National Waste Report

The National Waste Report 2022 estimates that from the 75.8 tonnes of waste generated in Australia for FY 2020-2021, 25.2 million tonnes came from building and demolition materials. The report also estimates that 63.8 million tonnes of the generated waste was 'core waste'[1], from which 29 million tonnes (38%) came from the construction and demolition sector, compared with 14 million tonnes (18%) from households and local government activities. This indicates that there is a considerable supply of recoverable materials available for reuse in the road construction sector.

1 Core waste is generally managed by the waste and resource recovery sector, comprising of solid waste and liquid hazardous waste, and generated in the municipal, construction and demolition, and commercial and industrial sectors, and including biosolids. Core waste generally excludes, to the extent they can be identified, wastes from primary production (National Waste Report 2022).

3. Use of recycled materials in road construction

Recycled materials can be used as a supplement for traditional aggregate in concrete. Figure 1 shows where concrete and therefore, recycled materials, can be used in road infrastructure. Examples include bridges, kerbs, footpaths, roads and pavements, pipes, drain covers, and parking lots.

Figure 1: Applications of concrete in road infrastructure. (a) bridge, (b) kerb, (c) footpath, (d) road, pavement, (e) pipes, (f) drain covers, and (g) parking lots

The types of recycled material that can be used in road construction include:

- Crushed concrete and brick
- Recycled crushed glass (RCG)
- Reclaimed asphalt pavement (RAP)
- Crumb rubber products
- Ground granulated blast furnace slag (GGBFS)
- Fly ash
- Bottom ash
- Recycled plastics

Several major road projects in Australia have incorporated recycled materials, setting a precedent for future projects. A noteworthy example includes the Mordialloc Freeway in Melbourne, which is made from more than 150,000 tonnes of recycled asphalt, 193,000 tonnes of recycled road base, and 570 tonnes of plastic materials (Sustainability Victoria 2022).

In recent years, the focus has shifted toward maximising the benefits of recycled materials in road construction through optimising their use, enhancing the quality of the products, and exploring innovative applications. This has been facilitated by advancements in recycling technology, improved understanding of material properties, and continued collaboration between government, industry, and research institutions.

3.1. Benefits

The use of recycled materials in roads can bring significant benefits through affecting the triple bottom line (environmental, economic, and social outcomes). These benefits impact the whole life cycle associated with the incorporation of recycled materials and industrial by-products in road and pavement construction.

3.1.1. Environmental benefits

The benefits associated with the use of materials in roads depend on several factors, such as the type and processing of the materials. Some of the benefits of using recycled materials in roads include:

- **Reducing waste disposal:** By incorporating recycled materials into road construction projects, less recoverable materials are sent to landfills.
- **Reducing greenhouse emissions:** The production of new materials and the disposal of waste materials often involve processes that generate greenhouse gas emissions. Using recycled materials in road construction can significantly lower these emissions.
- **Conserving energy and water:** Conservation of energy and water associated with the production of new materials and the disposal of waste materials
- **Increasing recovery and recycling rates:** When recycled materials are used in road construction, it supports the development of a circular economy.
- **Reducing our reliance on virgin materials and non-renewable resources:** The use of recycled materials in road construction decreases the demand for virgin materials and non-renewable resources and mitigates the impacts associated with extracting and processing these materials.

The ARRB (2022) provided a comprehensive review of the environmental, economic and social impacts of using recycled materials in major infrastructure projects across the road and rail industries in Australia. The report concludes that using recycled materials in roads and rail infrastructure has a significant environmental benefit in terms of reducing greenhouse gas (GHG) emissions. The emission reduction depends on the type of recycled materials used and can vary between 47% to 98%. **The highest emission reduction results from the use of two recycled materials: reclaimed asphalt pavement in surface and base layers and fly ash as a replacement for hydrated lime and cement in stabilised asphalts and concrete pavements. Both recycled materials can reduce GHG emissions by approximately 98%.**

The Recycled Materials Resource Center at the University of Wisconsin Madison developed a life-cycle assessment tool for environmental and economic effects (including reduction of carbon dioxide emissions, energy consumption, and water consumption) associated with the substitution of recycled materials - such as fly ash in concrete, reclaimed asphalt pavement, and recycled concrete aggregate - for conventional virgin materials in highway construction. Using the data collected across six US states, the savings from recycled materials used across all member states were equivalent to the energy consumption of 110,000 U.S. households per year, 9,300 bathtubs of water, and the carbon dioxide emissions produced by 58,000 cars per year (Del Ponte, et al., 2017).

Another estimate was presented by the Southern Sydney Regional Organisation of Councils (SSROC), an association of 11 councils spanning Sydney's southern suburbs, eastern suburbs, CBD, and inner west, which collectively manages approximately 20% of the waste in NSW. As part of their Procure Recycled: Paving the Way initiative, SSROC (2021) estimated that **using recycled crushed glass (RCG) gathered from kerbside collection across 16 Sydney Councils can result in recycling about 93 million glass bottles per year,** without compromising high-order recycling of glass back into beverage containers.

Furthemore, the MRA Consulting Group (2019) was commissioned by ACOR to investigate the use of recycled content in road building materials. The study identified two major road infrastructure projects in construction in each state, reviewed the current recycling material used within each project, and investigated further use of recycled materials in road construction and upgrades. The results show that **using recycled materials (plastic, tyre crumb, and glass) in just two major road projects per state, could consume almost 2.3 million tonnes of recyclables.**

3.1.2. Economic benefits

The economic benefits of using recycled materials in road infrastructure, particularly material cost saving, depend on factors such as materials and market maturity. Some of the benefits include:

- **Reducing waste disposal costs:** Utilising recycled materials in construction projects sends less waste to landfills. This reduces the costs associated with waste disposal, such as landfill fees, transportation, and long-term monitoring expenses.
- **Job creation:** The increased demand for recycled materials in infrastructure projects supports the growth of the recycling sector, which in turn creates new job opportunities.
- **Material cost saving:** Recycled materials often cost less than their virgin counterparts, resulting in significant material cost savings for construction projects. The savings vary depending on factors such as geography, market maturity, and material quality.

