RECYCLED MATERIALS IN ROADS AND PAVEMENTS

A Guide for local councils

In partnership with

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Local Government NSW and Waste Transformation Research Hub,
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DISCLAIMER

TRANSITIONING LOCAL COUNCILS TO THE CIRCULAR ECONOMY

Local councils have the opportunity to utilise recycled materials in their roads and pavements, as part of the transition to the circular economy.

This is achieved through the application of the principle of "designing out waste" and maximising material resource value while in use (Ellen MacArthur Foundation, 2013).

In doing so, Councils will contribute to various United Nations Sustainable Development Goals and align with the principles of the 2018 National Waste Policy.

The growing circular solution, despite its multi-faceted complexities, will create new circular businesses in NSW impacting positively on the future of waste in NSW.

To help guide decision making in the transition to a circular economy, the NSW government has developed:

- "Too Good to Waste", a discussion paper on a circular economy approach for NSW (NSW EPA, Oct 2018); and
- NSW Circular Economy Policy Statement paper (NSW EPA, Feb 2019).

Figure 1 Depiction of a linear, recycling and circular economy
Image source: lowwastewellness.com

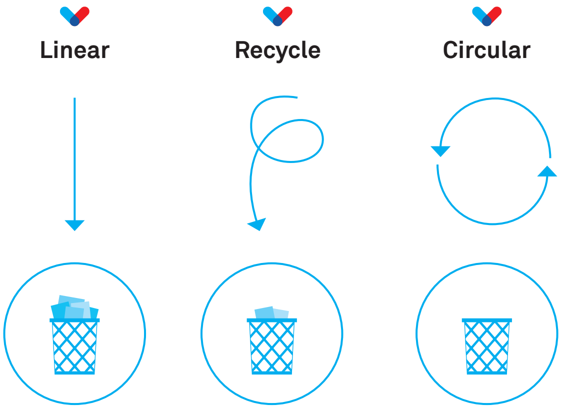
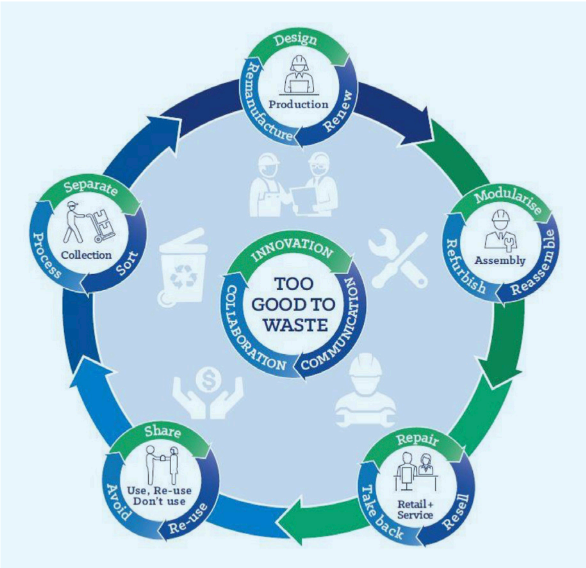


Figure 2 The circular economy life cycle
Image source: Too Good to waste discussion paper, pg. 15 (NSW EPA, Oct 2018)



