THE USE OF RECYCLED MATERIALS FOR PAVEMENTS IN WESTERN AUSTRALIA

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ABSTRACT

There have been a number of innovations and developments in Western Australia in recent years on the use of recycled materials in road pavement construction. Materials used or being researched include demolition materials (concrete, bricks and tiles), asphalt millings, existing granular pavement material, scrap rubber, glass, plastic and vitrified clay pipe. There are sound environmental reasons for making use of recycled materials. In terms of cost, savings in landfill fees are a significant factor. In some cases, the addition of recycled material to standard road pavement materials such as bitumen and asphaltic concrete results in an improvement in properties. A key objective of this paper is to facilitate the wider adoption of the use of recycled materials in road pavement construction. This document was produced by a working group from the Western Australian Pavements Group (a subcommittee of Australian Geomechanics Society comprising Consultants, Main Roads WA, Local Government, Material Suppliers, Contractors and Researchers).

"*Old boots, tin kettles and other things of that kind, formed a capital first foundation for a new road over a meadow. In laying out a new estate, he knew of nothing better, except perhaps burnt ballast.*" Longrove (1879)

1. INTRODUCTION

Road construction materials have remained relatively unchanged in the last 50 years. Bitumen, asphalt, concrete, natural gravels and crushed rock has proven themselves over and over again for road construction and there have been few drivers for change. However, developments in the last decade around climate change and sustainability are triggering pressure for change in all industries and the road building sector has begun to adapt. The dumping of demolition waste and asphalt millings in landfill is no longer good practice and the recycling value of these and other inert materials is now well established. The introduction of significant levies on landfill through legislation is further driving the recycling of these materials which should no longer be viewed as waste but as valuable resources in their own right. Much work has been done by both the private and public sector to experiment with new materials and techniques and numerous trial projects have been constructed. Many procedures have advanced well beyond the trial phase and are now accepted techniques in some sectors of the industry. To facilitate the use of recycled materials for road pavement construction in Western Australia (WA) a group from Australian Geomechanics Society has put together a combined paper addressing the use or potential use of recycled materials for road construction in WA. Materials addressed include crushed recycled concrete, comingled demolition material, crushed vitrified clay pipe, crushed glass, scrap rubber, asphalt millings and plastic.

2. SOCIAL AND ENVIRONMENTAL BENEFITS AND ISSUES IN USING RECYCLED MATERIALS

2.1. BACKGROUND

There are approximately 187 500 km of roads in Western Australia and over 30% of these are sealed (Western Australian Local Government Association 2015 and Main Roads WA 2014). The majority of the network was constructed decades ago and many of these roads are reaching the end of their useful design life. Expenditure on road preservation, rehabilitation and reconstruction activities is outstripping capital expenditure and this ratio is expected to increase. The mining and agricultural expansion in regional areas has seen a vast increase in the volumes of heavy vehicles on country roads and this has further driven the need for road rehabilitation activity. This is greatly exacerbated in the Wheatbelt region of WA as deregulation of transport by the state government and the closure of many railway lines has shifted more grain and fertiliser cartage onto the road network. Local Government is responsible for approximately 88% of the total road network (excluding Department of Parks and Wildlife and private roads) and in 2013-14, 71% of expenditure was on maintenance and renewal. This increasing trend in rehabilitation and reconstruction activities is driving the case to recycle the existing in situ materials rather than disposing of them in landfill and importing virgin materials.

To properly understand the potential impact of recycling in the WA road industry it is desirable to estimate the total annual demand for gravels and aggregate in the road building industry. In 2013/14 Local Government used about 1.9 million cubic metres (3.8 million tonnes) of road construction material (estimated from reported activities, WALGA 2015). Main Roads WA used about 1.4 million tonnes of road construction material in 2013 (Main Roads WA 2014).

Construction and demolition material has the potential to provide a significant proportion of the total quantity of material required for road construction as evidenced by Table 1:

Table 1: Construction & Demolition Materials Recycled in WA 2012 -13 (Source: ASK Waste Management 2013)

Material	Net Recycling (tonnes)
Asphalt	106 896
Bricks	59 624
Concrete	351 721
Sand, Soil, Clean Fill and Rubble	661 855
TOTAL	**1 180 095**

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2.2. BENEFITS OF USING RECYCLED MATERIAL FOR ROAD CONSTRUCTION

2.2.1. Cost savings

Significant direct cost savings can be achieved by in situ recycling of existing road base materials. A typical road pavement can be recycled by in situ stabilisation in less time than it would take for full reconstruction. The savings in transport and material costs are substantial. There are also significant indirect savings through a reduction in greenhouse emissions, environmental degradation through quarrying activities and a reduction in traffic disruption. In WA the in situ reuse/recycling of existing road pavement materials (often with the addition of cement, bitumen or limes is routine practice and is not addressed further in this paper.

The use of construction and demolition material, asphalt millings and other recycled products has become significantly more attractive since the increase in the landfill levy in WA from $8 to $40 per tonne. Sending material to a recycling centre rather than a waste disposal site provides a cost saving in many locations.

2.2.2. Reduced Traffic disruption

In situ recycling of existing pavement material results in a reduction in heavy vehicle traffic that would be required to transport new materials from quarry to site.

2.2.3. Reduction in Land fill

Land fill space is highly valuable and the occupation of this space by the discarding of inert recyclable materials should be avoided. The use of recycled materials for road construction can play a significant role in reducing the quantity of material going to a landfill and conserving space for materials that cannot be recycled.

2.2.4. Reduction in Atmospheric Emissions

The construction industry is a major contributor to overall emissions and in coming years there will be mounting pressure to reduce emissions. Recycling of existing materials, the use of construction and demolition material and other waste material provide a clear avenue to achieve significant reductions. The recycling of in situ materials using purpose built recycling machinery is now a well-established technology around the world. In situ recycling of road base material significantly reduces emissions that would have occurred through the extraction and transportation of virgin materials and the disposal of the replaced material. The use of demolition material similarly produces savings by replacing the extraction and transport of virgin materials. The use of demolition material does generate transport and manufacturing emissions but this is offset by the emissions that would occur if it had to be transported and placed in a land fill site. Similar arguments are relevant for the reuse of reclaimed asphalt.

2.2.5. Reduced Environmental Degradation

Gravel, sand and rock for road construction are mostly extracted by open pit excavation and often from undisturbed environments. Damage to the environment is inevitable through the loss of natural vegetation, animal habitats and scarring of the landscape. Large excavations can be detrimental to surface runoff and interfere with groundwater movement. There will always be a requirement to mine natural gravels in the regional environments but efforts to reduce this should be encouraged. The use of in situ recycling, demolition material, recycled asphalt and other recycled materials directly offset the traditional use of quarried materials. Natural gravels are a finite resource and good quality gravels are becoming harder to find, the use of demolition material and the in situ recycling of existing materials presents a more sustainable solution.

2.2.6. Reduced Noise and Dust

Quarrying operations are noisy and require strong process controls to prevent the generation of large amounts of dust. The use of in situ recycling and recycled materials will reduce the dependence on quarried materials. When purpose built equipment is used, the recycling of in situ materials virtually eliminates the emissions of dust that would occur when loading, unloading, placing and grading of materials through conventional techniques.

Recycling of demolition material requires careful management as recycling facilities may be located in built up areas.

2.3. RESTRAINTS ON THE USE OF RECYCLED MATERIALS IN ROAD CONSTRUCTION

Industry surveys to identify inhibitors to the use of recycled products in road construction in WA have been conducted by Leek & Huband (2010) and by ASK Waste Management (2013). The identified restraints from these surveys and from information gathered from workshops conducted by Western Australian Local Government Association (WALGA) are summarised below:

- A lack of confidence in the performance of recycled products.
- A fear of change, the use of conventional techniques and materials are well established and it is easier to carry on doing things the same way.
- A perception that the use of recycled materials increases the level of risk in pavement performance.
- Concern over contaminants including heavy metals, poisons and asbestos.
- Ignorance about product specifications and design procedures.
- Insufficient information to assess the economic advantages.
- Insufficient knowledge about construction techniques.
- Lack of a landfill levy outside the metropolitan area.
- Performance concerns and a lack of promotion and endorsement from state agencies especially concerning the use of demolition material.

3. CRUSHED RECYCLED CONCRETE AND COMINGLED DEMOLITION MATERIAL

3.1. TERMINOLOGY AND GENERAL COMMENTS ON THE USE OF DEMOLITION MATERIAL

The Western Australian Waste Authority defines Construction and Demolition Waste as "that which arises from construction, refurbishment or demolition activities. Construction and Demolition Waste materials include concrete brick, rubble, asphalt, metals (ferrous and non-ferrous), timber, wallboard, glass, plastics, asbestos, soil and other materials and products". Construction and Demolition Waste is a valuable resource from which material to construct roads can be sourced. Not all such material is suitable for recycling into road building material. For public and occupational health reasons asbestos is excluded. Timber is unsuitable due to the potential for degradation and termite attack. Metals must be excluded as iron will oxidize and expand causing problems analogous to concrete cancer. Aluminium must be excluded as the alkali environment of crushed concrete prevents a stable oxide layer from forming and the material degrades to an expandable gel like substance.
Terminology with regard to crushed recycled concrete and crushed concrete containing other materials such as bricks has not been standardized in WA (or in Australia). A number of pavement trial and demonstration projects have been carried out in WA, some using material that is almost all crushed concrete and some that had the crushed concrete comingled with other recycled construction material such as clay bricks and tiles.
For convenience the materials have been separated into two classifications:
Crushed Recycled Concrete (CRC) is crushed construction and demolition waste that contains at least 90% crushed concrete and is largely free of deleterious contaminants.
Comingled Demolition Material (CDM) is crushed construction and demolition waste that contains 50% to 90% crushed concrete, blended with crushed bricks, crushed clay tiles, reclaimed road base or reclaimed asphalt.

This division based on 10% or more of non-concrete is for convenience when describing various demonstration projects. In only one project (Kwinana Freeway) was the proportion of material other than concrete accurately determined. On other field trials there was no direct measure of the proportion of non-concrete material and the distinction between CRC and CDM was based on the description (e.g. "all structural grade concrete") or photographs.

3.2. MAIN ROADS WA PERSPECTIVE ON CRC AND CDM

The eastern states of Australia have a long history with the use of pavement material sourced from construction and demolition waste. In Western Australia, the industry is having difficulty in gaining market acceptance, despite the reports of several successful demonstration projects within the state including trials by the City of Kwinana (previously Town of Kwinana), City of Canning, City of Cockburn and City of Gosnells.

Main Roads WA introduced a sub base specification for CRC/CDM in 1995 largely based on practice in New South Wales and Victoria. A Main Roads WA basecourse specification for the use of CRC/CDM was introduced in 2004 and withdrawn in 2011.
In 2012, the Main Roads CRC sub base specification was withdrawn from general use due to concerns over the risk of asbestos contamination. The Department of Environmental Regulation put in place new Guidelines and Licensing Requirements for C&D Waste Recycling Facilities in 2013 to more tightly manage the risk of asbestos contamination. These guidelines require recycling premises to put in place asbestos management plans including undertaking testing for asbestos content.
In 2015, the Department of Environmental Regulation (WA) published additional Guidelines (Material Guideline: Construction Products) on the maximum acceptable limits of other potentially hazardous contaminants in recycled materials. These Guidelines outline Recycling Facilities' responsibilities, but also make it clear that the end user is responsible for ensuring that the material is fit for use.
Main Roads WA has continued to use CRC as a sub base material since 2013 (on Alliance contracts) with additional management controls, including working closely with the Department of Environmental Regulation and the Department of Health, and also engaging an independent asbestos expert on each project to independently audit and test recycled materials for asbestos contamination.

3.3. LOCAL DEMONSTRATION PAVEMENTS

3.3.1. Kwinana Freeway, Main Roads WA

Background
Main Roads WA constructed a C & D pavement demonstration section on Kwinana Freeway in 2009. The recycled basecourse material was supplied by All Earth Recyclers and referred to as "co-mingled", but has been classified as CRC in this paper based on the reported proportion of non concrete material.
The pavement was constructed on Tamala Sand subgrade and comprised:

- 30mm - open graded asphalt
- 30mm - dense graded asphalt
- 10mm/5mm two coat emulsion seal on a prime
- 260mm – CRC basecourse
- 170mm – crushed limestone sub-base

Is was reported that a tightly bound surface was produced and the basecourse achieved a characteristic dry density of 101% of modified maximum dry density was dried back to 80% of optimum moisture content.

Laboratory Testing Results
The material properties of the recycled product used are summarised in Table 2. Typically, the results indicate that the recycled basecourse material met the requirements of the Main Roads WA (MRWA) specification.
Foreign Material testing indicated that Sample 7149 had 0% asbestos. In addition, it showed that the sample slightly exceeded both the allowable percentage of high density material (brick, glass etc) with 5.1% retained (specification limit 5%) and vegetable matter 0.1% retained (specification limit 0%).

Table 2: Particle Size Distribution CRC basecourse on Kwinana Freeway demonstration section.

Particle size distribution (PSD)			
Sieve size (mm)	**MRWA CRC Specification for Basecourse**	**Sample No: 7149 Percent Passing (%)**	**Sample No: 7042 Percent Passing (%)**
26.5	100	100	100
19.0	95-100	100	99
9.5	59-80	61	73
4.75	41-60	42	52
2.36	29-45	32	40
1.18	20-35	26	33
0.600	13-27	20	25
0.425	10-23	15	19
0.300	8-20	11	13
1.150	5-14	6	7
0.075	3-11	4	4
LL (%)	35% max.	-	35
LS (%)	3.0% max.	-	0.4

Particle size distribution (PSD)			
Sieve size (mm)	**MRWA CRC Specification for Basecourse**	**Sample No: 7149 Percent Passing (%)**	**Sample No: 7042 Percent Passing (%)**
CBR Soaked (%)	100% min.	150%	-
Los Angeles Abrasion value (%)	40% max.	**Sample No.** A4360 = 37	-
7 Days Unconfined Compressive strength (UCS) & soaked for 4 hours	1.0MPa max.	Sample No. P09/752 = 0.3 MPa	Sample No. P09/753 = 0.18 MPa

Deflection Testing

FWD curvature data for CRC, Crushed Granite Rock Base (CRB) and Full Depth Asphalt (FDA) is plotted in Figure 1 to assist in characterising the relative stiffness of the CRC base course material. Monitoring has been conducted at 6 monthly intervals comprising FWD testing and rut measurements.
Average rut depth of the CRC trial section in October 2015, six years after construction was 2.6mm.