The ARRB (2022) estimates that most recycled material applications in road and rail infrastructure can increase the cost saving between 2% to 83%. RAP has the highest economic benefit, with a cost saving of 83%.

Additionally, the adoption of recycled materials can have a positive impact on employment as it creates more job opportunities in the recycling sector to meet the increase in demand for recycled materials. Notably, job creation in the recycling sector is higher than waste disposal with **9.2 jobs created for every 10,000 tonnes of materials recycled, compared with only 2.8 jobs created for sending waste to landfill** (ARRB 2022).

The Recycled Materials Resource Center at the University of Wisconsin–Madison also estimated the environmental and economic life-cycle benefits associated with the incorporation of recycled materials and industrial by-products in highway construction. Using the data collected across six US states, the total economic savings from using recycled materials in highway construction was estimated to be $62.5 million (Del Ponte, et al., 2017).

3.1.3. Social benefits

The social impacts of using recycled materials in roads are closely linked to the environmental, health, and economic advantages that arise from this practice. Some of these benefits include:

- **Improving welfare through job creation:** The use of recycled materials in road construction supports the growth of the recycling sector, which in turn can create new job opportunities. These jobs can range from waste collection and processing to manufacturing recycled products, which ultimately contributes to local economic development and overall community welfare.
- **Improving community satisfaction and civic pride:** Sustainable road construction practices demonstrate a commitment to environmental stewardship and responsible resource management. This can enhance community satisfaction and promote civic pride, as residents appreciate living in a region that values and invests in sustainable practices. (ARRB, 2022).
- **Improving intergenerational equity by preserving natural resources for future generations:** Using recycled materials and preserving natural resources can ensure that future generations have access to the resources they need to sustain their communities. This intergenerational equity is an essential component of social sustainability, fostering a sense of responsibility and stewardship for the well-being of future generations.
- **Improving public health:** The use of recycled materials in road construction can lead to improved public health outcomes by reducing greenhouse gas emissions and other

pollutants associated with the extraction, production, and transportation of virgin materials. Additionally, by reducing the need for quarrying operations, which often produce blast noise and vibrations, the use of recycled materials can help mitigate the negative health effects associated with these activities (ARRB, 2022).

3.1.4. Performance benefits

Performance benefits play a crucial role in increasing industry confidence in the use of recycled materials in road infrastructure. The performance benefits of using recycled content vary from material to material, however, there are some common benefits (IPWEA, 2016):

- **Reducing the total volume of material required:** By using recycled materials with enhanced properties, the overall quantity of raw materials needed for a project can be reduced. This results in cost savings and decreased environmental impact.
- **Reducing reflective and fatigue cracking:** The incorporation of certain recycled materials, such as crumb rubber, can improve the resistance of road surfaces to reflective and fatigue cracking. This can increase the overall lifespan of the road, reducing maintenance costs and disruptions.
- **Increasing longevity of the roads**: Recycled materials can enhance the durability and performance of road surfaces, increasing their overall lifespan.
- **Reducing traffic noise**: Some recycled materials, such as crumb rubber, can help decrease traffic noise levels when used in road surfaces. This can improve the quality of life for residents in nearby areas and contribute to overall community well-being.

Confirming these benefits, the MRA Consulting Group estimates that the **addition of recovered soft plastics used as recycled polymers enhances the performance characteristics of asphalt, delivering a 65% increase in fatigue life over standard asphalt, and a huge improvement in deformation resistance, from a measurement of 9-11mm for standard** (MRA Consulting Group, 2019).

A United States based company Technisoil, which uses melted-down plastic waste as a form of bulking agent for bitumen, claims that the result of using recycled materials is between **two and three times longer-lasting than standard bitumen, as well as being more flexible and forgiving than standard concrete** (Technisoil, 2020).

Moreover, researchers at RMIT and the University of South Australia tested asphalt with crumb rubber and found that it could **double the durability of roads in hot weather.** Crumb rubber has also positive effects on pavements, including through reduced noise and risk of cracking (Jamal, et al., 2022).

3.2. Barriers and challenges

While the benefits of using recycled materials is encouraging, there are challenges and concerns that must be addressed to confidently apply these materials in roads.

The key challenges include the quality, price, availability, and long-term environmental effects of the recycled materials. These concerns vary according to the extent the material is used.

Some materials, such as crushed concrete, RAP, and crumb rubber benefit from established markets, are commonly used to supplement traditional materials, and industry confidence in their use is high. Other materials, such as plastics have a less developed market due to perceived uncertainty around their performance, impact on the environment, health and safety, and their reuse capability.

3.2.1. Material specific challenges

Below, we review the ARRB (2022) findings on the market maturity, specifications and guidelines, and the performance of the recycled materials in roads:

- **Recycled Crushed Glass (RCG):** Recycled Crush Glass has been used in embankments, fill, and drainage since the 1970s and several specifications have been developed to support its use. There are a number of barriers for the market; including processes for collection systems and contaminants that can affect the quality of the glass. Despite these challenges, there is a great opportunity to support the use of glass in road contruction.
- **Crushed Concrete and Brick:** The use of crushed concrete and brick is a well-established practice in Australia. It is estimated that using recovered construction and demolition materials can divert up to 8,000 tonnes of resources from landfill per kilometre of road construction. (Department of Transport and Main Roads, 2022). The market is supported by standards and specifications such as AS 2758.1-2014 Aggregates and rock for engineering purposes.
- **Reclaimed Asphalt Pavement (RAP):** Similar to recycled crushed concrete, RAP is also well-established in Australia and in some applications, up to 100% RAP can be used. A variety of standards, specifications, and guidelines has been developed to support its use. such as the AS 1141 series for sampling and testing aggregates or the Reclaimed Asphalt Pavement Management Plan (Australian Asphalt Pavement Association, 2018).
- **Crumb Rubber:** The reduction in noise and a decreased risk of cracking associated with using crumb rubber have been well recognised by the industry. Crumb rubber has developed a relatively mature market in Australia, with adequate supply of end-of-life tyres to increase the use of the material in roads. It is also supported by several specifications and guidelines such as the Crumb Rubber Modified Open Graded and Gap Graded Asphalt (Australian Asphalt Pavement Association 2018) and D&C Specification 3256 Crumb Rubber (TfNSW 2020).
- **Ground Granulated Blast Furnace Slag (GGBFS):** GGBFS has been globally used in roads since the 1960s and has developed a relatively mature application. However, its application is limited in Australia with few producers of the material, with some supplies imported.
- **Fly Ash:** Fly ash has been used in several applications including in concrete since 1975 in Australia. In terms of performance, fly ash has been found to be a good alternative to non-recycled materials. Several specifications and guidelines have been developed to support the use of fly ash. For example, AS/NZS 3582.1-2016 Supplementary Cementitious Materials: Part 1: Fly Ash. However, within existing state specifications there is no consistency of allowable rates. For instance, WA specifies the recovery rate of generated fly ash at 72% compared to 18% in Qld and 10% in NSW.
- **Bottom Ash:** Bottom ash is a by-product from coal combustion or waste to energy plants. This material is confidently applied in roads globally, predominantly in Europe. Considering the development of the waste management sector in Australia, bottom ash has potential to be commercially available in the near future.
- **Recycled Plastics**: Recycled plastic has several applications in infrastructure including roads. However, the market maturity of using recycled plastics in roads is quite low and there is a lack of industry confidence due to environmental questions surrounding microplastics and leachates. On the other hand, the recovery rate of plastics in Australia is only 14% which indicates there is a significant available supply (Department of Climate Change, Energy, the Environment and Water, 2022). Additionally, several emerging initiatives to enhance plastic recycling have been developed by different level of governments to increase the use of recycled plastics across the economy. For example, to address microplastic concerns, Austroads (AP-R669-22) has developed the basis of a performance-based evaluation protocol to assess emissions and microplastics from plastic-modifed bitumen and asphalt.

Table 2 summarised the market maturity of the recycled materials explained above (ARRB, 2022)

Table 2: The maturity of Australia's recycled materials market

Material	Australian Market
Crushed Concrete and Brick	**Mature** It is estimated that it can deliver 8,000 tonnes of construction and demolition waste from landfill per kilometre of road construction
Reclaimed Asphalt Pavement (RAP)	**Mature** In some applications, up to 100% recycled RAP can be used
Crumb Rubber	**Mature** Adequate supply of end-of-life tyres
Fly Ash	**Mature**
Recycled Crushed Glass (RCG)	**Relatively new** The supply of glass waste to recyclers is above the demand, but there are a number of barriers for the market including processes for collection systems and contaminants that can affect the quality of the glass
Ground Granulated Blast Furnace Slag (GGBFS)	**Limited** Only one operational producer of the material
Recycled Plastics	**New** A significant available supply
Bottom Ash	**No market in Australia** Confidently applied in roads globally, predominantly in Europe

3.2.2. Market challenges

In addition to the above-mentioned material challenges, market challenges and barriers can negatively affect the use of recycled materials. These include:

- **A lack of evidence to show the long-term outcomes and sustainability benefits of the use of recycled materials:** This includes uncertainty regarding the end-of-life options (e.g., recyclability and resource recovery) of roads containing recycled materials once they reach their end of life. There are concerns regarding whether the roads with recycled materials can be recycled further, if the materials would impact the reuse performance, or require additional energy. There are also concerns regarding chemical additives, health, and safety precautions.
- **Procurement issues:** There is a gap in current procurement policies to optimise the application of recycled materials. Although the Commonwealth's Sustainable Procurement Guide recommends creating mandatory, minimum or desirable requirements for use of recycled material, most government procurements have only mentioned recycled content without setting a specific target or requirements (ARRB, 2022).
- **Lack of nationally harmonised standards and guidelines:** Many existing state specifications prescribe which materials can be used, rather than focusing on performance outcomes. Allowable limits of recycled materials also vary across different jurisdictions. This can limit the demand and hinder growth for the recycled materials market.
- **Lack of guidance and education:** One of the significant non-market challenges in the use of recycled materials is the general lack of harmonised guidance and education about the different types of recycled materials available, the associated benefits, and the standards that enable their use in road construction.

The following parts of this report will discuss the barriers preventing the adoption of recycled materials in road construction and identify opportunities that can be addressed by Australian Standards. Amongst the barriers reviewed above, Standards Australia can assist in creating nationally harmonised, performance-based standards and develop practical guidance for the uptake of enabling standards.

4. Opportunities to address market challenges

As reviewed in Section 3, one of the challenges of using recycled materials in roads is the lack of nationally harmonised standards and stakeholder education that supports the application of each of these materials. This section reviews the existing specifications by recycled materials to identify where the development of standards and education regarding their use can facilitate their uptake in road construction.

4.1. Existing standards, specifications, and guidelines for the use of recycled materials

The application of recycled materials in road construction is primarily guided by state-based specifications. A review of these specifications reveals considerable inconsistencies and contradictions. This section presents examples of such inconsistencies and discusses the potential for harmonising existing state-level guidance and incorporating performance-based Australian Standards.

The specifications are reviewed per material as follows:

Recycled Aggregates: Australian Standards, specifications and guidelines have been developed regarding the use of recycled aggregates including crushed concrete and brick by Standards Australia[2], Austroads, CSIRO, and AfPA. State governments also developed their own specifications. The allowable limits, however, vary amongst states. Table 1 presents the allowable limits by states.