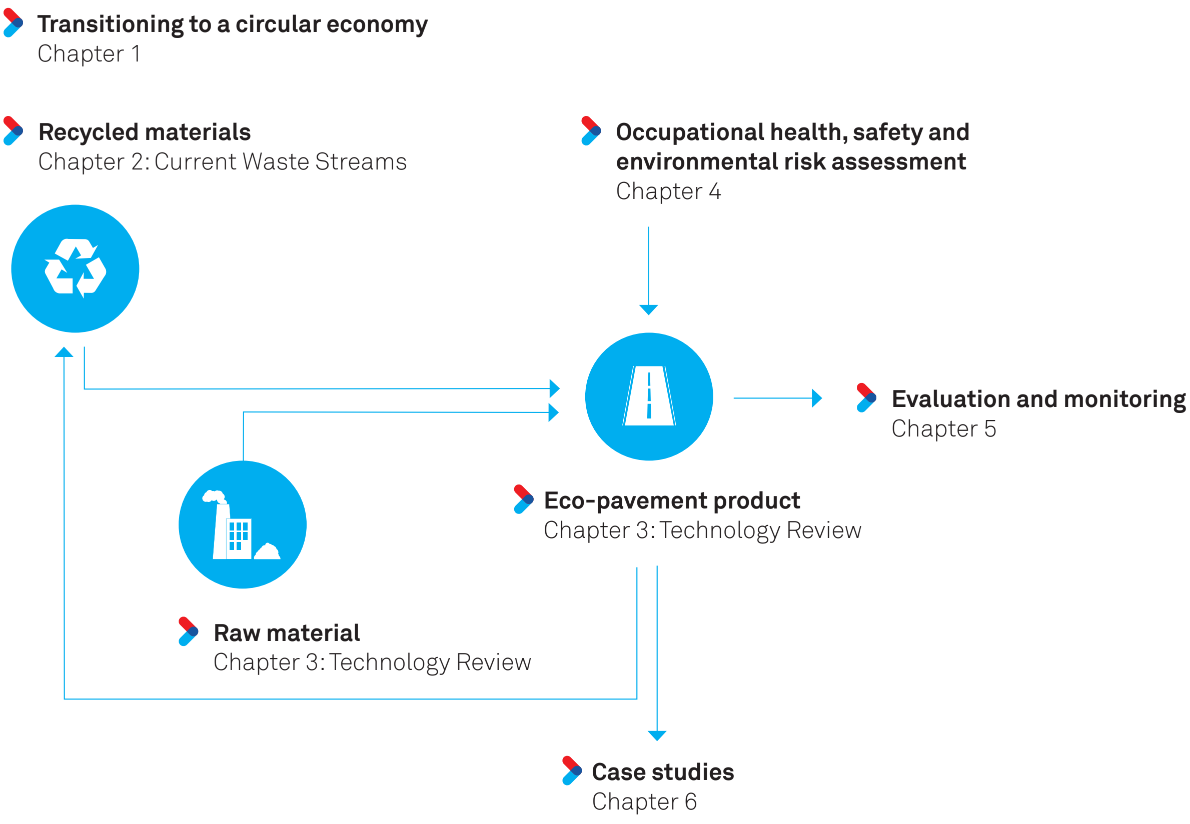
PURPOSE

LGNSW commissioned the Waste Transformation Research Hub (WTRH) at the University of Sydney to develop a Guide for the use of recycled materials in roads and pavements. The Guide attempts to address the concerns preventing the use of recycled materials by local councils and thus promote national uniformity and good practice in the specification and application of material reuse in roads and pavements by local council engineers. This Guide should be read together with the accompanying document, *Recycled Materials in Roads and Pavements- A Technical Review*, referred to as "Technical Review".

OVERVIEW

The figure below depicts the areas covered in the *Technical Review* and reference to the relevant chapters.

Figure 3 The flowchart of the Technical Review



BACKGROUND

At present, the increasing generation of waste is impacting the sustainability of our environment, society and the economy. In 2017–18, NSW generated 21.4 million tonnes of waste (equivalent to about 30% of Australia's overall waste generation), which is expected to grow to more than 31 million tonnes over the next 20 years (NSW DPIE, 2020). Analysis of current waste streams using key sources such as the National Waste Report 2018 and the National Waste Avoidance and Resource Recovery Strategy Progress Report 2017-18 (NSW EPA, 2019b), shows steady waste trends and the potential to increase utilisation of selected waste streams.

The incorporation of recycled materials into roads and pavements, using a circular economy approach, is an innovative opportunity to reduce the need for depleting virgin materials, increase diversion rates and contribute to creating end markets for recycled materials, as described in the 20-year Waste Strategy being developed for NSW (NSW DPIE, 2020). Despite increasing confidence in the technology, the wide-scale construction of roads and pavements with recycled materials still present a challenge due to various concerns such as product performance, safety risks and compliance.

