Recycled Materials in Road Pavement Infrastructure:

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Introduction

In Australia, significant advances have been made in the manufacture of road making materials from industrial and demolition wastes such that industry now manufactures significant large volumes to compete in the road infrastructure market. However the adoption of such products has been restricted by the necessity to comply with traditional material specifications developed for crushed quarry materials and attempts to meet inappropriate environment contaminant requirements. As a result, recycled materials are generally not recognised in the same sense as quarried materials, being often considered as inferior in performance and posing health and environment risks in their application.

This paper outlines issues associated with the general perception of the performance of recycled materials when compared against traditional virgin quarried materials. The paper details the basis upon which traditional pavement specifications were developed and presents a new approach (based upon the first principles of performance based attributes) to facilitate the seamless acceptance of recycled materials into the road infrastructure industry. Example product developments to meet market needs in South Australia are also illustrated.

A Strategy for Introducing New Products

Figure 1 shows a strategy for pavement material product development. In the development and launch of any new road-making material, it is necessary to firstly identify the market where the product could be applied and then prove its performance. From this the commercial and technical viability can be translated into developing specifications for its manufacture and test plans that ensure its continued compliance. At this stage customer acceptance will generally be provided by compliance and trials to prove performance in specific applications.

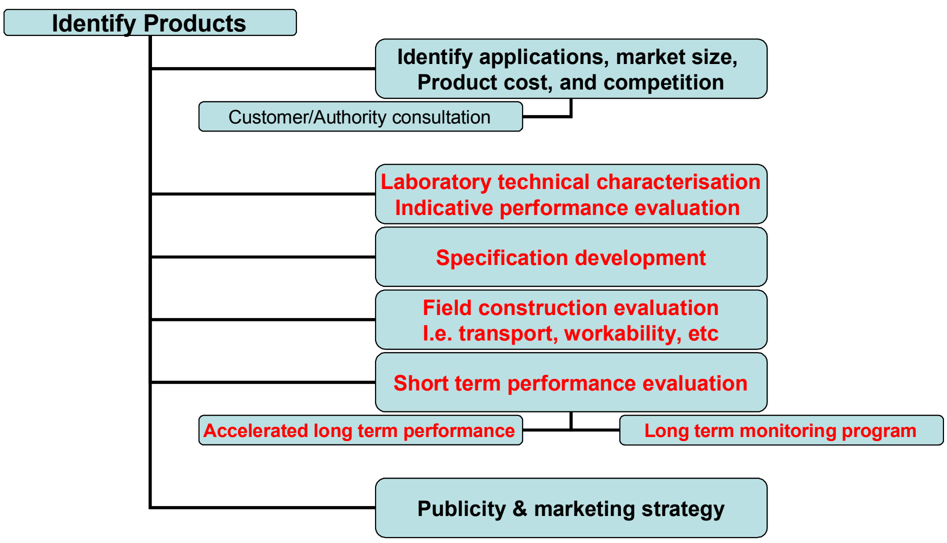


Figure 1: Strategy for pavement material product development

Roadbase Specifications

Traditional material specifications for quarried materials have been developed in an empirical manner over many years centering on product manufactured properties of: particle size distribution, plasticity and hardness.

Particle Size Distribution

The strength of a granular material is derived solely from mechanical interlock of particles throughout the particle size spectrum and is often referred to as the "maximum density grading principal" in which successively smaller-sized particles fit into the remaining voids space, thereby reducing the void space (maximizing density) to a minimum.

In addition, workability and compactablity can be controlled through the use of a material having a suitable grading and plasticity (and moisture control during compaction).

The maximum density grading can be expressed by the following equation:

$$P = 100\left[\frac{d}{D}\right]^{n}$$

where P = % passing sieve of aperture size 'd',

D = maximum particle size (mm), and

N = grading constant (slope of grading curve).

Plasticity

The plasticity of crushed rocks is limited to provide volume stability in terms of limiting volume expansion of the clay fractions due to wetting and drying in addition to requirements for applying a bituminous seal.

Rock Hardness

The hardness of the aggregate stone is measured by either a resistance to crushing or abrasion. Sufficient hardness is required to resist particle breakdown under wheel loading and provide durability over the life of the pavement.