Summary of Trial
It is clear that the material is very stiff having a curvature response similar to full depth asphalt indicating that the base course may be behaving as a bound layer. Unconfined compressive strength (UCS) testing undertaken in accordance with Test Method WA143.1 did not identify the material as likely to be bound in service. The UCS values were up to 0.3 MPa, suggesting that post construction hydration of cement in CRC occurs over a longer timeframe than the standard test procedure of 7 days curing used with virgin cement.

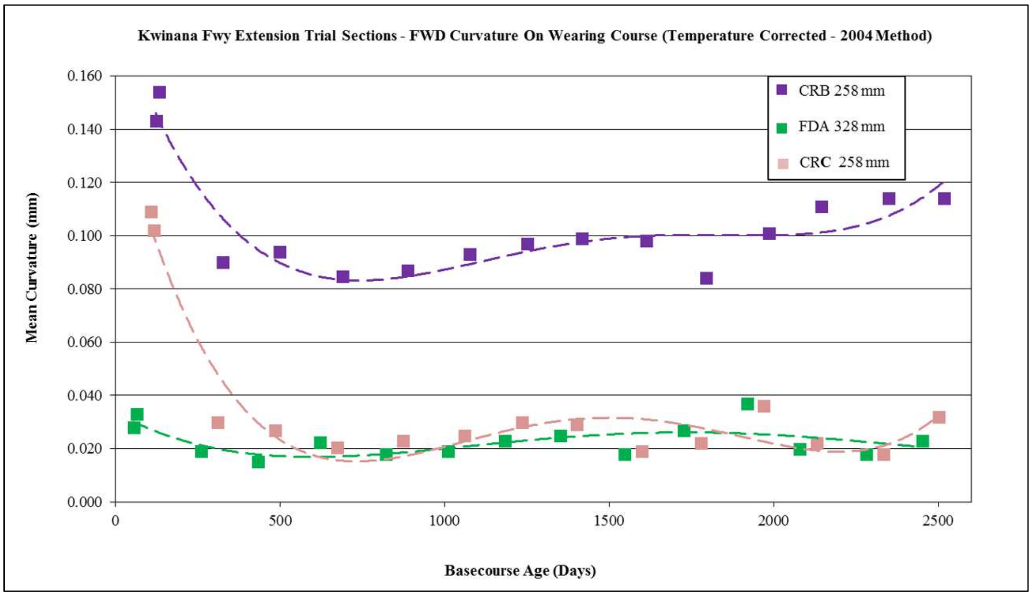

Figure 1: Kwinana Freeway Extension Demonstration Sections – FWD Curvature (700kPa) on Wearing Course (Temperature Corrected – 2004 Method).

3.3.2. GILMORE AVENUE TRIAL, TOWN OF KWINANA

Background
As part of an initiative by the State Government (Cheema 2004), Waste Stream Management set up a construction and demolition material recycling plant at the Town of Kwinana landfill site to produce CRC basecourse and sub base. Trial sections were constructed on Gilmore Avenue between Wellard Road and Mandurah Road by the Town of Kwinana in April 2003 with technical assistance from MRWA. The purpose of the trial was to compare the field performance of crushed recycled concrete (CRC) with conventional crushed granite road base (CRB) as a basecourse material suitable for road pavements. The trial is reported as a CRC trial, however photographs of the stockpiles show that there were some clay bricks in the source material. In this paper the Gilmore Avenue material will be treated as CDM.

Gilmore Avenue was designed for a 30 year design traffic of approximately 7 million equivalent standard axles (ESA). Both the trial and control sections consisted of a 275 mm pavement made up of 150 mm limestone subbase, with 125 mm CRB or CDM base course. The surfacing consisted of 30 mm dense graded asphalt.

Laboratory Testing of Gilmore Avenue Materials

Particle size distribution of the CRC and the CRB used in the trial are shown in Table 3 and Table 4 respectively. The specification limits refer to the Main Roads WA 2004 specification for CDM basecourse. The particle size distributions suggest the CRB supplied for this project was deficient in coarse aggregate while the CDM had a slight deficiency in the fine fraction (% passing 0.075mm). Index testing for the CRB and CDM materials used in Gilmore Avenue are presented in Table 5. California Bearing Ratio (CBR) results exceeded 100%.

Unconfined compressive strength (UCS) testing was conducted to assess the extent of secondary cementation due to residual unhydrated or partially hydrated cement in the CDM stockpile at the plant site. The compacted specimens were wrap-sealed and cured for 7 days, then soaked for 4 hours and drained for 15 minutes prior to crushing. The results are also shown in Table 5. The mean 7 day UCS was found to be in the order of 0.85 MPa. It is now recognised that the chemical reactions within CDM and CRC may be slower than for virgin cement and a longer curing periods need to be investigated.

Table 3: Particle size distribution of CDM used in Gilmore Avenue trials ex stockpile

AS 1152 sieve size (mm)	Target grading (% passing)	MRWA Spec 501 specified limits (% passing)		Results (% passing)					
		Min.	Max.	Sample 7533	Sample 7534	Sample 7535	Sample 7536	Sample 03M18	Sample 03M19
26.5	100	100	100	100	100	100	100	100	100
19	100	95	100	97	97	97	97	97	99
9.5	70	60	80	70	64	67	70	71	75
4.75	50	40	60	48	44	45	51	52	53
2.36	38	30	45	38	34	34	38	40	41
1.18	25	20	35	30	27	27	30	30	32
0.6	19	13	27	23	21	21	22	22	24
0.425	17	11	23	17	16	16	17	17	19
0.3	13	8	20	12	12	12	12	12	13
0.15	10	5	14	5	5	6	6	6	7
0.075	8	5	11	3	3	4	4	4	4

Table 4: Particle size distribution of CRB (Control Section) used in Gilmore Avenue trials

AS 1152 sieve size (mm)	Target grading (% passing)	MRWA Spec 501 specified limits (% passing)		Results (% passing)			
		Min.	Max.	Sample 03M127	Sample 03M128	Sample 03M129	Sample 03M130
26.5	100	–	100	100	100	100	100
19	100	95	100	100	100	100	100
9.5	82	70	90	94	92	93	95
4.75	70	60	80	86	83	84	88
2.36	50	40	60	65	62	61	65
1.18	38	30	45	47	45	43	46
0.6	25	20	35	33	30	31	31
0.425	19	13	27	24	21	23	22
0.3	17	11	23	21	18	20	19
0.15	13	8	20	18	16	17	17
0.075	–	5	14	14	12	14	13

Table 5: Index testing for CDM and CRB used in Gilmore Avenue trials

Test	Test method	MRWA Spec. 501 limits	Test results					
			CDM			CRB		
			Sample 03M18	Sample 03M19	Sample 03M127	Sample 03M128	Sample 03M129	Sample 03M130
Liquid limit	WA 120.2	35% Max	29.6%	28.9%	22.9%	22.7%	22.9%	22.8%
Plastic limit	WA 121.1	NS	NP	NP	NP	NP	NP	NP
Cone plasticity index	WA 122.1	NS	NP	NP	NP	NP	NP	NP
Linear Shrinkage	WA 123.1	3% max.	0	0	0.4%	0.8%	0.8%	0.4%
California Bearing Ratio	WA 141.1	100% min.	175%	165%	170%	130%	170%	160%
Unconfined Compressive Strength	WA 143.1	1.0 MPa max	0.9 MPa	0.8 MPa	-	-	-	-

Deflection testing Gilmore Avenue
MRWA undertook regular deflection testing on Gilmore Ave, initially using the Benkelman Beam, and later the Falling Weight Deflectometer (566 kPa drop stress). The results are shown in Figure 2. The values obtained with the Benkelman Beam should not be directly compared to directly to those measured with the FWD. It is noted the moisture contents were high (over 80% of Optimum Moisture Content, modified compaction) at the time of sealing.

The early Benkelman Beam results demonstrated a small difference in curvature (d0 –d200) between the CRC and the CRB, with CDM having a 90th percentile value of 0.16 mm compared to a value of 0.21 mm on the CRB immediately after construction.

The deflection testing indicates that the CDM reached a minimum curvature (maximum stiffness) at year one, and then increased in curvature (decreased in stiffness) over the subsequent 11 years. Testing indicates that the CDM section was stiffer than the CRB sample throughout the entire test period, although the difference in deflection curvature between the CDM and the CRB sections began to reduce from October 2010.

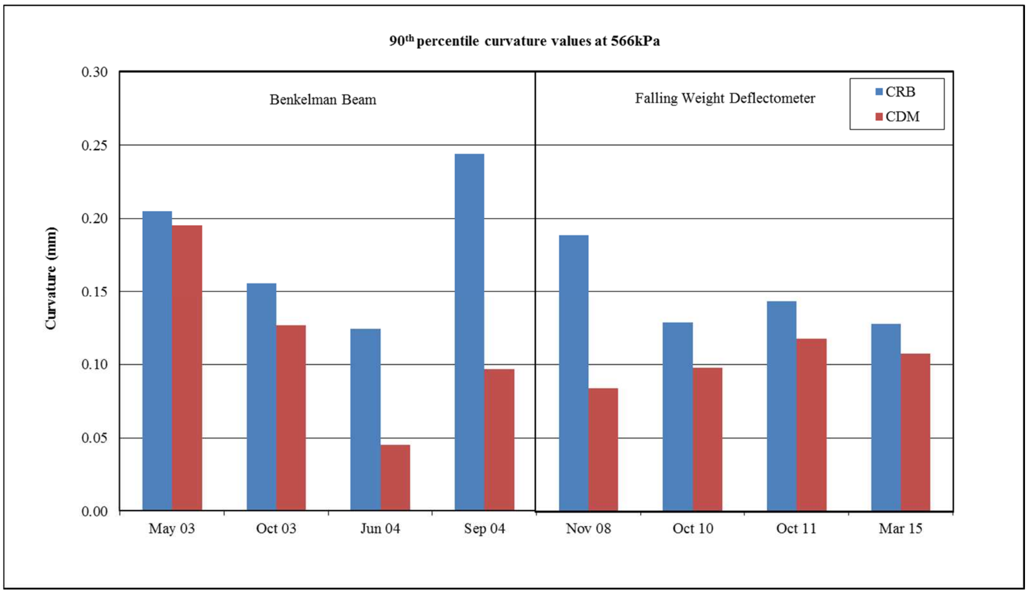

Figure 2: Deflection testing results (Curvature) on Gilmore Ave

Results of Trial
By 2010, the Gilmore Ave control section (CRB) had extensive rutting and fatigue cracking as shown in Figure 3 and was reconstructed in 2015. The CDM section performed better than the control, and in 2016 was still in good condition with a few transverse cracks similar to those photographed in 2011 (see Figure 4). The relatively poor performance of the CRB control section may be due to the deficiency in coarse aggregate, indicated by the particle size distribution testing.

Figure 3: Gilmore Ave showing one of many fatigue failed sections in the CRB control section (January 2011)

Figure 4: Gilmore Ave showing one of isolated transverse cracks in CDM section (December 2011)

3.3.3. WELSHPOOL ROAD WESTERN AUSTRALIA

Background

The Welshpool Road study (Leek 2008) involved demonstration sections of different recycled material combinations and compared them to a control section of conventional crushed granite rock base (CRB). The trial pavement under consideration is an 860 m long section of Welshpool Road west of Sevenoaks St to Leach Hwy in Welshpool in the City of Canning. Welshpool Road carries approximately 8,030 vehicles per day with approximately 15% of the vehicles being trucks, giving design traffic of approximately 20 million standard axles over a 30 year design life.

A trial was constructed to compare recycled materials from C&D Recycling to CRB. Construction commenced in November 2007 and was completed in March 2008.

The demonstration was expanded from using CDM as subbase to using CDM and CRC as basecourse material, after inspection of the compacted CDM subbase.

Four different pavement profiles were constructed:

- 250 mm of 25 mm CDM sub base and 150 mm of 20 mm CRB basecourse
- 400 mm of 25mm CDM basecourse
- 250 mm of 50 mm CDM sub base and 150 mm of 25 mm CRC basecourse
- 400 mm of 25 mm CRC combined sub base and basecourse

The trial sections were sealed with a two coat bitumen emulsion seal followed by 30 mm thickness of dense graded asphalt.

Laboratory Testing

The maximum dry density (MDD) of the CDM and CRC materials used in the trial were compared to CRB. The recycled materials were found to have a lower MDD than crushed rock base (CRB) (1.95 t/m^3 compared to 2.21 t/m^3). The

optimum moisture content (OMC) of the CDM and CRC materials was higher than the OMC of the CRB (11% compared to 6%).
The City of Canning had previously undertaken Repeat Load Triaxial (RLT) testing on CRB from various sources, and CDM from C&D Recycling. These results are presented in Table 6. The terms Stage 1, Stage 2 and Stage 3 refer to various stress levels in the test.
Classification tests were also undertaken on the recycled material and compared to the MRWA Specification for CRC/CDM (2004). The particle size distribution testing, for CRC and CDM are shown in Table 7 and indicate that the recycled material was within the required grading envelope with the exception of the very fine and very coarse fractions, which were marginally out of specification. Atterberg testing indicates that the CRC and CDM samples were non plastic, with the CRC sample exceeding the allowable liquid limit with a value of 41% (specification limit 35%)
No index tests were undertaken on the CRB used in Welshpool Road, but experience has shown that the quarry supplying this material has a good record for meeting the specification.