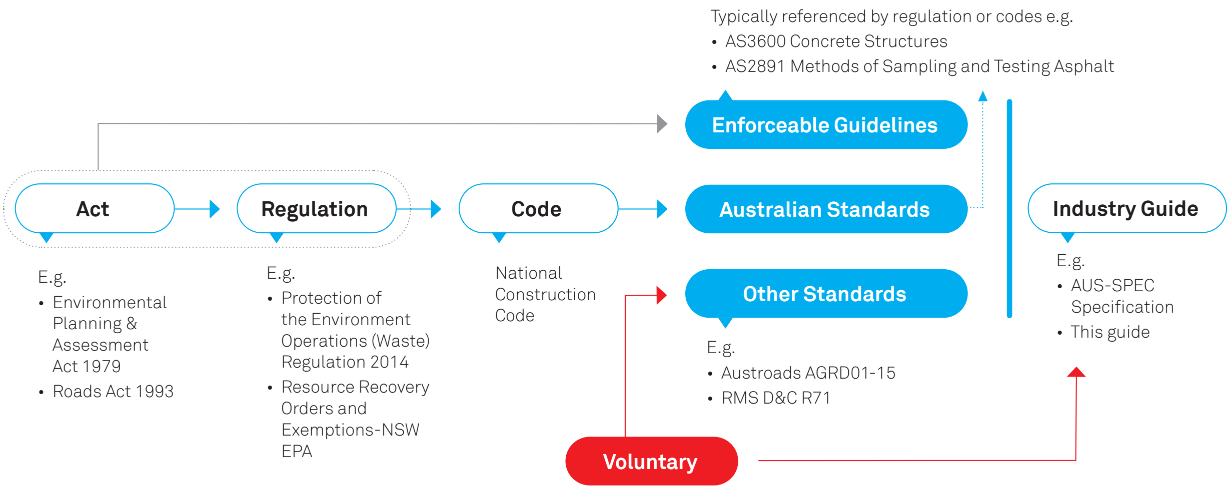
A report by NATSPEC (NATSPEC, 2019b), revealed that some councils especially in NSW are leaders in using waste-derived materials in roads and pavements, while other councils merely rely on the available natural resources with no policy in place to encourage the use of recycled materials.

HIERARCHY OF REGULATIONS AND STANDARDS

The sources of the regulations, codes, standards, guidelines, and specifications that are relevant to the construction of roads and pavements are complex in NSW. At the local council level, the National Construction Code, Australian Standards, RMS specification and NATSPEC specifications are all important technical references used in construction of roads and pavements. Chapter 5 of the Technical Review presents a detailed review of the regulatory documents available for evaluation and monitoring of reusable waste raw materials and final products (roads and pavements). A summary of these regulatory references is presented in this document as a quick guide into the "key implementation steps" in carrying out a recycled road/pavement project. Figure 4 (below) shows the hierarchy of construction guidelines and regulations that should be followed when executing a recycled road project:

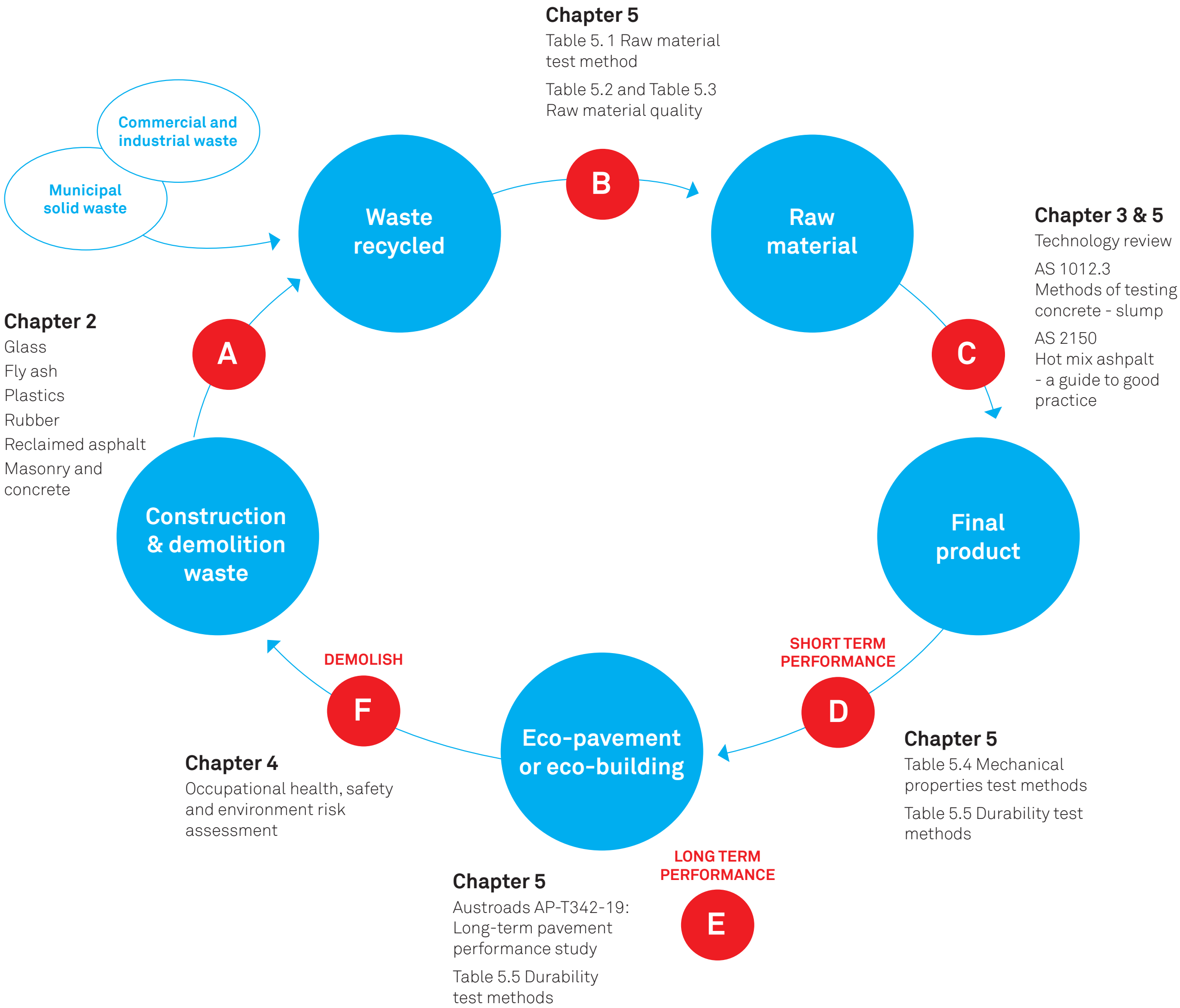
This Guide and the accompanying document (Technical Review) is an Industry Guide, which is a voluntary document in the hierarchy of the constructional legislation and therefore non-mandatory. Engineers and material suppliers are, however, encouraged to use the Guide and Technical Review as a reference document according to the flowchart of circular waste material reuse in Figure 5. The recommendations from the Guide and Technical Review are non-exhaustive and should be considered on a case-by-case basis.

Figure 4 Hierarchy of constructional legislation applicable in NSW



KEY IMPLEMENTATION STEPS

Figure 5 Loop of reused construction materials



Step A refers to the current waste streams of interest including glass, fly ash, plastics, rubber, reclaimed asphalt, and crushed rock, masonry and concrete which are thoroughly discussed in Chapter 2 of the Technical Review. They have been chosen due to their technical properties which make them suitable for incorporation into roads and pavements as supported by an increasing number of successful trials and case studies recently.

Step B refers to the assessment methods discussed in Chapter 5 applicable to the raw materials to define their classes (Class R1, Class R1, ...) and ensure their fitness for the intended applications (Road Base, Bedding, ...).

Step C refers to the considerations with regards to the compatibility of waste materials and their potential combinations in recycled roads and pavements in order to achieve the maximum quality. This information, along with the current technological advancements in preparing the final blends and test methods to assess their workability, are presented in Chapters 3 and 5 of the Technical Review.

Steps D and E refer to test methods for short-term and long-term performance evaluation and monitoring including mechanical properties, durability and toxicity of the final roads and pavements which are discussed in Chapter 5 of the Technical Review.