A typical specification is shown in *Table 1*. These specifications make the assumption that conformance will assure these pavement performance attributes independent of the type of source rock or the environment in which it is applied.

A Performance Approach to Pavement Material Specifications

Whilst traditional specifications have provided materials which have exhibited satisfactory performance, modern traffic loads are very quickly revealing the structural inadequacy of some conforming materials by rutting within the pavement layers, rapid development of surface roughness and low skid resistance due to aggregate penetration into a granular basecourse.

Since 1990, Austroads, in association with various industry groups, have undertaken extensive research into development of performance related testing of pavement materials supported by full scale accelerated loading tests. The outcomes of this research have been the development of laboratory tests which identify the structural capacity of a pavement material, its durability and its predicted performance.

Determination of Performance Attributes Using Resilient Modulus Test

The resilient modulus test developed to determine both resilient modulus-stress relationships and permanent deformation-stress relationships is detailed in AS1289.6.8.1. This test provides both parameters for the structural design of road pavements and also allows some predictions of long term performance in terms of vertical deformation in wheel paths to be determined.

Table 1: Typical Specification for Crushed Rock Pavement Materials

TEST PROCEDURE	MANUFACTURING TOLERANCE [GRADING BASED]			
QUALITY CONTROL TESTS				
Particle Size Distribution TP134	**Product**	**20 mm Class 2 PM 2/20QG**	**30 mm Class 2 PM 2/30QG**	**40 mm Class 2 PM 2/40QG**
	Sieve Size (mm)	Percent Passing		
	53			100
	37.5		100	90-100
	26.5	100	90-100	74-96
	19	90-100	77-95	62-86
	13.2	74-96		
	9.5	61-85	51-75	42-66
	4.75	42-66	35-57	28-50
	2.36	28-50	24-44	20-39
	0.425	11-27	9-22	8-21
	0.075	4-14	4-12	3-11
AS 1289.3.1.2	Liquid Limit	Maximum 28%		
AS 1289.3.3.1	Plasticity Index	Minimum 1% - Maximum 8%		
AS 1289.3.4.1	Linear Shrinkage	Maximum 4%		
AS 1141.23	LA Abrasion Grading 'A'	N.A.	N.A.	Maximum 45%
AS 1141.23	LA Abrasion Grading 'B'	Maximum 45%	Maximum 45%	N.A.

The apparatus is shown in *Figure 2*. Using the results of this test, a resilient modulus (how strong the material is) and a permanent deformation (long term deformation) characteristic are defined.

Figure 2: Laboratory dynamic testing of pavement materials

A comparison of the characteristics of the properties of recycled materials with a large range of quarry materials available throughout South Australia is shown in *Figures 3* and *4*.

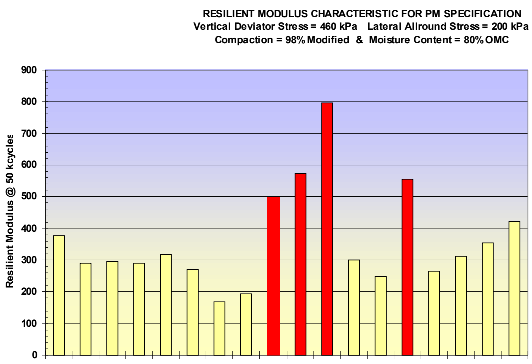


Figure 3: Modulus of recycled and quarry materials

This testing illustrates that the characteristics of recycled materials tested in this performance environment are on a par with, or exceed, those attributes associated with traditional materials.

Determination of Performance Attributes Using the Laboratory Wheel Tracking Test

In addition to the resilient modulus test, the deformation behaviour of pavements can also be modelled in the laboratory using a wheel tracking machine (*Figure 4*). Typical results are shown in *Figure 5*.