Table 6: Results of repeat load triaxial testing on pavement materials used in the construction of Welshpool Road

Material	Dry density (% MDD)	Moisture content (% OMC)	Resilient modulus (MPa)		
			Stage 1	Stage 2	Stage 3
CRB	98.2	76	210	Failed	Failed
	98.3	66	250	260	Failed
	99.4	47	380	440	460
CDM	97.5	77	250	270	220
	97.9	65	330	350	350
	98.0	60	400	430	440
CRC	98.6	74	320	340	330
	98.3	66	500	530	490
	98.1	59	630	690	670

Table 7: Particle size distribution of recycled materials in Welshpool Road

AS 1152 sieve size (mm)	Target grading (% passing)	MRWA Spec. 501 specified limits (% passing)		Results (% passing)		
		Min.	Max.	CRC 5/09/2007	CDM 5/09/2007	CDM 13/12/2007
26.5	100	100	100	98	100	99
19	100	95	100	92	92	86
13.2	82	70	90	81	81	78
9.5	70	60	80	72	71	67
4.75	50	40	60	48	51	48
2.36	38	30	45	34	39	38
1.18	25	20	35	25	31	32
0.6	19	13	27	18	23	25
0.425	17	11	23	13	18	20
0.3	13	8	20	9	13	15
0.15	10	5	14	5	7	8
0.075	8	5	11	3	4	5

Deflection Testing
Falling Weight Deflectometer (FWD) testing was carried out after construction (2008) and then at yearly to two yearly intervals until 2015. The results are detailed in Figure 5. The curvature of the pavements constructed from recycled products was less than the curvature of pavements constructed with CRB for the first six years. Similar to what was observed in the Gilmore Avenue trial, the curvature of the CDM pavement appeared to decrease with time until it reached a minimum curvature in 2014, after this point the curvature of the pavement began to increase. This trend was not as apparent in the CRC pavement which appeared to decrease dramatically over the first two years and then fluctuated slightly over the period of testing. There is some uncertainty about the accuracy of the calibration of the FWD with the 2014 results.

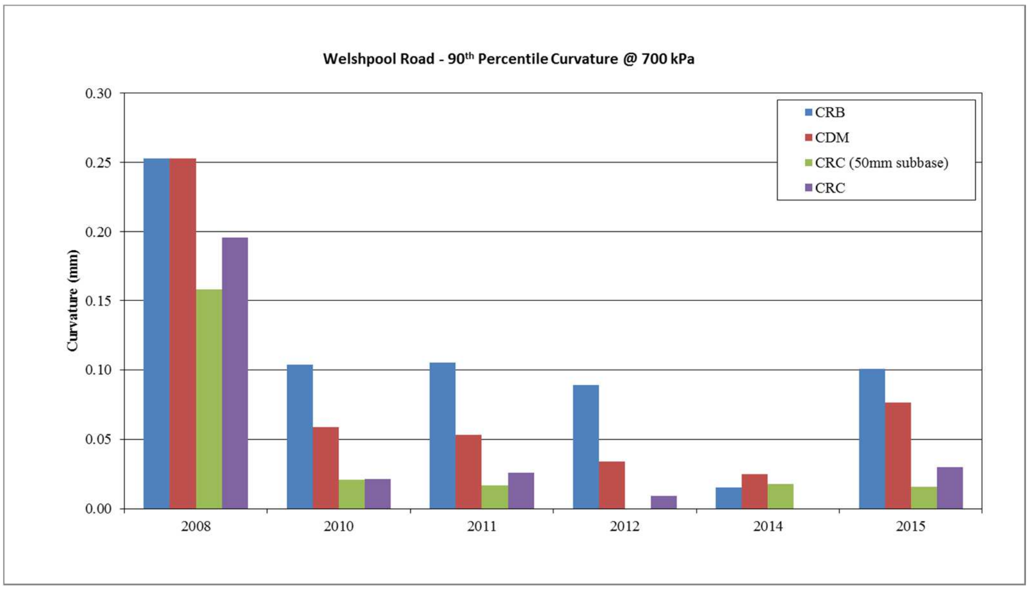

Figure 5: Curvature values at Welshpool Road

The initial FWD (566 kPa drop stress) data was analysed using EFROMD3 to estimate the back-calculated layer moduli. The results are shown in Table 8, and show that the modulus of the CRC and CDM is significantly greater than the modulus of the CRB soon after construction.

Table 8: Layer moduli back-calculated from 2008 FWD results using EFROMD3

Pavement construction	Back-calculated layer modulus (MPa)	
	Base layer	Sub base layer
150 mm CRB / 250 mm CDM	641	722
400 mm CDM	1024	678
150 mm CRC /250 mm 50 mm CDM	1275	505
400 mm CRC	1042	527

Performance of Welshpool Road

The RLT testing on the materials used in Welshpool Road is not definitive due to the small sample size. However, the initial indications are that the recycled products are less moisture sensitive and have a similar, if not higher, modulus value than the CRB.

The FWD testing, and the back-analysis of the moduli, tended to confirm the findings of the RLT testing, i.e. that the modulus of the recycled demolition materials is higher than that of the CRB.

The demonstration project found that the CDM and CRC on Welshpool Road performed at least equally, and possibly better than CRB. The recycled material was found to be stable at a range of moisture contents, easily worked and compacted, and withstood the effects of turning traffic better than CRB. After six years of trafficking, some widely spaced shrinkage cracking were observed in Welshpool Road on the CRC section, as shown in Figure 6. As at July 2016, no such cracking has been observed in the CDM section.

Figure 6: Welshpool Road –CRC section showing transverse crack (January 2015)

3.3.4. Warton and Nicholson Roads

Background

The City of Gosnells used material sourced from Capital Recycling to construct a section of Warton Road. This material was CRC sourced from all structural concrete. The City of Gosnells was concerned about the apparent stiffness developed by the material during construction. At the same time the City of Canning was constructing Nicholson Road using a comingled recycled material (CDM) from C&D Recycling.

RLT Testing

RLT testing was undertaken on samples from both Warton Road and Nicholson Road post-construction, and the results are shown in Figure 7. Resilient moduli of samples recovered from the pavement were lower than that of samples taken from stockpiles (see figure 12).

There are two possible reasons for this, sample preparation or material differences, either in supply or as a result of working the material during construction. As all testing was undertaken by the same person, it is likely that the differences are more attributable to material breakdown during construction, but more work would be required to confirm this assumption.

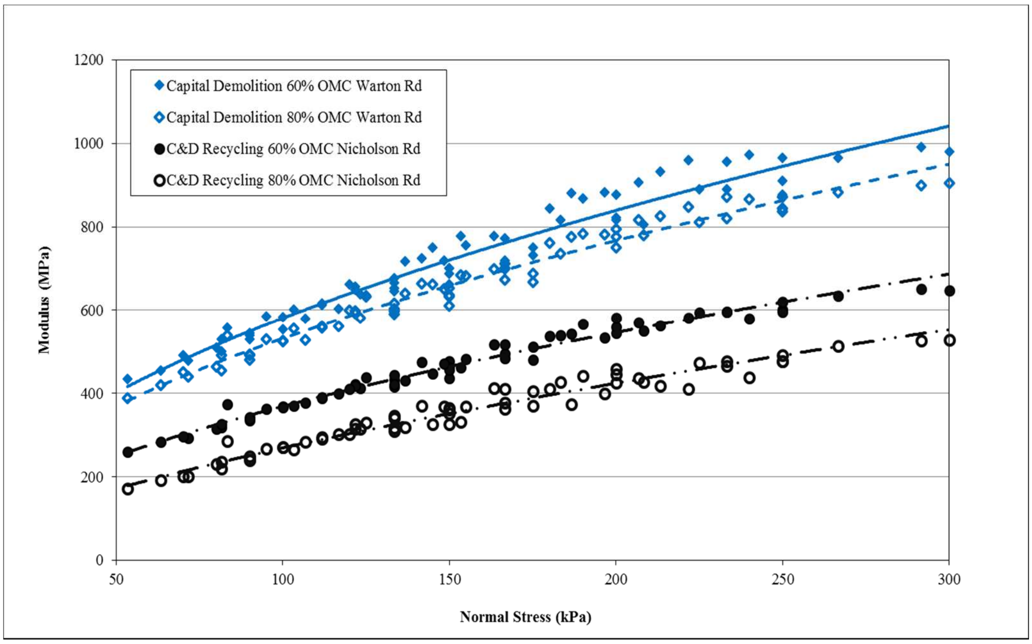

Figure 7: RLT test results from Warton Road (CRC) and Nicholson Road (CDM) materials

Deflection Testing

FWD testing was carried out by ARRB Transport Research Group (ARRB) in February, 2010 at various locations. The deflection, curvature and layer moduli are summarised in Table 9.

Table 9: Deflection, curvature and back calculated layer moduli for Welshpool, Nicholson and Warton Roads

Road	Pavement Details	Mean deflection (mm)	Mean curvature (mm)	Basecourse modulus (MPa)	Sub-base modulus (MPa)
Welshpool	30 AC 150 25mm CRB 250 25 mm CDM/ Sand subgrade	0.28	0.07	900	1200
	30 AC 150 25mm CDM 250 25 mm CDM Sand subgrade	0.16	0.03	4200	4400
	30 AC/ 150 25mm CRC 250 50 mm CDM Sand subgrade	0.13	0.01	5000	5000
	30 AC 150 25mm CDM 250 25 mm CDM/ Sand subgrade	0.11	0.01	5000	4900
Warton	30 AC 200 25mm CRC 350 limestone Sand subgrade	0.20	0.05	5200	6300
Nicholson	30 AC 150 25mm CDM/ 250 25 mm CDM Sand subgrade	0.16	0.03	3800	4100

The FWD testing indicates (back calculated) in-situ moduli of between 3800 MPa and 5200 MPa for the recycled products and 900 MPa for the CRB. The back calculated moduli are significantly higher than the post construction RLT results.

At the time of FWD testing, Welshpool Road had been in service for nearly 2 years while Nicholson Road and Warton Road had been in service for approximately 6 months. There is a likelihood that that the cement in the material underwent post construction hydration and formed a bound layer. This bound layer may result in the development of shrinkage cracking and fatigue cracking of the basecourse.

If the post hydration of the pavement materials provides sufficient strength and remains stable, then the low curvature values should result in very long asphalt life, but a risk of reflection cracking originating in the bound CRC/CDM layers does exist. Research undertaken at Hong Kong Polytechnic University (Poon et al. 2008) indicates that the post construction hydration effects may be controlled by limiting the active fines in the <0.15 mm size. As such, further research into the performance of recycled pavements focussing on controlling the < 0.15 mm source material needs to be undertaken to assess the effects in the field performance.

This may require an adjustment to the crushing and screening operations if shown to be successful such that the <0.15 mm size particles are not sourced from concrete based materials.

All of these pavements have developed some cracking as shown in Figure 8 and Figure 9.

Figure 8: Warton Road – City of Gosnells (January 2012)
Transverse crack in asphalt surface on CRC base

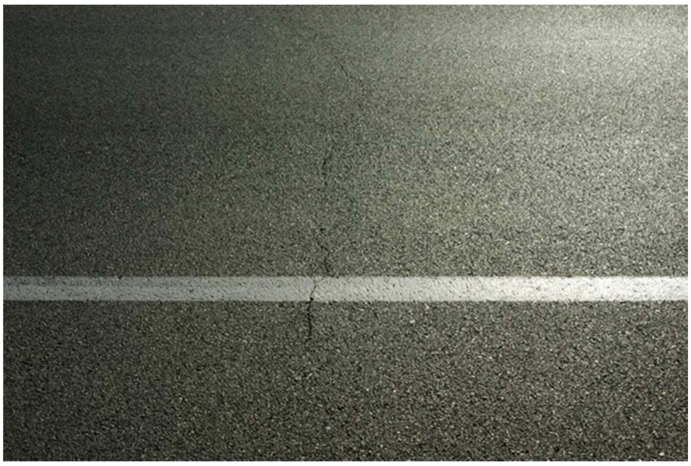

Figure 9: Nicholson Road – City of Canning (January 2015)
Transverse crack in asphalt surface on CDM base 2 coat primer seal

3.4. STRATEGIC WASTE INITIATIVE SCHEM (SWIS) RESEARCH PROJECT

3.4.1. Background

Curtin University of Technology gained a research grant under the SWIS scheme administered by the then Department of Environment and Conservation, and contracted ARRB Group to coordinate the project. The aim of this project was to assess the performance characteristics of road base sourced from recycled crushed concrete and to develop a specification for the application of this product in road construction.
Road base from three material sources were tested including:

- Capital Demolition CRC material, predominantly structural grade concrete with no brick and tile
- All Earth and C&D Recycling CDM material, which each contained predominantly non-structural concrete with some brick and tile, estimated to be between 10% and 15% by weight

3.4.2. Laboratory Testing

Maximum dry density (MDD) and optimum moisture content (OMC)
MDD/OMC testing of the three recycled products found that the dry density ranges between 1.86 t/m³ and 1.96 t/m³ while the OMC ranges between 10.9% and 11.3%

Particle size distribution

The particle size distributions are shown in Figure 11. The grading shows that all materials were low in fines, and that for the samples tested, the grading of the All Earth material was out of the Fuller grading envelope on the fine side, and the grading for C&D Recycling was slightly out of the envelope on the coarse side.

Unconfined compressive strength of CDM and CRC

UCS testing is summarised in Table 10. Tests were undertaken on samples cured for both 1 day and 28 days. An additional sample was tested at 7 days. These results show that there is some degree of rehydration occurring in the recycled materials, and that there is considerable variability between suppliers.

The variability between C&D Recycling and All Earth test results is not viewed as a difference in processing methods, instead it provides an indication of the potential variation in source materials.