STEP B.
ASSESSMENT OF THE RAW MATERIALS

In order to safely promote the use of wastes in roads and pavements, the quality of recycled materials should not be inferior to the traditional ones. Like any type of virgin raw materials, waste-derived materials from different suppliers should possess uniform properties to ensure consistent properties in the final products. The material suppliers and engineers from both councils and the private sector may use the specifications summarised in Table 1 to test the waste raw materials.

Table 1 Raw material test method

Test method	Standard
Sampling and testing aggregates	AS 1141-1974 Methods for sampling and testing aggregates
Water absorption and apparent particle density	AS 1012.21-1999 (R2014) Methods of testing concrete determination of water absorption and apparent volume of permeable voids in hardened concrete
Particle density of fine aggregate	AS 1141.5-2000 (R2016) Methods for sampling and testing aggregates Particle density and water absorption of fine aggregate
Particle density and water absorption of coarse aggregate	AS 1141.6.2-1996 (R2016) Methods for sampling and testing of aggregates Particle density and water absorption of coarse aggregate - Pycnometer method
Grading of aggregates	AS 1141.11.1-2009 Methods for sampling and testing aggregates Particle size distribution - Sieving method
Organic impurities	AS 1141.34:2018 Methods for sampling and testing aggregates Organic impurities other than sugar
Sugar impurities	AS 1141.35-2007 Methods for sampling and testing aggregates Sugar
Fine particle size distribution	AS 1141.19:2018 Methods for sampling and testing aggregates Fine particle size distribution in road materials by sieving and decantation
Particle distribution of road aggregates by washing	RMS Test method T201 Particle distribution of aggregates (by washing)

The recycled materials used in roads and pavements need to strictly comply with the legislations governing material reuse. *Resource recovery orders and exemptions* allow some wastes to be safely reused independent of the NSW laws controlling applying waste to land (NSW EPA, 2019a). The general provisions relating to exemptions are specified in clause 91 of the Protection of the Environment Operations (Waste) Regulation 2014; and the exemptions relating to resource recovery in clause 92.

All sampling and testing requirements included in an order and exemption must be met, for the reuse of the resource recovery waste to be lawful (NSW EPA, 2019a). It should be noted that this is in addition to the testing requirements previously mentioned for the supplied raw materials. Several recovered waste materials such as recovered aggregate have current orders and exemptions approved for use by everyone. These are provided on the EPA website: www.epa.nsw.gov.au/your-environment/recycling-and-reuse/resource-recovery-framework/current-orders-and-exemption.

For materials that do not have a current order and exemption, but could still be used in roads and pavements, it is possible to apply to the EPA for an exemption (NSW EPA, 2019a). It is expected that these application and approval processes may take months, and planning ahead for these approvals is warranted. See Chapter 5 of the *Technical Review* for further details. It is the responsibility of the user of the guide, to always refer to the latest information and guidelines (NSW EPA, 2017) provided by NSW EPA.

STEP C.
PRODUCING FINAL PRODUCT

For the development of concrete and asphalt products using recycled materials, factors such as the compatibility of material properties should be considered. Further guidance for specifying recycled materials for road works using AUS-SPEC, is provided in Technote GEN 028 (NATSPEC, 2019a). Product combinations covered in the *Technical Review*, include:

- Using fly ash in concrete as a replacement of cement
- Using fly ash in asphalt as replacement of common filler
- Rubber concrete
- Concrete with recycled glass
- Concrete with recycled plastic waste
- Asphalt with recycled rubber
- Asphalt with recycled glass
- Using waste plastic in road construction
- Alternative materials as binder in asphalt
- Other recycled materials (reclaimed asphalt, waste toner, coal-fired bottom ash).

By understanding the fundamental technology used, the sustainability of roads and pavements can be improved. The interaction between wastes is also an important consideration to maximise recycled material utilisation, whilst ensuring strength and performance are not compromised. For several recommendations of recycled material percentage compositions there are various trials and studies in literature, see Table 3.3 and Table 3.4 of the *Technical Review*. Refer to *AUS-SPEC Case studies and Technical information*, for further information and detailed examples demonstrating the use of AUS-SPEC specification system, which is an important technical reference for local government infrastructure works (NATSPEC and IPWEA, 2019).