Figure 4: Laboratory wheel tracking for deformation characteristics

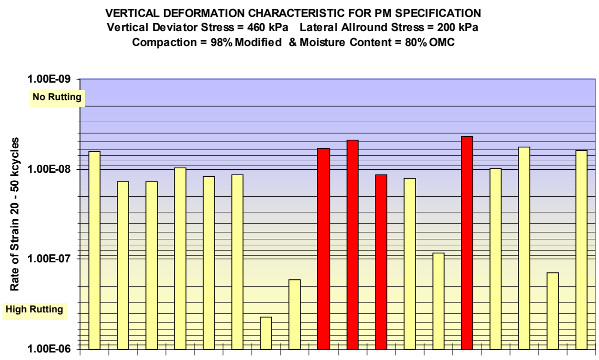


Figure 5: Resistance to deformation determined using the wheel tracking test

Determination of Performance Attributes Using the Accelerated Loading Test

The Accelerated Loading Facility (ALF) is a mobile full scale, road test system which enables pavement performance to be assessed within a short time scale (*Figure 6*). Rolling wheel loads are applied in one direction to pavement test strips 12 m long at a constant speed of 20 km/h. The dual-wheel half-axle load can be channelled or applied over any transverse distribution of load up to 1.2 m width. The ALF can apply approximately 370 load cycles per hour or about 50,000 cycles per week based on 22 hours per day operation. Axle loads can vary from the standard 8.2 tonne load (40 kN on the ALF half axle) up to twice this figure (80 kN on ALF the half axle).

Uniform test sections of each basecourse material to be tested are constructed and surfaced using normal construction equipment. The design of these pavements would be based on the earlier laboratory characterisation, experience with the field trial construction and the desired trafficking life. A series of pavement performance measures such as deformation would be defined, together with an end of life criteria, usually in terms of deformation.

Figure 6: ARRB Transport Research Accelerated Loading Facility

Examples of the use of accelerated pavement testing to examine the performance of pavements incorporating recycled materials include:

- cement-stabilised fly ash pavements for local roads – Pacific Power, NSW (Jameson *et al.* 1996)
- deep lift insitu recycled highway pavements, Cooma NSW (Jameson *et al.* 1995)

Using this type of performance testing, new performance based specifications can be developed by Road Authorities which are better placed to deliver high quality pavements suited to modern traffic.

Environmental Compliance for Recycled Materials

In terms of recycled materials, one of the most difficult assessments as to its suitability as fit for purpose is associated with the identification of contaminants and their release into the environment. The main legislation and guidelines relating to tolerable levels of contamination are those associated with general landfill requirements. In addition, the determination of contaminant levels in recycled materials is not defined and a National standard test which identifies long term leachability does not exist.

The 2001 Transport SA adopted the Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites (ANZECC 1992) as its specification. However, a more recent (1999) National Guideline of the National Environment Protection Council (NEPC), viz: *Guideline on the Investigation Levels for Soil and Groundwater Schedule B(1)*, has since been released. The extremes of categories quoted in this document are (Table 5A):

Type A: "Standard residential……..i.e. includes children's day-care centres, etc".

Type F "Commercial/industrial includes shops offices, etc.

In terms of the substances listed in the Transport SA specification (Clause 3.7 Table 2 ANZECC guidelines), the acceptable levels for Type A and Type F applications for the NEPC Guideline are listed in *Table 2*.

Performance and Environment Based Specifications

In recognition of the fact that the performance evaluation of pavement materials may not be solely governed by traditional empirical attributes, in 2001 TSA introduced new specifications for pavement materials which, in addition to the traditional specification (grading based), provided alternate accreditation (mix design) via performance-related testing from which source-specific values of traditional parameters (grading, plasticity and LA abrasion) were assigned.

Table 2: Comparison of Permissible Contaminant Levels

Substance	ANZECC (1992) Maximum Value mg/kg (dry mass)	NEPC (1999) Type A Maximum Value mg/kg (dry mass)	NEPC (1999) Type F Maximum Value mg/kg (dry mass)
Arsenic	20	100	500
Cadmium	3	20	100
Cobalt	170	100	500
Chromium III & VI	50	100	500
Copper	60	1000	5000
Lead	300	300	1500
Nickel	60	600	3000
Zinc	200	7000	35000
Poly Aromatic Hydrocarbons	5	20	100
Petroleum Hydrocarbons C6-C9	65		
Petroleum Hydrocarbons >C9	1000	5690	28450