Table 10: Results of UCS testing on CDM and CRC Materials

Supplier	Description	UCS 1 day cure	UCS 7 day cure	UCS 28 day cure
Capital Demolition	CRC	668	-	1625
C&D Recycling	CDM	220	-	474
All Earth	CDM	541	-	1323
All Earth	CDM	625	979	1023

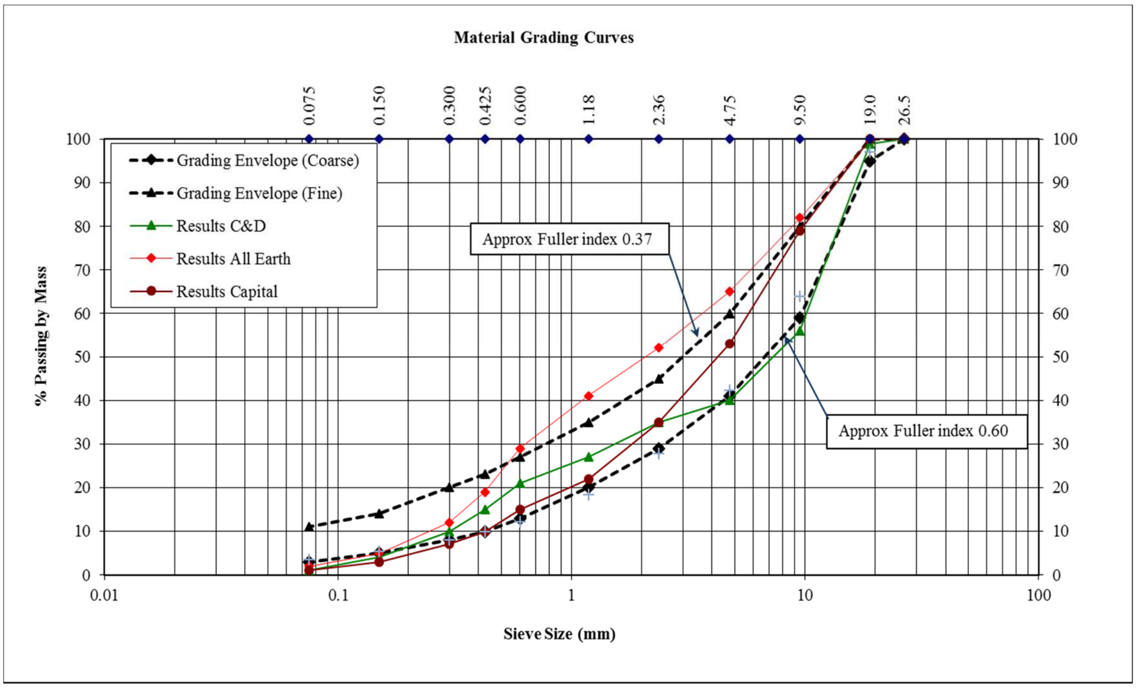

Figure 11: Particle size distribution for CDM and CRC materials in SWIS project investigation

RLT testing

RLT testing was undertaken at Curtin University on triplicate samples of recycled material sourced from the three suppliers, and two samples of new quarried CRB from Cemex and Boral. The samples were compacted to density at OMC, and dried back, prior to testing. Whilst it is desirable to allow a period of time to allow the moisture to redistribute through the material, this was not undertaken to eliminate the effects of post compaction hydration of cement in the recycled samples.

The relationship between modulus and normal stress for the various materials tested at 60% and 80% OMC is shown in Figure 12 and Figure 13.

The Capital Demolition CRC had the highest modulus values. The All Earth and C&D Recycling CDM had similar values. All of the recycled materials showed significantly higher modulus values than that obtained from the CRB materials.

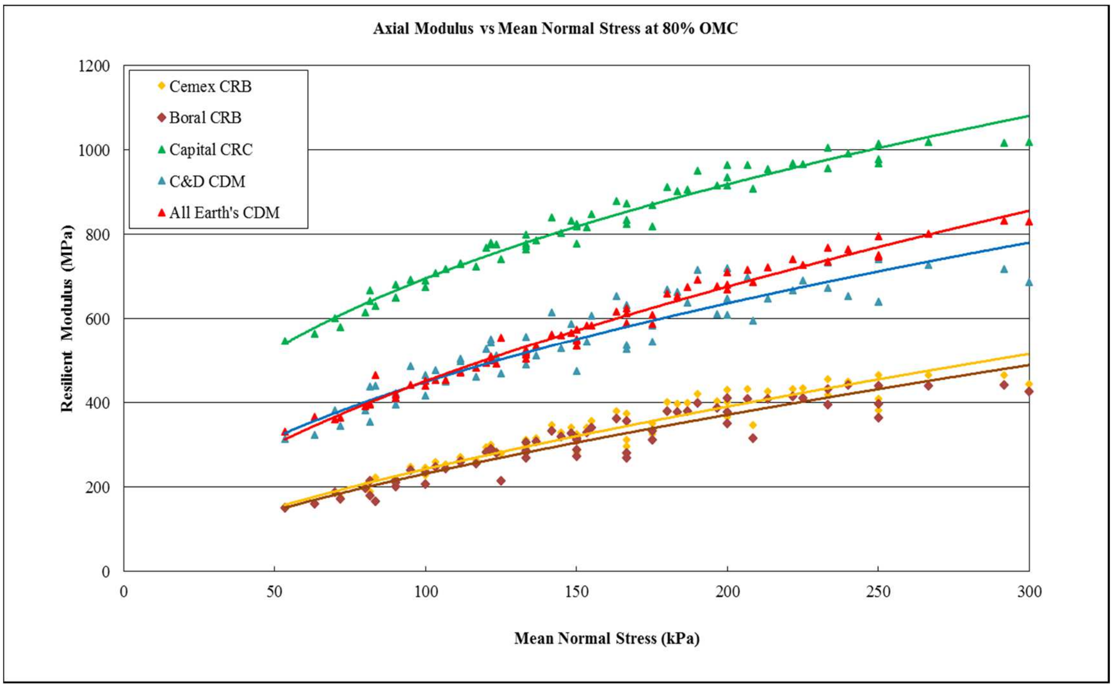

Figure 12: Modulus vs. normal stress for recycled (CRC and CDM) and quarried CRB materials at 80% OMC

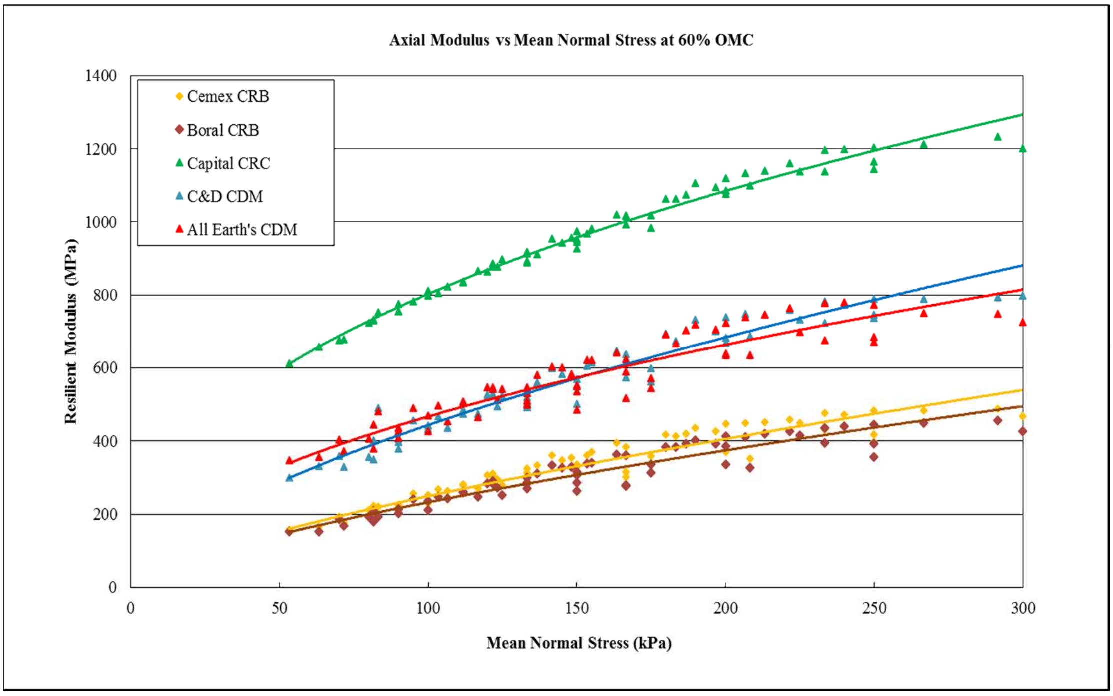

Figure 13: Modulus vs. normal stress for recycled (CRC and CDM) and quarried (CRB) materials at 60% OMC

In order to assess the potential changes of modulus with time, one product was selected to undertake resilient modulus testing at 60% OMC after a period of 1 day, 7 day and 28 day curing. All Earth CDM was chosen, as it represents the middle range of the uncured performance testing. The results of bulk stress verses resilient modulus are shown in Figure 14.

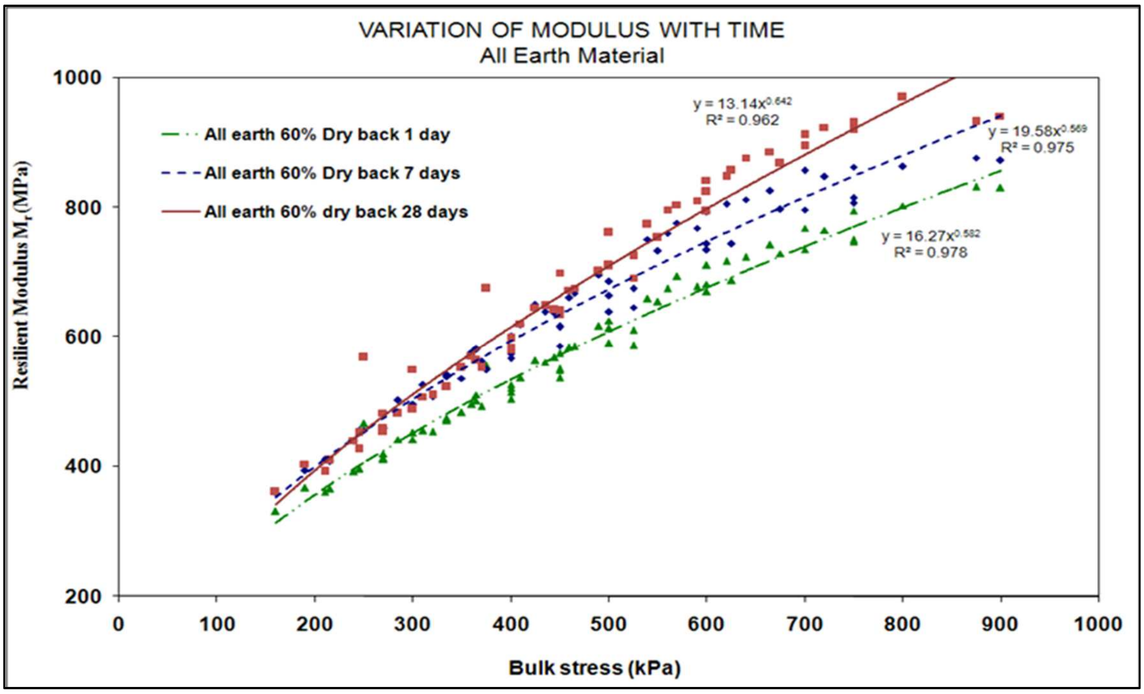

Figure 14: All Earth resilient modulus at 1, 7 and 28 days

3.4.3. Conclusions of SWIS Testing on CRC and CDM

Testing by Curtin University has confirmed that the optimum moisture content for CDM is higher than for CRB. It has also been found by repeat load triaxial testing (RLTT) that the resilient modulus of the CDM is higher than CRB by a factor of two or more. The RLTT also showed that the source of material strongly influences the modulus of the recycled material.

3.5. CONCLUSIONS REGARDING THE USE OF CDM AND CRC IN PAVEMENTS IN WA

Recycled demolition materials containing largely concrete, with some brick, tile, ceramics, and recovered road making materials are being used in pavements throughout the world, including some parts of Australia, but have not gained acceptance by Local Government and Main Roads in Western Australia. Research undertaken on projects completed in WA show that the recycled materials can perform well when they are used appropriately. IPWEA and WALGA (2016) have recently published a revised Specification for the supply of recycled material is road base course and sub-base on local roads.
Based on the trials reported, it appears that material variability is an ongoing issue with CRC and CDM in Western Australia. This complicates the interpretation of trial results as whether or not a material behaves as a bound layer (and is subject to fatigue and shrinkage cracking) depends on the blend of material used. Short term (7 day or 28 day) UCS testing is not a reliable predictor of bound behaviour. Until a reliable predictor of bound behaviour is developed for CRC and CDM it would be prudent to assume bound behaviour. The use of a thin layer of CRC or CDM over an unbound sub base should be avoided. On heavily trafficked roads CRC and CDM can be used as a sub base with a sufficient thickness granular base or asphalt to supress reflection cracking. With appropriate design, advantage can be taken of the high moduli of CRC, by using as a sub base to increase the fatigue life of asphalt layers above.

On lightly trafficked roads (e.g. local streets) CRC and CDM should be used as a sub base (below a granular layer) or as full depth pavement below the asphalt surfacing. Where CRC or CDM are used full depth some transverse shrinkage cracking can be expected (as occurs with lateritic gravel and ferricrete). For local roads, this is not of structural significance but can have significant aesthetic and contract compliance ramifications.

For heavily loaded roads, consideration needs to be given in mechanistic pavement design to the possible long term reduction in moduli of CRC and CDM from very high initial values, due to micro-cracking induced by traffic loading. There is currently no published transfer function to allow for this and designers must make their own assessment.

Close management of source material and independent testing is recommended to manage the risk of asbestos contamination. Inclusion of metals such as steel and aluminium must also be avoided.

4. CRUSHED VITRIFIED CLAY PIPE

4.1. VITRIFIED CLAY PIPE

Vitrified clay is formed by heating clay to a very high temperature such that it fuses. Vitrified clay pipe was commonly used for sewers in Perth up until the mid-1970s. It is the advantage that it is resistant to the acidic conditions that develop due to hydrogen sulphide in sewage. Vitrified clay has been replaced by plastic pipe for new sewers since the mid to late 1970s. The Ascot Waters development was constructed on the site of former clay pits and kilns used to produce vitrified clay sewer pipe. The clay pits had been backfilled with reject and broken clay pipe. As part of the redevelopment of this area for residential use the clay pipe and other waste was excavated from the backfilled pits and replaced with sand. Materials were sorted as they were excavated. The resulting stockpile of broken vitrified clay sewer pipe was either a liability, with a high cost for disposal at a landfill or an asset that could be used to produce a sub base for residential streets in the redevelopment of the site.

4.2. TRIAL CRUSHING

A trial crushing of the vitrified clay and of the concrete rubble was carried out in 1995. The crushed concrete had an excess of sand sizes for use as a road pavement and was used for temporary haul roads and as fill. Notes and facsimile from that time indicate that the crushed clay pipe complied with the specification limits set out in Table 11.