The slump test result (AS 1012.3.1) indicates the ease with which concrete can be transported and consolidated. However, there is no defined test for the workability of asphalt, according to a report from the Australian Asphalt Pavement Association (AAPA). The material suppliers may refer to experienced council engineers for advice. The major factors influencing the workability of asphalt are:

- Binder viscosity
- Binder content
- Filler type and content
- Nominal size of the mix
- Aggregate grading
- Aggregate shape
- The temperature of placing.

STEP D.
SHORT-TERM PERFORMANCE EVALUATION AND MONITORING

With a good quality control of the raw material, the property of the final product should be consistent. The quality control of final product is shown in Stage D & E of the Figure 5. Based on the standard test methods, the following properties should be assessed to ensure the short-term performance of the final products:

- Workability
- Compressive strength
- Elastic modulus
- Shrinkage
- Bitumen viscosity
- Bitumen content
- Resilient modulus of asphalt
- Other material properties

Table 2 (overleaf) summarises the relevant test methods for short-term performance assessment. The detailed procedure can be found in the corresponding documents.

In addition to the conventional tests, the toxicity assessment on the final products should be conducted before using the construction material in large-scale projects. The toxicity characteristic leaching procedure (TCLP) should be conducted according to AS 4439.3. Hazardous substances that may be found in the recycled construction materials include, but are not limited to, copper, cadmium, mercury, arsenic, and lead. Unless proven to be safe by this experiment, these harmful substances may leach out from the solidified product with an irreversible detrimental impact on the environment.

Table 2 Short-term performance test method

Test method	Standard
Shrinkage	AS 1012.13:2015 Methods of testing concrete determination of the drying shrinkage of concrete for samples prepared in the field or in the laboratory
Unconfined compressive strength	AS 1141.51-1996 Methods for sampling and testing aggregates unconfined compressive strength of compacted materials
Methods of testing bitumen and related roadmaking products	AS 2341 Methods of testing bitumen and related roadmaking products
Viscosity by flow through vacuum capillary tubes	AS/NZS 2341.2:2015 Methods of testing bitumen and related roadmaking products
Methods of sampling and testing asphalt	Australian Standard 2891 Methods of Sampling and Testing Asphalt
Bitumen content	AS/NZS 2891.3.1:2013 Methods of sampling and testing asphalt binder content and aggregate grading - Reflux method
Resilient modulus of asphalt	AS/NZS 2891.13.1:2013 Methods of sampling and testing asphalt determination of the resilient modulus of asphalt-indirect tensile method
Methods for the preparation and testing of stabilised materials	AS 5101 Methods for the preparation and testing of stabilised materials
Cement content	AS 5101.3.3-2008 (R2017) Methods for preparation and testing of stabilized materials Cement content of cement stabilized materials
Soil treatment	AS1289 Method of Testing of Soil for Engineering Purposes
Compaction pretreatment	RTA T102 Pretreatment of Road Materials by Compaction
Road material compressive strength	RTA T151 - Determination of absorption and compressive strength of road materials stabilised or modified with bituminous materials
Road material dry compressive strength	RTA T114 Maximum Dry Compressive Strength of Road Materials
Shrinkage of road material	RTA T113 Linear shrinkage of road construction materials
Road material compressive strength	RTA T116 Determination of Unconfined Compressive Strength of Remoulded Road Materials which are Self Cementing
Foreign material for road	RTA T276 Foreign Material Content of Recycled Crushed Concrete

STEP E.
LONG-TERM PERFORMANCE EVALUATION AND MONITORING

The recycled roads and pavements should retain their functionalities, without extra maintenance and repair, over the design lifetime. Table 3 lists recommended test methods that may be used by the engineers for long-term performance assessment of the final product. Relevant experimental details can be found in the corresponding Australian Standards, Roads and Maritime Services and ASTM International.