These TSA specifications were developed based on the outcomes of TSA research on the laboratory performance characterisation of South Australian crushed rocks, Austroads projects associated with laboratory dynamic load testing equipment development, and testing protocols for performance characterisation. In addition, cognisance was taken of international research programs, particularly the European Community Cooperative Research Projects (i.e. European Commission DGVll 4th Framework program):

- COST 337 Improved Use of Granular Materials
- COURAGE Construction with Unbound Road Aggregates in Europe
- ALTMAT Alternative Materials in Road Construction (Recycling)

The performance and environmental attributes associated with a performance based specification are shown in *Table 3*.

Table 3: Performance and Environment Specification Attributes

TSA TP183	Resilient Modulus	Minimum 300 MPa
TSA TP183	Deformation	Maximum 10^{-8}
AS 1141.23	LA Abrasion Grading 'B'	Supplier Nominated Value
TSA TP184	Triaxial Compression	Cohesion Max 150 kPa, Friction Angle Min 45^0
	Contaminants	NEPC Guideline
RTA T276	Type II Foreign Materials	Maximum 1%
RTA T276	Type III Foreign Materials excluding bitumen	Maximum 0.5%
TP470	Bitumen Content	Maximum 1%

Whilst these new specifications have been developed by Transport SA, and it was anticipated that they would provide a broad range of material sources across the State (including recycled materials), there remain some reservations about their unilateral use in terms of changing customer perception.

Resource NSW has recently developed a specification for recycled materials for pavements, earthworks and drainage. This specification only addresses the engineering attributes and is based upon the traditional parameters associated with quarry materials.

Recycled Materials Perceptions

The same acceptance framework applies for products originating from recycled material sources but with the addition of environment contamination criterion extrapolated from landfill requirements.

In general it has been found that recycled products manufactured from demolition waste and waste road materials fail to comply with the highest quality prescriptive requirements and therefore their application is limited to lower pavement layers and light traffic situations.

From an environment point of view, recycled materials are not permitted in a number of domestic circumstances and the contaminants associated with asphalt waste are prohibitive for clean landfill requirements.

In terms of performance, customer issues associated with demolition wastes are as follows:

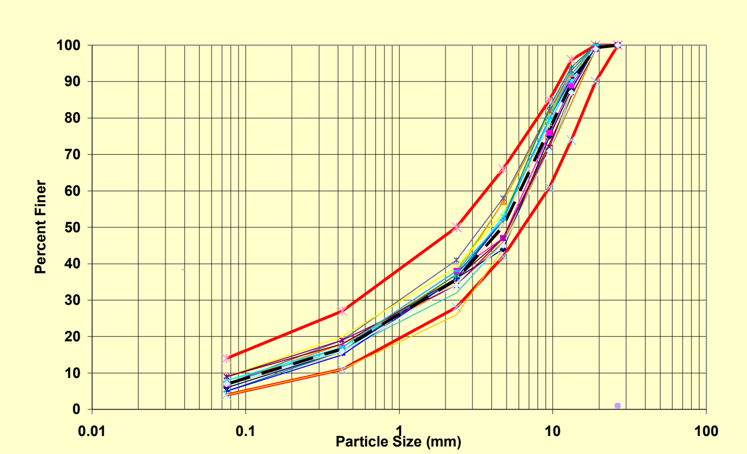
- Products generally meet traditional Class 2 requirements and therefore the customer limits its use. In contrast, limited (to date) research suggests that demolition recycled materials have equivalent or higher performance based attributes. This put recycling companies at a distinct disadvantage in not being able to be a single supplier of pavement material to contracts.
- With demolition concrete there is concern over the latent cementation that may occur over time, which causes the pavement to develop shrinkage cracking which reflects through the bituminous seal surfacing.
- The contaminant levels in recycled materials present an unacceptable risk in a lot of circumstances.
- Presence of acid salts can give rise to bituminous sealing issues

Manufacturing variability

Of concern also is the variability of the incoming source material (Figure 7) for processing and the consequential perceived inability to supply a consistently complying product.