Table 11: Specification for crushed vitrified clay pipe at Ascot Waters

Sieve size mm	**Percentage Passing**
53.0	100
37.5	95 - 100
19.0	50 - 85
6.7	30 - 55
2.36	25 - 50
1.18	20 - 40
0.6	15 - 35
0.3	10 - 25
0.15	5 - 15
0.075	2-9
Liquid Limit (%)	$\leq$ 30
Plastic Limit (%)	$\leq$ 20
Plasticity Index (%)	$\leq$ 10
California Bearing Ratio (%)	$\geq$ 80
Characteristic Clegg Impact Value	$\geq$ 30
Wood & Organic Matter (%)	$\leq$ 0.5

4.3. ROAD PAVEMENTS AT ASCOT WATERS

Waterway Crescent, Cygnus Road, Lakewood Avenue and various lanes in Ascot Waters were constructed in 1996 using the crushed clay pipe as a sub base. Details of pavement composition are summarised in Table 12.

Table 12: Pavement composition at Ascot Waters

Layer	Material	Typical Thickness (mm)
Surface	Asphalt	40
Basecourse	Crushed granite	100
Sub base	Crushed clay pipe	450
Subgrade	Sandy Clay	

Benkelman Beam tests were carried out on the completed pavement and Clegg Impact Value tests carried out on the compacted crushed clay pipe. The results are summarised in Table 13.

Table 13: Tests on completed pavement at Ascot Waters

Test	Average	Standard Deviation
Peak deflection D0 (mm)	0.76	0.14
Deflection 300mm from peak D300 (mm)	0.42	0.09
Clegg Impact Value on Crushed Clay Pipe	37	7

Pavements at Ascot Waters have performed well since construction in 1996 in a low traffic volume environment.

It is unlikely that such a large source of vitrified clay pipe will become available in the future in WA. However the data is of historical interest.

5. BLENDED AND CRUSHED FERRICRETE AND CONCRETE

5.1. ORIGINS OF BLENDING FERRICRETE AND CONCRETE

The idea of blending and crushing recycled concrete with ferricrete (laterite cap rock) was first proposed in 1996 by Warren Slater (of Quarry Park Pty Ltd) as a means of utilising demolition rubble from the Broome meatworks. Samples from concrete and ferricrete crushed separately were assessed for particle size distribution. Theoretical particle size distributions were calculated for various combined proportions of the two materials. The Broome study led to a recommended blend of two parts ferricrete to one part concrete.

In 1997 the Eastern Metropolitan Regional Council (EMRC) commissioned a trial of a blend of ferricrete (2 parts) and concrete (1 part). The ferricrete came from the Red Hill waste disposal site where it had been excavated as part of construction of waste cells. The concrete came from recovered concrete road kerbing and similar sources. There were two reasons for the trial:

- Adding moist ferricrete to the dry concrete before crushing was intended to reduce the dust created in the concrete crushing process.
- Based on theoretical particle size distributions, the blended material should have superior properties to the crushed concrete on its own.

5.2. VICTORIA ROAD DEMONSTRATION SECTION (CITY OF SWAN)

A blend of crushed recycled concrete and crushed ferricrete was used to construct a 500m long section of Victoria Road in West Swan between West Swan Road and Tomlin Road. The typical pavement composition is shown in Table 14.

Table 14: Pavement composition at Victoria Road, West Swan

Layer	Material	Typical Thickness (mm)
Surface	Asphalt	40
Basecourse	Crushed Concrete and Ferricrete Blend	110
Sub base	Crushed Limestone	235
Subgrade	Clayey Sand	

Falling Weight Deflectometer (FWD) tests were carried out on the completed pavement. Deflection results (normalised to a drop stress of 566kPa) are presented in Table 15. Clegg Impact Value tests were carried out on the compacted basecourse immediately prior to application of the primer seal. The results are also presented in Table 18.

Table 15: Tests on Victoria Road

Test	Average	Standard Deviation
Peak deflection D0 (mm)	0.67	0.18
Deflection 300mm from peak D300 (mm)	0.30	0.09
Clegg Impact Value on Crushed Concrete and Ferricrete Prior to Primer sealing	58	3

Clegg Impact Tests were also carried out on specimens of the blend compacted in a CBR mould. Using non-linear regression, the following relationship was derived:

$$CIV = 64.9\ R_D^{7.76}\ R_W^{-0.56}$$

Where: R_D is dry density ratio, modified compaction (expressed as a ratio, not as a percentage)

R_W is moisture ratio (moisture content divided by laboratory optimum moisture content).

A visual assessment of the pavement in 2016 (about 17 years after construction) indicated very good performance with defects limited to meandering cracks adjacent to Moreton Bay fig trees at two locations.

5.3. PROPERTIES OF BLENDED AND CRUSHED CONCRETE AND FERRICRETE USED IN THE VICTORIA ROAD DEMONSTRATION PROJECT

Subsequent to the crushing of the material used to construct Victoria Road in West Swan, testing for Particle Size Distribution, Atterberg Limits and mechanical properties was undertaken. These results are summarised in Table 16.

Table 16: Properties of Blended and Crushed Ferricrete and Concrete from Victoria Road

Sieve size mm	**Percentage Passing by Wet Sieving**	**Percentage Passing by Dry Sieving and Decantation**
26.5	99	100
19.0	88	87
16.0	83	
13.2	78	
9.5	69	67
6.7	58	
4.75	51	49
2.36	39	38
1.18	29	31
0.6	22	25
0.425	18	21
0.3	16	18
0.15	11	13
0.075	8	10
0.0135		5
Liquid Limit (%)	23 (cup)	26 (cone)
Plasticity Index (%)	4 (cup)	8 (cone)
Linear Shrinkage (%)	2.4	2.4
California Bearing Ratio (%)	> 210	
Maximum Dry Density (Modified) (t/m^3)	2.106	
Maximum Dry Compressive Strength (MPa)	4.9	
Los Angeles Abrasion (%) on sample from Red Hill stockpile	44	
Flakiness Index (%)	9	

5.4. INVESTIGATION INTO THE EFFECTS OF POST CONSTRUCTION HYDRATION OF CEMENT IN CRC AND BLENDS OF CRC WITH FERRICRETE

Research has been undertaken at Curtin University Geotechnical Laboratory to investigate ways to limit the strength gain exhibited by CRC and thus reduce the risk of the material becoming bound and developing cracks. This strength gain is thought to stem from the post construction hydration of the Portland cement content contained in the CRC. Two different methods are examined; firstly, by blending with inert non pozzolanic materials to limit the capability of cementitious bonds to reform, and secondly by the forced development of micro-cracks by recompaction during the early stages of curing.

Unconfined compressive strength tests (UCS) were performed at Curtin University Geotechnical Laboratory. In these tests, different blends of CRC with Brick & Tile and Ferricrete were compacted in cylinders. All test cylinders were oven dried back to 60% of OMC and then wrapped and cured for 56 days. This was undertaken to ensure that the samples has an even moisture distribution, and to allow for the post compaction hydration of the cement to develop. Test cylinders were not soaked before crushing.

Two materials were investigated for the blending of non pozzolanic materials with the CRC:

- A blend of brick and tile.
- Crushed ferricrete.

Figure 15 and Figure 16 show the material used for blending with CRC in this research.

Figure 15: Crushed brick and tile used in this research

Figure 16: Ferricrete used in this research

The results of UCS testing are summarised in Table 17.

Table 17: Test results of UCS (56 days) tests on CRC and blends

Material	Average UCS (unsoaked) (MPa)	Standard Deviation of UCS (MPa)	Number of replicates
100% CRC	0.77	0.094	5
90% CRC with 10% Brick and tile	0.70	0.041	8
70% CRC with 30% Brick and tile	0.89	0.102	7
50% CRC with 50% Brick and tile	0.77	0.075	7
90% CRC with 10% Ferricrete	0.87	0.135	7
70% CRC with 30% Ferricrete	0.94	0.111	7
50% CRC with 50% Ferricrete	0.76	0.077	6

No consistent trend for the effect on UCS with the addition of either ferricrete or brick and tile to CRC was found.

The research showed that the blending of either of the crushed brick and tile or ferricrete reduced linear shrinkage but the strength of the materials as measured by the Unconfined Compressive Strength Test (UCS) was little affected by the blending of these materials.

6. RECYCLED ASPHALT PAVEMENT AND WARM MIX ASPHALT

6.1. BACKGROUND

Recycled asphalt pavement (RAP) is a product comprising a blend of graded crushed rock, sand, filler and bitumen which is available from pavement rehabilitation or rejected and surplus asphalt production. When RAP is analysed, it generally comprises 4 to 5% bitumen by mass with the balance generally consisting of well graded, clean hard durable aggregate. It has significant commercial value primarily because of its quality mineral aggregates and bitumen. RAP can be used as aggregate and bitumen in new asphalt, granular pavement layers, general fill, and as a wearing course surface for gravel roads or parking areas.

The value of RAP is generally wasted when it is used in lower value applications such as granular pavement layers or fill, as the residual bitumen and high quality aggregate is not warranted in these applications. It may be appropriate to utilise RAP in these lower value applications when it is the only locally available material or where the RAP has been contaminated or is not viable to use in hot asphalt because of long haul distances. The benefit of using RAP in low value situations should be considered on a case-by-case basis.

RAP is typically recovered by milling or excavating existing asphalt pavements or as waste from asphalt production. RAP that is recovered by milling or as plant waste is generally clean RAP with no contaminates. RAP that is recovered to full depth by conventional excavation can become contaminated with granular base course during the removal process.

RAP is used in hot mix asphalt to varying degrees throughout the world. In United States of America approximately 80% of all States allow in excess of 25% RAP in intermediate and surfacing layer mixes, although only about 42% of states actually use in excess of 20% RAP in new pavements (Australian Asphalt Pavement Association, 2010).

In Germany a federal law was passed in 1996 that decrees wherever possible recycled materials are to be used over virgin materials during road construction. Therefore, asphalt produced from RAP that is of an equal quality to virgin aggregate must be given preference to a virgin mix (Nolting, Riebesehl & Denck, 2011).

The Netherlands are particularly focused on recycling due to the shortage of new mineral aggregates (coarse crushed stone) as well as limitations set to waste landfills and typically use up to 50% RAP in base course, binder course and dense wearing course mixtures (Mohajeri, 2015). Ongoing work is being carried out to increase the RAP content with the ultimate goal of 100% RAP mixes.

6.2. AVAILABILITY OF RAP IN WESTERN AUSTRALIA

RAP in Western Australia is quite a limited resource as most of the pavements comprise thin layers of asphalt on deep granular pavements, unlike other parts of the world that have had thick lift asphalt pavements for many years and their rehabilitation strategies require considerable depths of material to be removed.

Notwithstanding RAP does get collected in Western Australia and used by the asphalt suppliers on certain roads. In recent times the asphalt suppliers have seen the financial benefits of using RAP and are now consciously stockpiling the product with a view to incorporating it in larger quantity as time goes on and confidence in its use increases.

6.3. LIMITATIONS TO USING RAP

Currently Main Roads WA does not permit the use of more than 10% RAP into their mixes and they do not permit its use in the surface wearing course. Many Local Government bodies permit RAP and recycled glass to be used in their asphalt wearing course.

If higher percentages of RAP were permitted in the mixes, it is likely that the asphalt suppliers would invest more in their plant as the commercial gains are more considerable as the RAP content is increased.

6.4. WARM MIX ASPHALT

6.4.1. Introduction

Hot mix asphalt is manufactured by blending graded aggregates, mineral filler and bitumen together. The viscosity of bitumen is influenced by temperature, and the higher the temperature, the less viscous it becomes. Consequently, the asphalt is mixed at a temperature that ensures the mix is workable but the bitumen is not excessively oxidised by overheating it. The optimal temperature for hot mix asphalt is approximately 170^0C, if it is heated above these temperatures the bitumen deteriorates rapidly which influences the long term performance of the mix. Production of hot mix asphalt at lower temperatures results in reduction in the bitumen viscosity and oxidation, but presents problems with workability and compaction.

Warm mix asphalt (WMA) employs a technology that temporarily reduces the bitumen viscosity at lower temperatures by other means. This allows the mix to be manufactured at lower temperatures, keeping the mix workable and permitting compaction to take place.

6.4.2. Types of Warm Mix Technologies

There are numerous WMA technologies and products on the market, which rely on one of four of the following systems to temporarily reduce the viscosity of the bitumen

6.4.3. Free Water Systems

Free water systems blend the hot bitumen, water and compressed air in an expansion chamber which leads to a violent increase in volume of the bitumen. The hot bitumen converts the water to steam leading to the bitumen foaming. The foamed bitumen has a reduced viscosity but expands 5 to 6 times its normal volume due to the presence of bitumen bubbles filled with air and steam which allows it to be readily mixed with the aggregate. After the mixing process is complete the bulk of the foam has collapsed with a small quantity remaining as trapped bitumen foam in the asphalt. These trapped bubbles improve the workability of the mix and eventually collapse during compaction. After the mix has cooled it closely resembles conventional asphalt. The volume of water in the mix during foaming is less than 5ml/m^3 of asphalt mix. Consequently, moisture related issues are not a consideration. The free water system was adopted for the demonstration project discussed in this document. It was chosen as it has very low operating costs beyond the initial out lay. Typically, warm mix asphalt is placed at $13^0$0 C. Manufacturers are Astec, Gencor, Maxam, Meeker, Stansteel and Terex.