Table 1: Allowable limits for content of aggregates in recycled concrete; quantities in % maximum allowable content

Material	Resource NSW	MR WA	NZTA	DTEI SA
Supplementary materials (brick, crushed stone, tiles, masonry, glass)	3 – 30	5	3	20
Friable materials (plaster, clay lumps)	0.2	2	1	1
Foreign materials (rubber, plastic, paper, cloth, paint, wood, vegetable matter)	0.1	0.5	0.5 (includes bitumen)	0.5
Bituminous materials (asphalt, seals)	0.1	0	0	1 (bitumen content)
Asbestos	0	0	0	0

2 AS 2758.1-2014 Aggregates and rock for engineering purposes

Recycled Crushed Glass: Several specifications have been developed by state governments and a national guideline was developed by Austroads on the use of crushed glass in roads. Table 2 summarises the allowable limits for RCG as set out by specifications across Australian states. As the table shows, the specifications consider different applications for RCG in roads and thus, the allowable limits also are not consistent depending on the applications.

Table 2: Allowable limits for RCG in road and rail infrastructure

State/Road agency	Application	Maximum allowable limit (% of mass)
ACT/TCCS	Granular base and subbase	10
NSW/TfNSW	Granular base and subbase	10
	Asphalt (wearing coarse)	2.5
	Asphalt (other than wearing coarse)	10
	Slab replacement work for concrete pavements	15
NSW/Lake Macquarie City Council	Asphaltic concrete (Roadways)	30
	Lean mix concrete subbase	30
	Plain and reinforced concrete base	30
NSW/IPWEA	Select fill (Class S)	10
	Bedding material (Class B)	50
	Drainage medium (Class D75 & D20)	50
	Drainage medium (Class D10)	100
	Road Base and subbase (Class R1 & R2)	10
NT/DIPL	Bedding for drainage works	100
Qld/TMR	Dense graded asphalt layers (other than surfacings)	10
	Dense graded asphalt surfacings	2.5
	Unbound pavements (subtypes 2.3, 2.4 and 2.5)	20
	Bedding and backfill material	100
SA	Anti-skid mixtures for pavement markings	30
Tas	Aligned with DoT	
Vic/DoT	Granular base	5–10
	Granular subbase	15–50
	Subsurface drainage – granular filter material	100
	Intermediate and base course layers in dense-graded asphalt	100 (of total natural sand)
	Dense-graded asphalt (wearing coarse)	5
WA/MRWA	Imported fill for embankment construction	20

Source: ARRB 2022

Reclaimed Asphalt Pavement: The use of RAP in roads has been supported by national guidelines (developed by Austroads and AfPA) and state specifications. Depending on application, however, the allowable content varies in state specifications. Tables 3 and 4 presents the allowable contents

Table 3: Allowable contents of RAP in granular layers for each state and territory in Australia

	RAP content limit	
	NSW	
Base and subbase	Up to 40% by mass in unbound, modified and bound base and subbase	TfNSW QA 3051
	NT	
Base and subbase	Not specified	
	QLD	
Base and subbase	Up to 20% RAP is allowed in base and subbase of unbound pavements. In lower subbase and subgrade (Subtype 2.5 unbound pavement), up to 45% by mass is allowed	MRTS05
	SA	
Base and subbase	Up to 20% (by mass) RAP is allowed in ganular pavement materials	RD-PV-S1
	TAS	
Base	Aligned with VIC	
	VIC	
Base and subbase	Up to 15% for unbound base (Class 3), and up to 40% for unbound and bound subbase (Class 4)	Code of Practice RC 500.02
	Up to 20% in lower trafficed base and up to 50% in lower trafficed subbase	Section 813
	WA	
Base and subbase	The use up to 10% (by volume) RAP in stabilised base and subbase layers is allowed	Specification 512
	Up to 15% (by mass of the material larger than 4.75mm) of pavement materials can be RAP)	Specification 501

Source: ARRB 2022

Table 4: Allowable contents of RAP in asphalt layers for each state and territory in Australia

	RAP content limit	
	NSW	
Surface	Up to 20% in wearing course and up to 40% for other than wearing course in heavy duty dense graded asphalt	TfNSW QA R116
	Up to 25% by mass in wearing course and up to 40% by mass for other than wearing course in light duty dense graded asphalt	TfNSW QA R117
Mix type	RAP is not allowed in CRA, SMA or OGA mixes. For PMB mixes, up to 10% RAP could be used	
	NT	
Surface	In dense graded asphalts, up to 10% by mass in the wearing course, and up to 15% by mass in base layers	Standard Specification for Roadworks v4.2

RAP content limit continued		
	QLD	
Surface	In dense graded asphalt, up to 20% by mas RAP is allowed in surfacing course. Maximum allowable limit is 15% if the dense graded asphalt contains PMB and multigrade bitumen In dense graded asphalts, up to 40% (by mass) RAP is allowed in base, intermediate and corrector courses	MRTS30
	The maximum allowable RAP in EME2 is 15% by mass	MRTS32
Mixed type	RAP is not allowed in SMA and OGA mixes	
	SA	
Surface	RAP is allowed to be used for wearing courses up to 10% (by mass) in coarse dense mix asphalt and up to 20% in fine dense mix asphalt Up to 50% (by mass) RAP is allowed in asphalt pavement layers (other than wearing course). In asphalt mixes containing PMB, the maximum allowable is 20%	RD-BP-S2
Mix type	RAP is not allowed in SMA and OGA mixes	RD-BP-S2
	TAS	
Surface	Aligned with Vic	
Mix type		
	VIC	
Surface	Up to 40% (by mass) RAP content is allowed for dense graded asphalt depending on traffic volume. (Maximum 25% for RAP Level 1 and maximum 40% for RAP Level 2)	Section 407 Code of Practice RC 500.01
	Up to 10% (by mass) RAP in Regulation Gap Graded Asphalt	Section 405
Mix type	RAP is not allowed in SMA, OGA and high binder crumb rubber asphalt (HBCRA) mixes and mixes containing PMBs or EME2 binders	
	WA	
Surface	The use of RAP for surface layers is not allowed	Specification 504
	The use up to 10% RAP in asphalt intermediate course layers is allowed	Specification 510
Mix type	RAP is not allowed in SMA, OGA, or PMB mixes	

Source: ARRB 2022

Crumb Rubber: The application of crumb rubber in roads has been supported by two national guidelines (developed by Austroads and AfPA) and state specifications. However, the specified permitted level of crumbed rubber varies depending on the application, mixing methods and performance requirements. For instance, Table 5 displays the requirements for use of crumb rubber in bitumen as a modifier.