Table 3 Long-term performance test method

Test method	Standard
Resilience of the asphalt	AS 2891.13.1-1995 Determination of the resilient modulus of asphalt- Indirect tensile method
Artificial weathering pretreatment	RMS T103 Pretreatment of Road Materials by Artificial Weathering
Wetting and drying test	ASTM D4843 Standard Test Method for Wetting and Drying Test of Solid Wastes
Resistance to freezing and thawing	ASTM D4842 Standard Test Method for Determining the Resistance of Solid Wastes to Freezing and Thawing
Durability of cement stabilised material	RMS T133 Durability of road materials modified or stabilised by the addition of cement

The long-term performance of pavement, including deflection, roughness, rutting and cracking, are important control factors for road asset management. The Accelerated Loading Facility (ALF) test has been used by some local councils in Australia as an alternative test method to the actual Long Term Pavement Performance (LTPP) test. Although the ALF test method has been widely used for a small segment of the pavement, no standard test method for a large area (road network) has been previously reported by local council engineers.

The comprehensive pavement condition assessment of the road network is essential to evaluate its long-term performance. Some innovative large-area pavement test methods reported in the peer-reviewed technical journal papers could be used as the reference. For the convenience of local council engineers and other stakeholders, the Guide has selected some large-area pavement test methods proposed by researchers from China, Europe and the United States.

OTHER SPECIFICATIONS

The previous sections mainly focus on the Australian Standards which are national-wide. Some local council engineers in NSW may use other specifications from RMS, NATSPEC and Austroads. Table 4 lists some important specifications which are relevant to the recycled materials. It is the responsibility of the engineers to select the specification in the design stage.

Table 4 Other relevant specifications applied to the use of recycled materials in roads/pavements

Publisher	Specification
RMS	3153 - Reclaimed asphalt pavement material
	3154 - Granulated glass aggregate
	3204 - Preformed Joint Fillers for Concrete Road Pavements and Structures
	3252 - Polymer Modified Binder for Pavements
	3253 - Bitumen for Pavements
	3268 - Aggregate precoating agent (for polymer modified binder)
	R118 - Crumb Rubber Asphalt
NATSPEC	0053 Rural pavement design – sealed
	0054 Rural pavement design – unsealed
	0173 Environmental management
	1113 Stabilisation
	1144 ASPHALT (ROADWAYS)
	1141 Flexible pavement base and subbase
Austroads	ATS-5330-20 Supply of Geopolymer Concrete
	ATS-5380-20 Fibre Reinforced Polymer Composite Strengthening
	ATS-3110-20 Supply of Polymer Modified Binders
	AGPT-T142-20 Rubber Content of Crumb Rubber Modified Bitumen: Soxhlet Method
	AGPT Guide to pavement technology

OCCUPATIONAL HEALTH, SAFETY AND ENVIRONMENT RISK ASSESSMENT

This section aims to address the concerns raised by various stakeholders regarding the occupational health, safety and environment (OHSE) issues relating to the use of recycled wastes in roads/pavements. Table 5 below summarises the key points discussed in the literature and various trials as an attempt to respond to these common concerns followed by recommendation to mitigate the risk. See Chapter 4 of the *Technical Review* for the detailed discussion.

Table 5 Summary of the OHSE related issues regarding the use of recycled wastes in roads/pavements