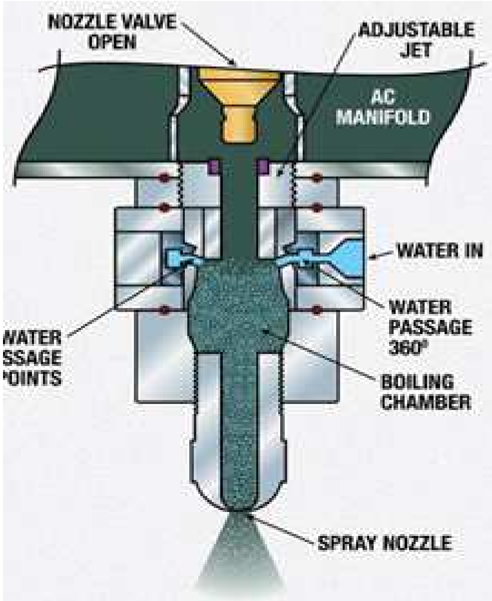

Figure 17 Cross-sectional detail of the foam injection nozzle (Astec)

Figure 18 Typical free water foaming manifold with 6 injection nozzles (Astec)

6.4.4. Water Carrying Additives (Chemical)

These additives are blended into the mix as a dry ingredient comprising 20% water and 80% mineral filler. When they are introduced to the mix the moisture converts to steam which in turn produces foam. WMA can be produced and placed at temperatures as low as 120^0C. The chemical water carrying additives are synthetic zeolites such as Aspha-min, and Advera WMA,

6.4.5. Water Carrying Additives (Non-Chemical)

The coarse aggregates are heated and blended with bitumen, followed by the addition of fines that are at a moisture content of 3%. The moisture in the fines generates steam which in turn creates foamed bitumen in the mix at temperatures as low as 100^0C.

6.4.6. Chemical Additives

Chemical additives can be introduced to reduce the internal friction of the mix. They have no effect on the binder properties and are typically blended or pumped into the plant. They include Evotherm ET, Evotherm DAT, Evotherm 3G, Cecabase and Hypertherm. Typical mixing temperatures are 85 to 140^0 C

6.4.7. Rheological Modifiers

Rheological modifiers are typically added into the bitumen or the mix and temporarily alter the binder rheological properties. As the mixes cool, the properties revert back to the original properties. Products include Sasobit, Rediset, TLA-X, Thiopave and Sonne Warmix. The recommended mixing temperatures are around 120^0 C. Sasobit is endorsed and used by MRWA as a means of reducing compaction temperature during multiple lift rehabilitation work and in situations where long haul distances are demanded. It has also been used during the manufacture and placement of open graded asphalt during the cooler winter months experienced in Western Australia.

It appears that the injection of water into the mix is the most effective long term solution as it requires an initial capital investment thereafter there is no cost for the additive. It appears as though the chemical additives and rheological modifiers pricing will be driven by the cost of energy. The pricing targeted to keep the product cost effective to warrant the savings of using it. As the price of energy escalates, so will the cost of the additive likely to rise. This is not likely to be the case with free water systems.

6.5. BENEFITS OF WARM MIX ASPHALT

In the US and Europe, it has been the contractors that have driven the adoption of WMA as it has been found to improve the quality of the completed mat. The benefits of using warm mix asphalt include, improved and extended workability, consistent compaction, energy savings, reduced emissions, extended paving season, increased haul distance, reduced issues with crack sealant, less oxidized binder at time of construction, reduced brittleness of binder improved rideability.

WMA can be adopted for most existing HMA mixes if the WMA technology is applied. The plants need to be modified to introduce one of the chosen technologies.

Testing by National Centre for Asphalt Technology (NCAT), Auburn USA, Kvasnak (2010) has found that the bitumen is less oxidized than HMA immediately after placement, but the rate of oxidation of binder in WMA is initially more rapid and is equivalent to HMA after 2 years. Laboratory testing of fresh WMA indicates that it is less stiff and or prone to rutting in the laboratory but this has not been experienced in the field.

Tensile strength ratio testing is considered one of the most important parameters of the WMA and although lower values are observed in the laboratory there has not been an increased occurrence of stripping in the field. The greater risk of manufacturing low temperature asphalt is the risk of not removing all the moisture from the aggregate at the lower temperatures during the drying and heating process. As a consequence, the dwell time in the plant is increased as the temperature is lowered. This has a direct impact on the production rate of the plant.

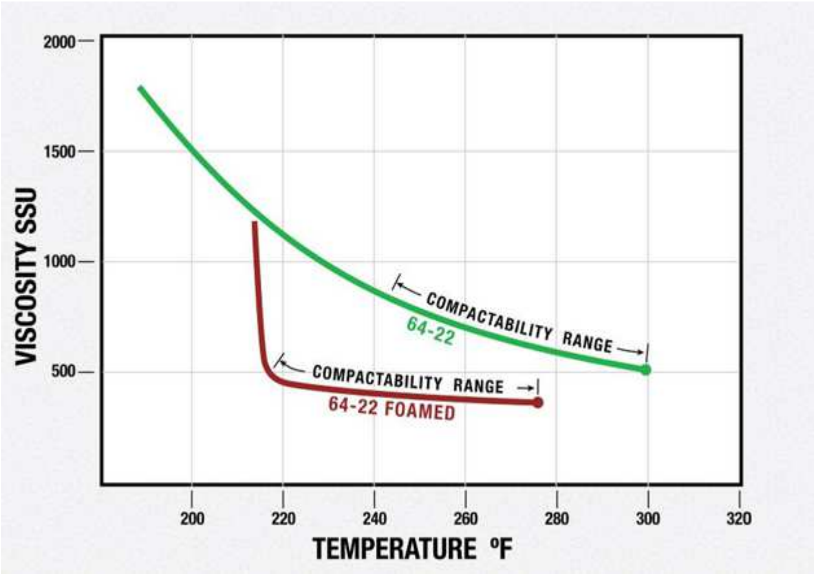

Figure 19 Relationship between binder viscosity, temperature and compaction

Figure 20 Fuming of HMA on left and no fuming of WMA on right

WMA is ideally suited to the inclusion of RAP as the residual stiffness of the oxidized binder in the RAP is offset by the reduced oxidation of the fresh binder when asphalt is produced as a WMA. There is a view that in some plants where the RAP is blended with the virgin stone, the harder binder pre-coats all of the aggregate, leaving the less oxidized binder available for the structure of the mix. This increases the durability of the mix in the longer term.

Typical hot mix asphalt is manufactured at 170^0C whereas warm mix asphalt can be produced at temperatures of the order of 130^0C or lower. This reduction in temperature has a significant impact on the heating energy costs. The lower mixing temperature leads to less fume/smoke production from the mix which is a health benefit to the asphalt placing crew. Mixing at lower temperature leads to less initial oxidation of the bitumen. Although not considered a major contributor to long term performance (Dickinson 1984) this reduction in construction related oxidation is still beneficial to performance.

6.6. IMPLEMENTATION OF WARM MIX ASPHALT IN WESTERN AUSTRALIA

Warm mix asphalt has been used in WA by Main Roads Western Australia (MRWA) in one form or another for many years as it recognized the benefit of using an additive to the bitumen which extends the compaction time of a hot mix asphalt. Research by Hurley (2005) of NCAT suggests that asphalt can be produced at 130^0C if Sasobit is used and compaction temperatures of 110^0C are possible, provided the aggregate is adequately dried.

6.6.1. Sasobit and Long Haul Distances

Sasobit is a pelletized wax, when added to bitumen temporarily reduces the viscosity of the bitumen whilst it is hot and does not appear to have any significant negative long term effect on the asphalt after it has cooled and is in service. It has been used in WA for a while, as it allows asphalt to be manufactured at 170^0C, and hauled significant distances. The long haul distances lead to cooling of the mix below normal desirable compaction temperatures and still allows a quality product to be placed. There have been situations where the mix has been hauled over 400km and the product successfully placed.

6.6.2. Sasobit and Polymer Modified Binders

Wearing and intermediate course asphalt mixes are being produced to new air voids specification (<7%) and require A15E binder to be used. The A15E binder is a blend of viscosity grade bitumen with about 6% SBS polymer added. The A15E binder makes the mix very difficult to compact as the temperature reduces. On major projects this product is placed throughout the year, and the low ambient temperatures lead to a rapid loss of temperature and a mix that cannot be compacted to less than 7% characteristic air voids in the mat, despite an increase of compactive effort.

The addition of Sasobit to the mix showed a marked increase in the workability, compaction temperature and density of the mat with the finished product achieving the specified compaction.

6.6.3. Sasobit and Warm Mix Asphalt in Road and Airport Rehabilitation

Rehabilitation of heavily congested freeways, airport taxiways and runways, can only be carried out within a very restricted time window of less than six hours at night. Deep lift asphalt up to 350mm thick is normally required and is placed in layers of about 80 to 100mm. The residual heat build up in the repairs, leads to temporary instability in the mix whilst it is hot and can lead to over-compaction or severe rutting when subject to traffic on opening. The use of lower temperature asphalt in these situations reduces the residual heat build up, completion time, and the risk of early age rutting. Mix temperatures as low as 140^0C have been used in these situations.

6.7. WMA AND RAP TRIALS ON GREAT EASTERN HIGHWAY, WESTERN AUSTRALIA

6.7.1. Implementation and Acceptance of WMA and RAP

The award of the Great Eastern Highway road project by MRWA to the City East Alliance was based on the premise that very high sustainability targets were achieved. As part of this sustainability KPI, the Alliance used recycled sand for fill, crushed recycled demolition waste for sub base. They also undertook to implement, demonstrate and construct warm mix asphalt with and without recycled asphalt pavement on the route. Free water foamed bitumen technology for the production of WMA was selected, as after the initial capital outlay, apart from routine maintenance of the foaming manifold, only water was required for the production of the foam.

To address the concerns of the introduction of the new technology, various implementation and risk work shops were held to address the concerns, and identify the scope of the work. The Alliance committed to an Astec free water foaming manifold which was retrofitted to the existing asphalt plant. Some compatibility issues were experienced with the retrofit which led to delays in the implementation of the WMA on the project, but were eventually resolved.

A trial section area along the route was identified and detailed plans were prepared so that the locations could be monitored in the future.

6.7.2. Trial Section Layout

The trials were located between the intersections of Belgravia and Belmont streets on the west bound carriageway but, were limited to the left through lane (outer lane). This section was chosen as it had the least number of residential and business accesses and would lead to the least amount of disruption should the section need to be closed for further monitoring and performance evaluation. Geotechnical Position Paper 7 Clayton (2010).

Asphalt mixes used in the trials were the MRWA approved Boral job mix 33 (JM33) which is a continuously graded 20mm mix using C320 binder that made up the bulk of the intermediate layers of the structural pavement. The layers were placed in lifts of around 60 to 85mm with a diluted cationic emulsion tack coat (CRS Cat 30) applied at each interface at a rate of around 0.6 L/m^2. The upper layer of the intermediate mix and the wearing course asphalt was the Boral (JM34), a 14mm continuously graded mix using an A15E polymer modified binder. The mixes were all compacted to 96% marshal density with a minimum allowable mat air voids content of 3%. A water proofing spray seal was applied on top of the first layer of 14mm mix and comprised a 10mm +5mm double-double seal using 2.0 L/m^2 of CRS60/170 applied as 1.1 and 0.9 L/m^2 to each layer respectively. Geotechnical Position Paper 7. Clayton (2010).

There are nine individual trial sections which are 110m to 150m in length which extended from chainage 3340 to chainage 4300. The aim of the trials was to construct individual sections that had only WMA with and without RAP at different locations within the pavement and compare the performance of each section over time against the control which is essentially the balance of the project.

RAP cannot be placed in a conventional dryer as the naked flame would burn, deteriorate and even ignite the bitumen bound to the RAP particles. RAP was limited to 10% by mass as the asphalt plants in Perth at the time had to dry and heat the RAP by blending it with the hot virgin aggregate as it entered the elevator and hot screening and storage bins.

The pavement has a sand subgrade with a design CBR of 12 and the sub base comprises a crushed limestone (calcarenite) or crushed recycled concrete. Due to construction expediency requirements Section 5a had an additional layer of 20mm DGA applied so a Section 5b was created to ensure all sections were of the same profile. Section 9 had a sub base of crushed recycled concrete and its performance could be ranked against Section 4 which was identical in all respects except it had a crushed limestone sub base.

6.7.3. Risk Assessment.

A very detailed risk assessment was undertaken by the Alliance, which was carefully recorded in the Alliance’s Geotechnical Position Paper 10a. Clayton (2010). The risks were identified and as part of the trials management or mitigation measures were implemented as required. The risks that were identified, included

- Variation of grading and binder content when RAP is used
- Moisture content in the RAP stockpile and the ex-plant WMA with RAP
- Clogging of the bag house system due to damp fines
- Poor aggregate coating
- Increased rutting due to under aged binder in the mix
- Poor fatigue properties due to RAP inclusion and WMA
- Asphalt deterioration due to stripping
- Ravelling of the wearing course due to poor adhesion and coating

Further workshops were arranged to align each of the contributors to the process and seek acceptance of the trials by MRWA branch heads that covered, Materials Engineering, Asset Maintenance, Major Projects Directorate, City East Alliance Board and the Commissioner of MRWA. A management plan was agreed and the trials were permitted to proceed, acknowledging that if they were successful they would make a significant contribution to both the industry and the environment.

6.7.4. Implementation of WMA

During the implementation of the WMA, the newly install foaming manifold was used to produce HMA (170^{0}C) and the paving crew immediately acknowledged that the product was easier to place and compact. There was a marked increase in the density achieved and the overall finish was improved. As a consequence, the foaming apparatus was used continuously during the production of the HMA for the entire project.

Continuously graded mixes (20mm and 14mm) were laid using C320 binder and the placing temperatures were lowered to 140^0 C. The workability was found to be quite acceptable with no detrimental effects on the asphalt test results.

The aim was to construct the WMA trials at 130^{0}C but during normal production as the temperature of the mix was reduced it was found that drying of the aggregate was not always satisfactory and binder coating was not acceptable. A temperature of 140^{0}C was found to be acceptable for the mixes produced with C320 binder.

6.7.5. A15E Binder Does Not Foam Well

During this process it was found that A15E did not foam very satisfactory and only small reductions in temperature were possible. Laboratory foaming trials carried out showed that the expansion ratios of foamed C320 were 6 to 7 with half-life of 120 seconds whereas the A15E had expansion ratios of 3 and a half-life of 60 seconds. Clearly the foaming properties of highly modified binders are impeded by the high viscosity irrespective of binder temperature.

Performance testing on WMA and WMA& RAP, included the evaluation of the mix modulus, indirect tensile strength, tensile strength ratio (TSR stripping evaluation), fatigue and wheel rutting showed no significant difference in the test results of mixes produced at 140^{0}C and at 170^{0}C.