Figure 7: Stockpile of incoming source material for recycling

In contrast, Figure 8 illustrates that, with proper stockpile management and processing, a uniform product can be manufactured consistently.



PI = 3.0 +/- 0.5 LA = 40 +/- 1.7

Figure 8: Recycled material production compliance over 24 months

Bituminous sealing

The presence of deleterious material in the form of sulphide mineralisation which oxidises when exposed to the atmosphere forms deleterious and highly soluble acid salts. Extensive rust-staining of sprayed bituminous surfacing and thin asphalt as well as destruction by cracking and blistering of thin asphalt surfacing has been observed.

Figure 9 Surface blistering

Measures are underway to control the pH of the product by the addition of and alkali in the water during the manufacture of wet mix products in the pugmill

Example Products - Resourceco (SA) Bitumix/Bitumate

Bitumix is a product being developed by Resourceco. It comprises recycled road material (Bitumate) and a specially formulated bitumen emulsion. The product provides all the advantages of a stabilised pavement layer and in some situations a pavement surfacing.

An intensive laboratory testing program using the repeated load apparatus described earlier was adopted to develop a suitable formulation followed by field trials and performance evaluation. From the testing a specification and technical fact sheet was developed for all products identified in the strategy.

The results of the preliminary laboratory characterisation undertaken are shown in *Figure 10*. An initial field trial was undertaken at Tanunda and the strength evaluated using modern road measurement equipment (Falling Weight Deflectometer). The test site and typical results are shown in *Figure 11*.