Table 5: Specified requirements for crumb rubber binders

		Requirements					
		PSTS112, 2017		AfPA	PSTS112, 2019	MRWA, 2018	MRWA, 2020
Property	**Test method**	**CR1**	**CR2**				
Viscosity at 175°C [Pa·s]	ASTM D2196	Report	Report	–	–	–	–
Viscosity at 175°C [Pa·s]	AGPT/T111	–	–	–	–	–	Report
Viscosity at 175°C [Pa·s]	ASTM D7741/ D7741M	1.5–4.0	1.5–4.0	1.5–4.0	1.5–4.0	1.5–4.0	1.5–4.0
Torsional recovery at 25°C [%]	AGPT/T122 / ATM 122	Report	Report	Report	Report	Report	Report
Resilience at 25°C [%]	ASTM D5329	25 min	20 min	20 min	20 min	20 min	20 min
Softening point [°C]	AGPT/T131	57 min	55 min	55 min	55 min	55 min	55 min
Consistency 6% at 60°C [Pa·s]	AGPT/T121	–	–	–	Report	–	Report
Penetration at 4°C, 200 g, 60 s (0.1mm)	AS 2341.12	10 min	15 min	12 min	15 min	15 min	15 min
Penetration at 25°C (0.1mm)	AS 2341.12	–	–	Report	–	Report	–
Compressive limit at 70°C, 2kg [mm]	AGPT/T132	–	–	–	–	–	0.2 min
Flash point [°C]	AGPT/T112	250 min	250 min	250 min	250 min	250 min	–
Loss on heating [% mass]	AGPT/T103	0.6 max	0.6 max	0.6 max	0.6 max	0.6 max	0.6 max

Source: ARRB 2022

Ground Granulated Blast Furnace Slag: GGBFS is supported by a few national guidelines developed by Austroads. There are also several state specifications with a significant inconsistency in permitted limits of the use of GGBFS. Table 6 presents the specified limits.

Table 6: Specified limits for GGBFS by road agency

State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
NSW	TfNSW	Concrete work for bridges Shotcrete work Shotcrete work without steel fibres Lean-mix concrete subbase Concrete for general works No fines concrete subbase	SCM in binary blended cement(1)	70	TfNSW D&C 3211
			SCM in ternary blended cement(2)	50	
		Concrete pavement base	SCM in binary and ternary blended cement	65	
		Stabilisation of earthworks Construction of unbound and modified pavement course Construction of plant mixed heavily bound pavement course Insitu pavement stabilisation using slow setting binders	SCM in binary and ternary blended cement	Not specified	
		Roller compacted concrete subbase Roller compacted concrete			
		Heavy duty dense graded asphalt Light duty dense graded asphalt Crumb rubber asphalt Open graded asphalt Stone mastic asphalt Thin open graded asphalt surfacing High Modulus Asphalt (EME2)	Binder	Not specified	
Qld	TMR	Insitu stabilisation	Binder (stabilising agent)	Not specified	MRTS07B
		Plant-mixed heavily bound (cemented) pavements			MRTS08
		Plant-mixed lightly bound pavements			MRTS10
		Lean mix concrete sub-base for pavements	SCM in blended cement	Not specified	MRTS39
		Concrete pavement base		65	MRTS40
		Concrete road and bridge structures	SCM in binary blended cement	40	MRTS70
			SCM in ternary blended cement	25	

Specified limits for GGBFS by road agency continued

State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
WA	MRWA	Stabilisation of subgrade	SCM in blended cement	Not specified	Specification 302
		Low strength infill for the backfilling of redundant or abandoned pipes, culverts and other buried structures		Not specified	Specification 410
		Insitu stabilisation of granular pavement layers		Not specified	Specification 515
		High performance concrete for structures		65	Specification 820
		Concrete for general non-structural works		Not specified	Specification 901
Vic	DoT	Cementitious treated pavement subbase	SCM in blended cement	50	Section 306, Section 815
			Cementitious binder in a slag-lime blend	90	Section 815
		In situ stabilisation of pavements	SCM in blended cement	50	Section 307
			Cementitious binder in a slag-lime blend	90	
		Dense graded asphalt	Added filler	Not specified	Section 407
		Structural concrete	SCM in blended cement	40	Section 610
		Concrete for paving (including geopolymer concrete)		Not specified	Section 703
		Geopolymer binder		100	Section 703
		Concrete for drainage pits and covers (including geopolymer concrete)		Not specified	Section 705
Tas	DSG	Aligned with DoT			
SA	DIT	Controlled low strength material	SCM	Not specified	RD-EW-C4
		Stabilisation	SCM in binder	80(3)	RD-PV-S1
		Stabilised pavement	SCM in blended cement	Not specified	RD-PV-S2
NT	DIPL	Stabilisation Miscellaneous concrete works Drainage work structures (e.g. culverts)	SCM in blended cement	Not specified	Standard Specification for Roadworks v4.2
ACT	TCCS	Subgrade stabilisation	Binder (stabilising agent)	Not specified	MITS 02C
	Austroads	Concrete pavements	SCM in blended cement	Not specified	AGPT04C-17
		Geopolymer concrete	Binder	Not specified	ATS-5330-20

Specified limits for GGBFS by road agency continued					
State	**Road agency**	**Application**	**Material/Product**	**Max limit (% by mass)**	**Reference**
		Stabilisation (pavement and earthworks)	Binder (in cement-GGBFS blends)	60	AGPT4L-09
			Binder (in lime-GGBFS blends)	70	
			Binder (in lime-fly ash- GGBFS blends)	50	
			Binder (in cement-fly ash-GGBFS blends)	40	

Source: ARRB 2022

Fly Ash: Austroads and state governments have developed several specifications regarding the use of recycled materials in road construction. The specified limits vary depending on the application of fly ash and the product. Table 7 presents the limits.