6.7.6. Trial Pavement Construction

For the asphalt plant to accommodate the WMA trials the mix had to be produced first thing in the morning after which the plant temperature had to be increased back to conventional temperatures to meet the rest of their clients' needs. Clearly this restriction will remain a significant road block for the implementation of WMA on future projects unless there is a dedicated plant for the project, or there is an industry wide change.

The mixes were placed without significant event, but unfortunately the 14mm DGA with A15E layers cannot be considered WMA as it was not possible to lower the temperatures satisfactorily.

6.7.7. Trial Section Performance

The various trial sections comprising RAP/hot mix, RAP/warm mix at the time of writing the trials have been in place for three years and an annual visual inspection has not revealed any difference in the performance of the pavement. MRWA view this section as a long term trial and have on their business plan in the following years to extract samples to check lead indicator performance such as modulus, indirect tensile strength and possibly fatigue testing in the foreseeable future, to assess the performance.

7. USE OF RECLAIMED ASPHALT WITHOUT BLENDING

7.1. BACKGROUND

The City of Canning has had a policy of storing all road profiling from any road construction or maintenance operations for future use, and this includes reclaimed asphalt from profiling jobs where only thin layers of asphalt are removed prior to resurfacing.

For many years, the City offered free tipping at its landfill site for this material, and recycled the material in various layers depending on the type of road.

The material has been used widely as a sub base in heavy duty pavements, and as a base in residential pavements. Reclaimed asphalt has been used in hard stands, where over time with the heat of the sun in summer, the material becomes lightly bound and resists traffic quite well.

Over the years however, other organisations have realised the value of recycled pavement materials and the supply of free material from other road agencies has now become scarce.

7.2. PERFORMANCE

The City has undertaken no specific performance tests on the recycled asphalt material, but has been able to monitor the performance of roads using recycled materials for many years. In the case of heavy duty pavements carrying significant truck traffic, it has only been used as a sub base, there have been no performance issues observed in the 25 year history of using this material in a sub base application that could be attributed to the sub base.

In the case of lower volume roads, such as Carden Drive in Cannington, the entire road was constructed using reclaimed pavement material with a large proportion of asphalt. This road carries 1700 vpd with 4% heavy vehicles and is now 22 years old and showing no signs of distress. The pavement consists of 300mm of RAP on a sandy clay subgrade with 30mm asphalt surfacing.

Many other existing pavements in Canning in residential areas have been constructed with RAP and are performing as well as any conventional pavement after more than 20 years, showing no signs of distress.

7.3. CONCLUSION REGARDING THE USE OF RAP WITHOUT BLENDING

Reclaimed pavement from old road pavements can successfully be used as a base in low volume roads and as a sub base in high volume roads. Where a high proportion of asphalt exists in the reclaimed material, it makes an excellent hardstand surfacing for informal truck and machinery parking areas, and will over time under the influence of heat from the sun, become sufficiently bound to remain stable under turning vehicles.

8. RECYCLED PLASTIC IN ASPHALT

According to A'Vard, D. and Allan P. (2014) the plastic recovery rate in Western Australia is 8%:

> "*Overall plastics consumption in Western Australian during the 2013–14 financial year was 168,200 tonnes, based upon a per capita estimation using national overall plastics consumption data. Overall recovery of plastics from WA during the same period was 13,400 tonnes, giving an overall plastics recycling rate of 8%*."

This provides the opportunity to incorporate recycled plastic into asphalt mixture aiming to reduce the plastic waste and its undesirable environmental consequences. For this reason, the performance testing of modified asphalt mixtures by recycled plastic before application to the road's pavement is essential.

8.1. EXPERIMENTAL STUDIES AT CURTIN GEOMECHANICAL LABORATORY

This section is a summary of studies carried out at Curtin University Geomechanical Laboratory on different recycled plastic additives as binder modifiers. A Cooper wheel tracking apparatus was used to measure the rutting resistance, Four Point Bending Beam apparatus (provided by IPC Global Australia) used to study the fatigue performance and IPC Universal Testing Machine (UTM-25) used to conduct Indirect Tensile Test to obtain resilient modulus of asphalt mixes. The asphalt mix which is used as control mix in the entire program was AC10 with 75 marshal blows containing bitumen class 320. Mix aggregates were provided by BGC Hazelmere WA. Table 22 shows the standards followed for each testing type. It should be noted that the percentage of all modifiers presented in this section are percentages by mass of bitumen.

It must be noted that these projects were undertaken as final year undergraduate research projects and sample sizes were small. Trends may not be statistically reliable. Only the results of wheel tracking tests are reported in this paper as there is a lack of consensus on the reliability of the interpretation of the fatigue and modulus test data.

Table 22: Standards followed to investigate on rutting resistance, fatigue performance and resilient modulus

Test	Standard
Wheel Tracking	AG:PT/T231 (2006)
Four Point Bending Beam	AG:PT/T233 (2006)
Indirect Tensile Test	AS 2891.13.1 (2013)

Plastics were blended by two methods depending on the melting point of the plastic. Where the melting point was lower than the temperature of the hot bitumen a high shear mill was used. Where the melting point of the plastic was higher than the bitumen temperature, the plastic was added to the hot aggregate.

8.2. THE EFFECTS OF PLASTIC ON ASPHALT PROPERTIES

Average test results on rut depth asphalt mixes modified by waste plastic additives are summarised in Table 23. According to Table 1, increasing the percentage of bitumen modifiers resulted in improved rut resistance.

Table 23: Summary of test results on rutting performance of asphalt mixes modified by waste plastic additives

Researcher	Modifier Type	% Modifier	Average Rut Depth (mm)
Elamen E. (2013)	Control Mix	0	5.05
	HDPE & EPDM	1.5	2.7
		3	2.25
		6	1.3
Li K. (2014)	Control Mix 1 (Sup. B)	0	5.05
	Control Mix 2 (Sup. B)	0	2.6
	EVA	3	4.4
		6	3.9
	PP (Sup. A)	1.5	5.2
		3	4.15
		6	1.9

9. RECYCLED GLASS IN ASPHALT

9.1. BACKGROUND

In 2002, Meda Sicoe of Fulton Hogan (then Pioneer Road Services) approached the City of Canning requesting permission to undertake trials of reclaimed glass in asphalt. The aim of these trials was to determine if the proportion of glass then being rejected for recycling back to glass could be used in asphalt instead of being landfilled.

The City of Canning agreed to the trials, and a very basic method of introducing the glass to asphalt was adopted. This involved screening the glass to remove light weight contaminants, and crushing the glass with a roller. The asphalt was laid in two locations, Ranford Road in Canning Vale which is a very heavily trafficked road, and Glennon Way, a lightly trafficked residential street.

Due to the size of the glass particles, interesting spectral results were achieved at night under lights, but no other significant performance differences have been noted over the succeeding 14 years. As part of a trial to determine the effects of early skid resistance of Stone Mastic Asphalt, by chance SMA and glass asphalt were laid at the same time in Ranford Road, and testing by WA Police showed the glass asphalt had slightly better skid resistance than both SMA and conventional dense grade asphalt without glass.

Following these trials, Fulton Hogan established a glass crushing plant and commenced producing asphalt for the City of Canning containing a minimum of 5% crushed glass, and by 2011 had used over 100,000 tonnes of otherwise wasted glass in asphalt.

The reuse of glass has now become more critical in WA, as there is no glass reprocessing plant in WA, and the market prices for clean reclaimed glass is such that it is no longer economic to transport glass to Adelaide for reprocessing.

9.2. PROPERTIES OF GLASS ASPHALT

It is always essential when changing the constituent materials in a product to ensure that the performance of that product is not compromised. Fulton Hogan undertook extensive testing on a range of asphalts with and without glass, and with and without RAP (reclaimed asphalt pavement). These tests showed that the performance of the asphalt was not affected by the glass.

9.2.1. Particle Size Distribution

The glass is crushed to a size of 3 mm maximum size, and the particle size distribution of the glass is shown in Table 24.

Table 24: Particle size distribution of crushed glass

AS 1152 sieve size (mm)	Min.	Max.
4.75		100
2.36	80	100
1.18	0	30
0.6	0	12

The glass is then blended into the asphalt to replace the sand size particles, whilst retaining the design job mix specification for each mix

9.2.2. Trial mixes with and without crushed glass

The trial mixes manufactured to compare the performance of the asphalt containing glass to conventional mixes are shown in Table 25. The mixes cover a range for light duty to heavy duty applications.

Table 25: Trial mixes tested with and without glass

Trial mix size	Trial mix grading	Marshall blows	Application	Glass added
10 mm	Dense	50	medium traffic	none
10 mm	Dense	50	medium traffic	5%
10 mm	Dense	75	heavy traffic	none
10 mm	Dense	75	heavy traffic	5%
7 mm	Dense	50	light traffic	none
7 mm	Dense	50	light traffic	5%
7 mm	Dense	35	light traffic	none
7 mm	Dense	35	light traffic	5%

9.2.3. Indirect tensile (resilient) modulus of asphalt containing crushed glass

Indirect tensile modulus is a fundamental property of asphalt that relates to the way a pavement will behave under load. The results of testing are shown in Figure 21. These results show that the glass has no significant effect on the indirect tensile modulus of the asphalt when glass is added in lieu of sand.

9.2.4. Fatigue testing of asphalt containing crushed glass

Testing for the fatigue performance of glass asphalt was undertaken on the trial mixes. These results showed some possible effects on the fatigue performance of asphalt by the addition of glass. Tests were undertaken at two strain levels, both well above what the design strain level would be in a normal application in deep strength asphalt. The testing at 130με, showed an improvement in fatigue performance for the 10mm/50blow and the 7mm/35 blow mixes, but a decrease for the 10mm/75 blow and 7mm/50 blow mixes. At 700με only the 7/35 blow showed a higher fatigue life for glass asphalt, however this is an unrealistic strain in pavement applications.

It should be noted that only 3 beams were tested at each strain level and these results are not statically significant. Further testing over a larger number of beams would be required to determine the effects, however on the basis of this testing, there is little evidence that the glass has an effect on fatigue.

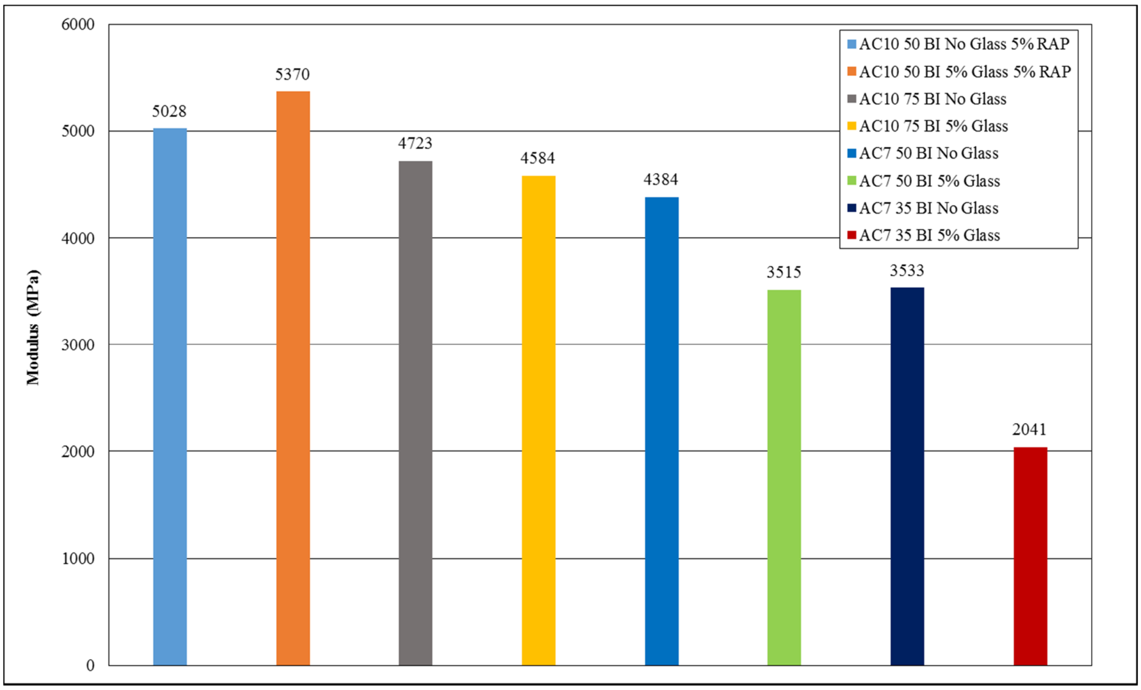

Figure 21: Indirect tensile modulus test results on asphalt containing glass

9.2.5. Tensile strength ratio of asphalt containing crushed glass

The tensile strength ratio is a test to determine the moisture sensitivity of an asphalt. The higher the ratio, the less susceptible to moisture damage an asphalt will be. Figure 18 shows the results of the testing undertaken on the trial mix. There is no significant difference between conventional asphalt and glass asphalt.