Recycled material	OHSE concerns	Findings from literature/trials	Recommendations
Recycled crushed glass (RCG)	• abrasiveness of crushed glass • respiratory hazards due to carcinogenic crystalline silica • leaching of the chemicals present in RCG	• RCG contains amorphous silica with no carcinogenic properties • RCG is in fact much safer that sand • RCG particles below 19mm impose no greater skin cut hazards than other typical construction aggregates • Glass particles less than 6mm can be considered as completely benign • chemical leaching to the levels commonly found for natural soils (Department of Environment and Climate Change NSW, 2007, Shin and Sonntag, 1994, Winder, 2011)	Take protective measures commonly used for other natural crushed aggregates as well as those specified in the Material Safety Data Sheets (MSDS) of crushed glass
Fly ash (FA) and recycled concrete aggregates (RCA)	Toxicity risks arising from the potential leaching of the heavy metals	• no detectable concentrations of heavy metals released from well-cured cement mortars from natural aggregates and RCA from construction and demolition(C&D) waste (Barbudo et al., 2012, Hillier et al., 1999, Kurda et al., 2018) • locking the FA in a well-cured concrete significantly decreases the concentration of released heavy metals below the threshold levels defined by EPA drinking water standard (Shirazi and Marandi, 2012, Siong and Cheong, 2003, Kurda et al., 2018) • Life cycle assessment (LCA) showed higher CO2 emissions reduction for FA compared to RCA (Kurda et al., 2018)	• Ensure the concrete is properly cured to avoid leaching the heavy metals • Take protective measures when handling FA and RCA according to Material Safety Data Sheets (MSDS) of FA and Portland cement
Recycled plastics	• toxic emissions during the melting process • generating microplastics	• no difference in the fumes generated from normal bitumen and those from recycled plastics (White, 2019) • no hazardous chemicals leaching out from bituminous binders with and without recycled plastics (White, 2019) • melting the recycled plastics and mixing it with the bituminous binder would prevent the plastics to leach out as microplastics (Sustainability Victoria, July 2018) • the OHSE risks cannot be dismissed completely (AUSTROADS 2019b)	Melting the recycled plastics and mixing it with the bitumen is likely to mitigate the risk of microplastics leaching. However, as stated by Austroads (AUSTROADS 2019b) using plastics in roads in Australia and New Zealand is a relatively new development with limited field testing. Without extensive research and long-term environmental impact assessments such projects should be approached with precautionary measures.

CASE STUDIES

An increasing number of studies and trials have demonstrated the successful use of recycled materials into roads and pavements, using features of a circular economy approach. Case studies of these projects provide a reference for conducting projects at your local council. In the *Technical Review*, three case studies have been selected to illustrate how such eco-pavement projects are evolving:

- University of Sydney-Delta Electricity Project (Small scale pavement for footpaths) for light load
- Downer asphalt trials (Large scale application) for heavy vehicle load
- City of Sydney-UNSW Geopolymer road trial utilising fly ash

Details of the University of Sydney-Delta Project are summarised below as an example.

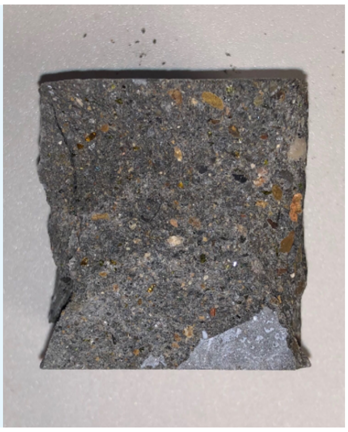
It is recognized that circumstances vary from council to council, which may be outside the scope of the chosen projects. For example, councils may differ in their type of roads (e.g. regional/rural or metro roads); and the source of recycled material they have access to (e.g. local or external supply), which affect factors such as procurement and cost. Thus, it is important to consider these features unique to one's local council and the nature of their roads, when using case studies as reference.

Examples of recycled material case studies in public work projects including regional council projects are provided by IPWEA (NSW) Roads and Transport Directorate in the *Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage 2010* (Savage, 2010). Specifically, case studies demonstrating the use of recycled glass can be found at www.roadsdirectorate.org.au/glass-recycling-information. These include examples from various local councils across Australia and provide details of aspects such as costing in their projects. Case studies from both references highlight considerable cost savings from using recycled material in their roads compared to virgin material.

Figure 6 Photograph of an eco-concrete sample, after 7 days compressive strength testing

Example: *University of Sydney-Delta Electricity Project (Small scale pavement footpaths) for light load*

This case study is the "Upcycling of power plant fly ash into low-carbon engineered eco-pavements", carried out by the Waste Transformation Hub at the University of Sydney in partnership with Delta Electricity. Carbonated fly ash and mixed ground waste glass were incorporated into concrete (Figure 6), with the final product exceeding the minimum compressive strength criteria for footpath applications (i.e. greater than 20MPa at 28 days). Trials are currently being conducted on selected areas of the university campus.



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