Table 7 Specified limits for fly ash by different road agencies

State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
NSW	TfNSW	Concrete work for bridges Shotcrete work Shotcrete work without steel fibres Concrete for general works No fines concrete subbase	SCM in binary blended cement(1)	40	TfNSW D&C 3211
			SCM in ternary blended cement(2)	30	
		Lean-mix concrete subbase	SCM in binary and ternary blended cement	75	
		Concrete pavement base	SCM in binary and ternary blended cement	40	
		Stabilisation of earthworks Construction of unbound and modified pavement course Construction of plant mixed heavily bound pavement course Insitu pavement stabilisation using slow setting binders Roller compacted concrete subbase Roller compacted concrete	Binder	Not specified	

Specified limits for fly ash by different road agencies continued					
State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
		Heavy duty dense graded asphalt Light duty dense graded asphalt Crumb rubber asphalt Open graded asphalt Stone mastic asphalt Thin open graded asphalt surfacing High Modulus Asphalt (EME2)	Added filler	Not specified	
Qld	TMR	Insitu stabilisation	Binder (stabilising agent)	Not specified	MRTS07B
		Plant-mixed heavily bound (cemented) pavements			MRTS08
		Plant-mixed foamed bitumen stabilised pavements			MRTS09
		Plant-mixed lightly bound pavements			MRTS10
		Lean mix concrete sub-base for pavements	SCM in blended cement	Not specified	MRTS39
		Concrete pavement base		40	MRTS40
		Concrete road and bridge structures	SCM in binary blended cement	40	MRTS70
			SCM in ternary blended cement	32	
		Asphalt	Added filler	Not specified	MRTS103
WA	MRWA	Stabilisation of subgrade	SCM in blended cement	Not specified	Specification 302
		Concrete for culvert		25	Specification 404
		Low strength infill for the backfilling of redundant or abandoned pipes, culverts and other buried structures		Not specified	Specification 410
		Insitu stabilisation of granular pavement layers		Not specified	Specification 515
		High performance concrete for structures		25	Specification 820
		Microsurfacing	Mineral filler	Not specified	Specification 507
Vic	DoT	Cementitious treated pavement subbase	SCM in blended cement	30	Section 306, Section 815
		In situ stabilisation of pavements		30	Section 307
		Dense graded asphalt	Added filler	Not specified	Section 407
		Concrete pavement courses	Fine aggregate	Not specified	Section 520
			SCM in blended cement	20	

Specified limits for fly ash by different road agencies continued

State	Road agency	Application	Material/Product	Max limit (% by mass)	Reference
		Structural concrete	SCM in blended cement	25	Section 610
		Concrete for paving (including geopolymer concrete)		Not specified	Section 703
		Geopolymer binder		100	Section 703
		Concrete for drainage pits and covers (including geopolymer concrete)		Not specified	Section 705
Tas	DSG	Aligned with DoT			
SA	DIT	Controlled low strength material	SCM	Not specified	RD-EW-C4
		Stabilisation	SCM in binder	67(4)	RD-PV-S1
		Stabilised pavement	SCM in blended cement	Not specified	RD-PV-S2
		Geopolymer concrete (for structures)	Binder	Not specified	ST-SC-S2
NT	DIPL	Stabilisation Miscellaneous concrete works Drainage work structures (e.g. culverts)	SCM in blended cement	Not specified	Standard Specification for Roadworks v4.2
ACT(5)	TCCS	Subgrade stabilisation	Binder (stabilising agent)	Not specified	MITS 02C
		Base and subbase	Filler and/or binder	Not specified	MITS 04
		Grout for concrete works	Grout material	Not specified	MITS 10

Source: ARRB 2022

Recycled Plastics: The incorporation of plastics in road construction is still in its early stages. A two-year national project funded by the Commonwealth/Transport Infrastructure Council through Austroads investigated the potential benefits, the methodologies, and frameworks for the development of performance-based assessment procedures for incorporating recycled plastics into asphalt (Austroads, 2022).

As a result, Austroads (2021) developed interim guidance (Guideline AP-G96-21) for different types of recycled waste plastic in Australia and how it can be incorporated into asphalt or sealing work. These guidelines are intended for local government for the surfacing of local roads that are not used by a heavy traffic volume or a high proportion of heavy vehicles for a 20 year design period. As confidence grows in the use of recycled plastics, more roads are being built using this material. In Victoria, a section of the M80 has incorporated the equivalent of 35.5 million plastic bags and 800 000 toner cartridges that would have otherwise ended up in landfill (Major Road Projects Victoria, 2022).

Additionally, there are several national and international standards, and a number of specifications developed by VicRoads regarding the use of plastic in noise wall. Table 8 presents the noise wall standards and specifications.