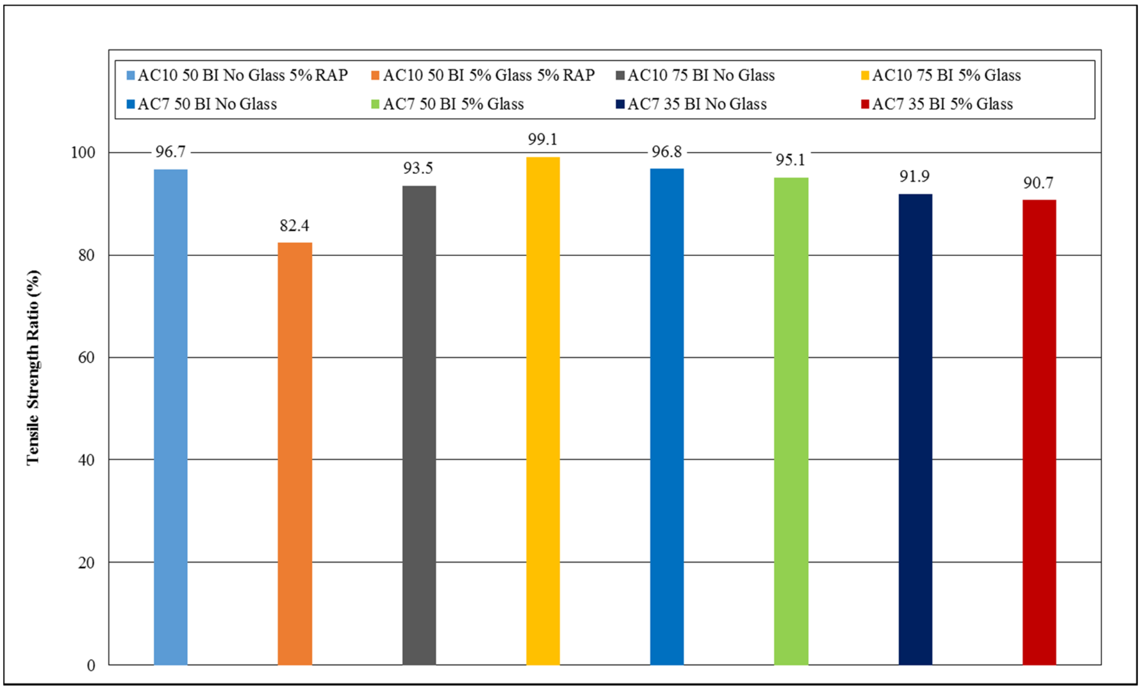

Figure 22: Indirect tensile strength ratio test results on asphalt containing glass

Table 28: Fatigue Testing of Asphalt with Crushed Glass

Nominal size (mm)	Marshall blows	Glass added	K	n	R^2	Cycles to failure	
Applied strain						130µe	700µe
10	50	None	10076	3.95	1	2.87×10^7	37,365
10	50	5%	2168	7.5	1	1.46×10^9	4,810
10	75	None	2778	6.36	0.99	2.91×10^8	6,465
10	75	5%	2226	5.98	1	2.36×10^8	1,008
7	50	None	3853	5.78	1	3.21×10^9	19,113
7	50	5%	2719	6.66	0.96	6.16×10^8	8,375
7	35	None	2373	7.12	0.96	9.58×10^8	5,956
7	35	5%	2658	6.91	0.98	1.14×10^9	10,103

9.3. DISCUSSION ON THE USE OF CRUSHED GLASS IN ASPHALT

The application of glass asphalt in the City of Canning has diverted a large quantity of glass from landfill to a useful application. There is no evidence from the test data or from the field that the application of glass in asphalt is detrimental to the performance of the road surfacing. The City of Canning requires that all of its asphalt with the exception of Stone Mastic Asphalt contains 5% glass, and further testing to determine if this can be raised is continuing.

Increasing the glass content of asphalt significantly above 5% is not recommended at this stage as the risk of moisture susceptibility may increase.

Recycling glass by crushing it and using as fine aggregate in asphalt is not a high end use of a material that takes a lot of energy to produce in the first place. Recycling of glass containers as glass would be preferable. This is currently not economic in WA as there is no glass recycling facility in this State. Crushing glass and using it in asphalt is preferable to burying it in a landfill but should be seen as an interim step until full glass recycling is available in WA.

10. SCRAP RUBBER IN BITUMEN SPRAY SEALS

10.1. BENEFITS OF SCRAP RUBBER IN SPRAY SEALS

Scrap rubber, more appropriately described as granulated or crumbed rubber, typically derived from vehicle tyres, may be used to modify bitumen to improve its performance in sprayed surfacing treatments. The use of this type of binder in Western Australia was initiated by Main Roads WA to utilise what would otherwise be scrapped vehicle tyres and at the same time provide an improved binder for use when standard bitumen did not perform adequately such as when sealing cracked pavements. Typically cracks in a pavement will reflect through a thin bituminous surfacing unless it is specifically designed to minimise reflection cracking. Use of rubberised binders provides one means of minimising such cracking. As use of rubberised binders has largely been confined to Main Roads WA, most other authorities preferring use of alternative commercial polymer modified binders, this report mainly focuses on the practices of the Main Roads WA.

10.2. TERMINOLOGY FOR SCAP RUBBER SEALS

The terminology used in this paper generally conforms to Australian Standards, Austroads or Main Roads WA terminology. The fundamental terms used are as follows:

- Bitumen – a very viscous liquid or solid consisting of hydrocarbons and their derivatives which is substantially non-volatile and softens when heated. It is obtained from native asphalt or by refining petroleum oils in a refinery.
- Polymer modified binder – A binder consisting of polymeric materials dispersed in bitumen with enhanced binder performance for particular applications.
- Scrap rubber/crumbed rubber/ granulated rubber - Rubber particles manufactured from waste or reclaimed rubber products such as vehicle tyres and graded to conform to a specified size range. Typically, it comprises a mixture of Styrene Butadiene Rubber, Butyl Rubber and Natural Rubber, depending on the source and the rubber has been vulcanised during the tyre manufacturing process.
- Rubberised Bitumen – A bituminous binder containing a dispersion of from 5 to 25% by mass of crumbed rubber. It comprises a two phase system of vulcanised rubber particles dispersed in bitumen where the particles are partially digested and partially swollen by the digestion of bitumen oils.
- Sprayed sealing – The sprayed application of a bituminous binder followed by an application of aggregate. This may comprise multiple coats of binder and aggregate.
- Strain Alleviating Membrane (SAM) – Application of a sprayed seal using a rubberised bituminous binder as a final surfacing treatment.
- Strain Alleviating Membrane Interlayer (SAMI) - Application of a sprayed seal using a rubberised bituminous binder as a treatment prior to application of a thin asphalt overlay.
- Waterproof Membrane for Concrete Bridge Decks - Application of a sprayed seal using a rubberised bituminous binder to a concrete bridge deck as a treatment prior to application of a thin asphalt overlay.

Main Roads WA typically differentiates between use of crumbed rubber modified binder and other polymer modified binder. This does encourage use of scrap rubber and help reduce the disposal problem of the estimated 1.8 million vehicle tyres scrapped each year in Western Australia (Waste Management Board. November, 2005).

10.3. HISTORICAL BACKGROUND ON THE USE OF SCRAP RUBBER IN WA

Main Roads WA began investigating the use of crumbed scrap rubber in bituminous binder in the late 1970s. At this time use of rubberised binder was in its infancy in the eastern states and there were no commercially available supplies in Western Australia.

Main Roads WA sourced the waste rubber ground off vehicle tyres by tyre retreaders by providing waste bins at the premises of a number of tyre companies. This material was collected, stockpiled under cover, then commercially screened to an appropriate size and handling and performance trials commenced. The Plant section of Main Roads developed suitable blending facilities and road trials commenced in May Drive Kings Park in 1980 (a SAM trial) and on the Heirrisson Island section of the Causeway in 1982 (a SAMI trial). These sections of pavement were badly cracked (the underlying pavement on Heirrisson Island was laterite and there was large block cracking and pumping of fines). Conventional seals would not have prevented reflection cracking. Both trials were successful and wider use of rubberised binders followed, their use expanding to include application on concrete bridge decks. Supply of scrap rubber ceased being a problem as commercial companies made appropriate recycled rubber crumb available and binder suppliers marketed pre-blended rubberised binder.

Further trials were carried out on a badly cracked rural road to extend performance based knowledge of modified binders. These trials included scrap rubber modified binder and proprietary polymer modified binders (Leach & Hardiman 1994 and 1996). Although the trials indicated a range of binder types could be used satisfactorily, in the main use of scrap rubber modified binders was limited to the Metropolitan area because of handling and logistic difficulties. It was generally focussed on applying SAMIs when resurfacing Perth's Main Roads, Highways and Freeways.

At the same time as the first field use was being made of rubberised bitumen, ARRB was investigating the theoretical basis for specifications for the rubber crumb and how to obtain the most effective dispersion of the particles (Dickenson E J, 1984). This work provided a scientific basis for best practice specifications and binder preparation.

10.4. THEORETICAL CONSIDERATIONS

It has long been known that cracks in pavements usually reflect through thin bituminous surfacing in a relatively short time, depending on the nature and cause of the cracks.

Modification of the flow and deformation properties of bitumen by adding elastic polymers was investigated by Oliver and Dickinson (1977). Their work included investigation of blends of scrap rubber blends in bitumen and the effect of the nature and production method of the crumbed rubber on the modified binder properties, a key property being elastic recovery.

It was found that for all types of scrap rubber, increasing the concentration in the mixture produced an increase in the elasticity of the product. It was also found that differences in the composition of the scrap rubber in terms of the types of rubber present and the method used to produce the scrap rubber influenced the elasticity of the blend.

Rubber particles produced by a tearing process such as rasping at ambient temperature were found to interact much more readily than those produced by hammer milling of rubber cooled by liquid nitrogen. Microscopic examination indicated that the morphology of the rasped particles included surfaces covered with porous sponge like nodules while the low temperature produced particles had smooth faces. This discovery lead to the development of a method of assessing morphology which is now included in most specifications for crumbed rubber.

Oliver (1982) investigated the effect of the temperature and time of digestion of the scrap rubber in bitumen in terms of the types of rubber in the scrap rubber. This work showed there were significant differences and that both temperature and time should be controlled. These requirements are now reflected in specifications.

The use of scrap rubber to modify bitumen does more than improve elastic properties. It also has the following effects (Scrap Rubber Bitumen Guide 1995):

- An increase in the softening point temperature
- A reduction in the temperature susceptibility (lowering of brittleness temperature)
- An increase in resistance to deformation under stress at high temperatures
- An increase in ductility at low temperatures.

These properties make scrap rubber modified bitumen ideal for use at the relatively high binder application rates that are necessary to mitigate the risk of reflection cracking. Although there is not complete understanding of all factors involved in reflection crack alleviation, SAM and SAMI treatments are considered most effective when the existing pavement or surface cracks have relatively stable fatigue cracks. The treatment of shrinkage cracks which open and close markedly with changing environment is not as effective, although some reduction in the extent and width of reflection cracking can be expected. SAMs or SAMIs are only intended for application to pavements, which are basically sound structurally, apart from the occurrence of cracks. The treatments should be carried out before the pavement has been weakened by the ingress of water through the cracks.

10.5. RECENT USES OF RUBBER SEALS IN WA

In the Metropolitan region of Perth, the primary use of rubber seals has been as 14mm/7mm double/double reseals with 15% rubber in the binder. The objective has been improved stone retention and reduced temperature susceptibility of the binder.

Since 2010 over 100 sections have been sealed in the Metropolitan region using rubber seals as a Strain Alleviating Membrane (SAM). Initially only using medium curing cutting oil (2%) when conditions were cool at night, but later the addition of cutting oil became routine. Geotextile Reinforced Seals (GRS) now routinely include 5% rubber to reduce the risk of flushing.

In 2014 resurfacing was carried out on the heavily trafficked Great Northern Highway about 100km north of Perth (in a rural region) with a 16mm/10mm double/double reseal using S45R binder.

In 2014 resealing (SAM) trials were carried out using S45R binder on the Leonora Laverton Road (about 100km from Perth). One of the objectives of the trial was to demonstrate that S45R can be transported long distances without the binder deteriorating. The existing road had extensive block cracking and a low traffic volume (75 vehicles per day in each direction with about 30% heavy vehicles). The binder application rate for the S45R was 2.4 to 2.5L/m^2. A problem that can occur with rubber seals is an uneven lateral distribution of binder leading to a defect referred to as "tram tracking". On the Leonora Leinster road trials this problem was overcome by using A4 spray nozzles, doubling the standard number of pump revolutions and doubling the spray truck speed.

10.6. MAIN ROADS WA GUIDELINES ON THE USE OF SCRAP RUBBER IN SEALS

The basis for Main Roads requirements for the use of rubberised bitumen is given in Engineering Road Note No 7 (ERN 7) "Bitumen Scrap Rubber Seals", which was first issued in 1985. This Road Note was upgraded and re-issued in 2003. This road note has been augmented by Main Roads WA Specification 503 "Bituminous Surfacing" and Specification 511 "Materials for Bituminous Surfacing".

ERN 7 (2003) provides the following guide to the proportion of scrap rubber required in the binder blend for various uses, the proportion of MC Cutter to be added and binder application rates. These guides are summarised in the following tables.

Table 29: Recommended Proportions of Scrap Rubber for the various Uses

Use	% Rubber Content (by mass of residual binder excluding MC Cutter)
SAM	15 - 18
SAMI	17 - 20
Waterproof Bridge Deck Membrane	20
Double coat geotextile seals (from MR Specification 503)	5

Note the rubber should be considered part of the residual binder.

Reference should be made to ERN 7 and Specifications 503 and 501 for design guidance and material property requirements. These documents are available on the Main Roads WA web site.

10.7. CONCLUSIONS REGARDING THE USE OF SCRAP RUBBER

Bitumen scrap rubber sealing has been used by Main Roads WA to alleviate reflection cracking and waterproof concrete bridge decks since the 1980s. Use was initiated after road trials to verify the effectiveness of SAM and SAMI treatments. The ongoing use of these treatments has been successful and a large portion of the metropolitan main road, highway and freeway system has been resurfaced using a SAMI prior to re-sheeting with a thin asphalt surfacing. More recently use of scrap rubber sealing has been extended into double coat geotextile sealing to minimise the risk of surface cracking. Besides being cost effective, treatment with scrap rubber sealing does have environmental benefits in helping to reduce the problem of disposal of used vehicle tyres and is expected to remain a standard construction technique.

11. RECYCLED PLASTIC IN PERMEABLE PAVEMENTS

Geocells manufactured from 100% recycled high density polypropylene have been used with free draining aggregate in fill on very lightly loaded pavements in WA. The figure below is of a road in the Sea Spray Caravan Park near Perth that has given several years of satisfactory service.

Figure 23: Nero Pave permeable pavement

12. CONCLUDING COMMENTS

Western Australia has a good history of carrying out research and construction of demonstration road pavement projects incorporating recycled materials. The use of RAP (at a low percentage) in asphalt has become routine as has the recycling of existing granular pavement materials using cement and foamed bitumen. The use of scrap rubber in bitumen seals looked like becoming routine in the 1990s but contractors found it more convenient to use polymers.

Some Councils such as the City of Canning have become leaders in the use of recycled construction and demolition material, RAP and crushed glass in pavements.

At this stage it is recommended that CRC and CDM be treated as bound materials when designing heavily trafficked road pavements.

Areas requiring further research before routine application are the use of recycled plastic and scrap rubber in asphalt.

13. DISCLAIMER

14. ACKNOWLEDGEMENTS

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