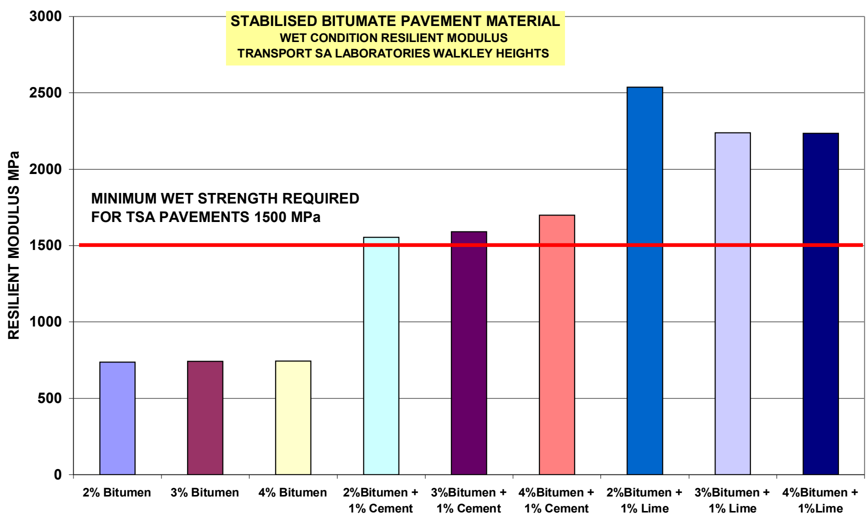


Figure 10: Results of Bitumix laboratory characterisation

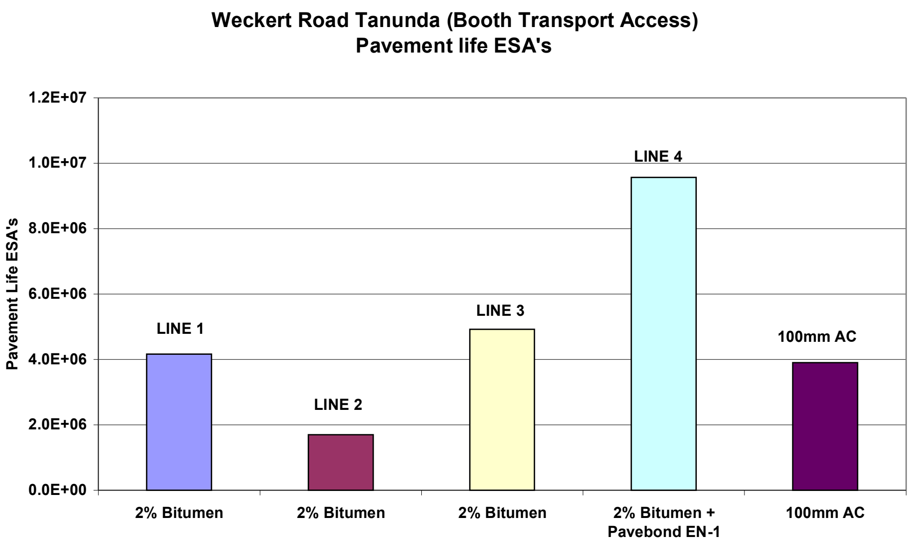


Figure 11: Tanunda field trial of Bitumix and FWD post construction analysis

To evaluate the potential leaching of contaminants to the environment, chemical analyses of both the Bitumate itself and the residual leachate test (AS4439.3) were undertaken. These results, including a comparison to category F of the NEPC guidelines are shown in *Table 4*.

Table 4 Leachate Analysis of Bitumate

Substance	Type F Limits Maximum Value (mg/kg)	Typical Bitumate Leachate Analysis
Arsenic	500	5.4
Cadmium	100	<1.0
Cobalt	500	3.4
Chromium III & VI	500	14
Copper	5000	10
Lead	1500	18
Nickel	3000	5.1
Zinc	35000	35
Poly Aromatic Hydrocarbons	100	55
Petroleum Hydrocarbons	450	<20

Whilst compliance requirements were met it is considered that further research is required to develop an accelerated test to determine the long term leachate potential.

Having proved the success of this initial trial, larger projects have been completed and further applications are being explored with potential customers (for example, see *Figure 12*).

Figure 12 Bulk grain storage facility floor application

Major Project

The $100 million Port River Expressway project (stage 1 recently completed) involved the incorporation of over 200 000 tonnes of 75 mm crushed product as a foundation layer to support a dual carriageway embankment and 150 000 tonnes of cement treated pavement material as a cement treated base supporting 185 mm of asphalt layers.

Preliminary trials of required cement content were undertaken on the premise that latent cement in the recycled product would realise lower cement content to achieve UCS = 5.0 MPa, however this was not the case with an additional 0.5% being required.

Manufacture of the crushed product occurred over two years with variation no different to that of traditional natural sourced quarry materials. QA testing of cement content required modification to sampling and testing procedures to obtain consistent results.

Figure 13 Paver laying CTB

Because of the close proximity of the manufacturing site to the project and the lower cost of the raw crushed product, significant savings were incurred with no compromise on quality or expected performance.

Penrice Quarry & Mineral

Penrice Soda Products are the largest manufacturer of soda ash in Australasia and quarries limestone from Angaston, hauling it by rail some 80 kms to Adelaide for processing. 100mm spalls are burnt to produce soda ash with over 100,000 tonnes of fine silt ($CaC0_3$ and CaOH) and sand sized (grit) material being generated as waste which is currently stored on vacant land or sold as an agricultural lime for soil conditioning.

In determining uses it was recognised that some cementation occurs when compacted however on its own silt cannot be recycled for any reasonable purpose.

Product identification included blending silt and grit to produce CALGRIT as an engineering fill material with a CBR in excess of 15% and also blending with 40mm and 20mm quarry products to produce a modified (stabilised) sheeting material for unsealed roads with low dust emissions and surface stability.

Geotechnical and environmental investigations were undertaken in association with manufacturing methodologies including construction and detailed monitoring of trial embankments and sheeting of unsealed roads. Calgrit was found to be best manufactured using a Bomag recycler mixing equal layers of silt and grit prior to stockpiling in readiness for sale. Sheeting material is mixed in the pugmill at the quarry made to order and distributed to local councils as part of their re-sheeting program

Specification development including inspection and test plans were developed such that the products are now in the early stages of impinging on the infrastructure market.

CALGRIT trials and mixing (left) unsealed sheeting (right)

Conclusions

This paper has described the technical background to the manufacture and approval of crushed pavement materials, with specific reference to recycled materials. The objective of the paper has been to promote a process by which the acceptance of recycled pavement materials can be enhanced to meet customer expectations and realise all the advantages recycling strategies have to offer.

Acknowledgements

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