Table 8 Noise wall standards and specifications

Standard	Title
Australia	
AS 5100	*Bridge Design: Part 1: Scope and General Principles*
AS/NZS ISO 717.1	*Acoustics: Rating of Sound Insulation in Buildings and of Building Elements: Airborne Sound Insulation*
AS 1191	*Acoustics: Method for Laboratory Measurement of Airborne Sound Insulation of Building Elements*
ISO 10140-2	*Acoustics: Laboratory Measurement of Sound Insulation of Building Elements: Part 2: Measurement of Airborne Sound Insulation*
Vic	
Section 765	Noise Attenuation Walls
Section 685	Anti-graffiti Protection and Graffiti Removal
Section 204	Earthworks

Source: ARRB 2022

Specification Inconsistencies

Review of the above tables demonstrates significant inconsistencies in the limits and applications of recycled materials across specifications, which can negatively impact the uptake of recycled materials in road construction and rehabilitation. For example, the allowable rate of fly ash in concrete pavement base varies between states, with Queensland allowing 40% and Victoria permitting 20% (Table 7). Similarly, recycled crush glass usage in granular base and subbase is permitted at 10% by TfNSW, compared to a 5-10% granular base and as a subbase at 15-50% by Vic DoT (Table 2). Additionally, some states (such as Western Australia) require that testing regimes for recycled construction materials are more complex than those that apply applies to raw materials.

These inconsistencies not only relate to the application of these materials, but also in their reusability and/or recyclability. For instance, Asbestos Containing Materials (ACM) highlights such inconsistencies. While the New South Wales Environmental Protection Agency (NSW EPA) applies zero tolerance for the reuse of construction and demolition (C&D) material with any quantity of ACM, the Victorian Occupational Health and Safety Act (2004) permits C&D materials “tainted” with up to 0.001% ACM contamination. In Western Australia, there are specific measures in place to manage asbestos at each stage of the recycling process. Such inconsistency can impose practical difficulties and challenges to incorporating the use of the recycled materials in roads.

In several jurisdictions, certain types of recycled materials continue to be classified as waste and are required to comply with a range of regulations requiring specific infrastructure for their storage. However, there are few constraints on virgin products which can be stored at staging yards or depots, especially for small projects. This adds another barrier to the implementation and use of recycled materials.

Industry Perspectives

A 2022 survey conducted by Infrastructure Australia for the Replacement Materials: report found that 88% of participants valued how standards and specifications enable the use of recycled materials. However, the report also noted that standards are “not up to date with all current waste streams and waste uses in construction material”. The report concluded that where new and updated standards are developed “they should aim for national consistency by lifting, not lowering, the bar, enabling optimal usage across state boundaries” (Infrastructure Australia, 2022).

Harmonising Potential

Despite the inconsistency in the limits and applications of recycled materials, most state specifications refer to existing performance-based publications for sampling, testing and/ or performance, including Australian Standards developed by Standards Australia. For example, ‘AS 1289 Methods of testing soils for engineering purposes’ has been referred to by both TfNSW’s ‘QA Specification R3051 Granular Pavement Base and Subbase Materials’ and VicRoads’s Specification 812 used in ‘TN 107 Use of Recycled Materials in Road Pavements’. However, the former specifies granular base and subbase limits at 10%, while the latter limits granular base to 5-10% and granular subbase to 15-50%. This highlights the opportunity to harmonise existing state level guidance while incorporating existing performance-based Australian Standards.

Opportunity: There is an opportunity for the key industry expert participants to collaborate in creating new and/or modifying performance-based Australian Standards that harmonise existing guidance and specifications. Development of performance-based standards and test methodologies that promote the incorporation of recycled materials (particularly less-familiar types of materials such as plastics) can streamline the use of innovative materials into roads and provide confidence in their application.

4.2. Education and awareness

Recycled materials have the potential to contribute significantly to the circularity of roads in Australia. However, as noted in the ARRB (2022) report, a general lack of knowledge concerning the types and limits of recycled materials hinders their uptake in roads. Addressing knowledge gaps around enabling standards and the characteristics of recycled materials is essential for the successful transition to more circular practices in road construction. Our previous research shows that there is a significant need for communication, information sharing, and awareness about existing standards as stakeholders may misperceive standards to prevent the use of recycled materials in roads. Shifting to more circular practices requires increased awareness of how these materials can be used and greater knowledge in the implementation of enabling standards.

Opportunity: There is an opportunity for Standards Australia, the Australian Government, the construction sector, the recycling sector, and circular economy leaders to work together to provide practical guidance for the use of recycled materials in roads and the associated enabling standards. Improved awareness through the development of educational material and enhanced industry engagement through knowledge sharing activities, can contribute to improving sustainability outcomes and promote circular economy practices in road construction throughout Australia.

5. Next Steps and Recommendations

Recommendation 1: The Australian Government, Standards Australia and key industry expert participants should collaborate to modify existing and/or create new performance-based Australian Standards that harmonise the inconsistencies in existing specifications.

Standards can function as market enablers to achieving broader business and public policy objectives. Up-to-date and fit-for-purpose standards are critical to enabling the use of recycled materials in roads and achieving the 2030 targets outlined in the National Waste Policy Action Plan. Created using a trusted and consensus-driven process, Australian Standards can provide confidence to engineers, procurement officers, and contractors in the performance, safety, and durability of recycled materials in roads.

Developing nationally consistent standards that promote the optimal usage of recycled materials in roads can also assist in reducing uncertainty in the applications of these materials across state and territory jurisdictions. Standards can also be used as a tool to drive demand for less familiar materials, such as plastics, by building confidence in their performance and safety.

Recommendation 2: Standards Australia, the Australian Government, the construction and recycling sectors, and circular economy leaders must continue to work together to provide practical guidance for the use of recycled materials in roads and the associated enabling standards.

As Australia transitions to a circular economy there is growing need to build confidence in new products, materials and processes. Using recycled materials in roads can not only help achieve environmental objectives, but also provide economic and social benefits. Addressing knowledge gaps is essential for the successful transition to more circular practices in the road construction industry. Stakeholders, including contractors, engineers, and policymakers, must be well-informed about the potential benefits and applications of recycled materials and the standards that enable their uptake.

To support the uptake of recycled materials and roads, Standards Australia, government and the road construction community should continue to develop resources and guidance that:

- Clearly communicates the benefits and applications of these materials in roads.
- Highlights the enabling standards and relevant use cases that govern the use of recycled materials.
- Provides the necessary knowledge to dispel misconceptions around the use of recycled materials and enabling standards.

References

Access Economic for The Department of Environment, Water, Hertiage and the Arts, 2009. Employment in waste management and recycling. [Online]

Available at: https://www.dcceew.gov.au/sites/default/files/documents/waste-and-recycling-employment.pdf

[Accessed 2022].

Australian Asphalt Pavement Association, 2018. Crumb Rubber Modified Open Graded and Gap Graded Asphalt Pilot Specification. [Online]

Available at: https://www.tyrestewardship.org.au/wp-content/uploads/2020/04/pilot-spec-crumb-rubber-modified.pdf

[Accessed 2023].

Australian Asphalt Pavement Association, 2018. Reclaimed Asphalt Pavement (RAP) Management Plan. [Online]

Available at: https://afpa.asn.au/wp-content/uploads/2018/06/AAPA-RAP-Management-plan-12-June-2018.pdf

[Accessed 2023].

Australian Government, 2021. Sustainable Procurement Guide - A practical guide for Commonwealth entities. [Online]

Available at: https://www.dcceew.gov.au/sites/default/files/documents/sustainable-procurement-guide.pdf

[Accessed 2023].

Australian Road Research Board, 2022. Best Practice Expert Advice on the Use of Recycled Materials in Road and Rail Infrastructure: Part A Technical Review and Assessment. [Online]

Available at: https://3003125.fs1.hubspotusercontent-na1.net/hubfs/3003125/ARRB%20Recycled%20Materials%20Best%20Practice%20Part%20A_Final%20June%202022.pdf

[Accessed 2023].

Australian Road Research Board, 2022. Best Practice Expert Advice on the Use of Recycled Materials in Road and Rail Infrastruture: Part B Sustainability Impacts Report. [Online]

Available at: https://3003125.fs1.hubspotusercontent-na1.net/hubfs/3003125/ARRB%20Recycled%20Materials%20Best%20Practice_Part%20B_Final%20June2022.pdf

[Accessed 2023].

Austroads, 2021. Guideline AP-G96-21: Interim Guidelines for the Use of Recycled Waste Plastic in Local Government Road Surfacing Applications, s.l.: Austroads.

Austroads, 2022. AP-R669-22 - Use of road-grade recycled plastics for sustainable asphalt pavements. s.l.:Austroads.

Del Ponte, K. et al., 2017. Life-Cycle Benefits of Recycled Material in Highway Construction. Transportation Research Record, 2628(1), pp. 1-11.

Department of Climate Change, Energy, the Environment and Water, 2022. Australian Plastics Flows and Fates Study 2020-21 – National Report. [Online]

Available at: https://www.dcceew.gov.au/sites/default/files/documents/apff-national-report-2020-21.docx

[Accessed 2022].

Department of the Environment and Energy, 2018. National Waste Policy: Less Waste, More Resources. [Online]

Available at: https://www.dcceew.gov.au/sites/default/files/documents/national-waste-policy-2018.pdf

[Accessed 2023].

Department of Transport and Main Roads , 2022. Recycled Materials in Queenland's Roads. [Online]

Available at: https://www.tmr.qld.gov.au/Community-and-environment/Planning-for-the-future/Building-sustainable-roads

[Accessed 2022].

Infrastructure Australia, 2022. Replacement Materials Understanding the market for replacement materials across major infrastructure road projects. [Online]

Available at: https://www.infrastructureaustralia.gov.au/sites/default/files/2022-12/IA22-Replacement-Materials_REPORT_HR.pdf

[Accessed 2023].

Institute of Public Owrks Engineering Australasia, 2016. The business case for using recycled materials in roads. [Online]

Available at: https://www.ipwea.org/blogs/intouch/2016/06/24/the-business-case-for-using-recycled-materials-in-roads

[Accessed 2022].

Jamal, M., Lanotte, M. & Giustozzi, F., 2022. Exposure of crumb rubber modified bitumen to UV radiation: A waste-based sunscreen for roads. Journal of Cleaner Production, Volume 328.

MRA Consulting Group, 2019. Public Procurement of Road Building Materials - Reserach into Recycled Content. [Online]

Available at: https://www.acor.org.au/uploads/2/1/5/4/21549240/171019_public_procurement_of_road_building_materials_acor_report_final__3_.pdf

[Accessed 2022].

Ortiz, J. L., 2020. 100% Road Recycling with Neo. [Online]

Available at: https://technisoilind.com/technisoil-roads.html

[Accessed 2022].

Prepared for The Department of Climate Change, Energy, the Environment and Water, 2023. National Waste Report 2022. [Online]

Available at: https://www.dcceew.gov.au/sites/default/files/documents/national-waste-report-2022.pdf

[Accessed 2023].

Southern Sydney Regional Organisation of Councils, n.d. Paving the Way to Sustainable Roads - Driving a circular economy through government procurement. [Online]

Available at: https://az659834.vo.msecnd.net/eventsairaueprod/production-impactenviro-public/f6a67b528f2a4b2b8e5b317b1bdb0742

[Accessed 2022].

SSROC, 2021. Paving the way. [Online]

Available at: https://ssroc.nsw.gov.au/wp-content/uploads/2020/08/RCG-RR18.2-200909-Paving-the-Way-Overview1.pdf

[Accessed 2023].

Standards Australia, 2002. HB 155-2002 Guide to the use of recycled concrete and masonry materials. [Online]

[Accessed 2023].

Standards Australia, 2014. AS 2758.1-2014 Aggregates of rock for engineering purposes. [Online]

[Accessed 2022].

Sustainability Victoria, 2022. From your bin to the Big Build. [Online]

Available at: https://www.sustainability.vic.gov.au/news/news-articles/from-your-bin-to-the-big-build

[Accessed 2023].

Transport for NSW, 2020. Specification D&C 3256 Crumb Rubber. [Online]

Available at: https://roads-waterways.transport.nsw.gov.au/business-industry/partners-suppliers/documents/specifications/dc_3256.pdf

[Accessed 2022].