An Investigation into the Performance of Recycled Concrete Aggregate as a Base Course Material in Road Pavements

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Synopsis: Recycled crushed concrete and demolition materials have been trialed successfully in a number of locations in Western Australia, but industry acceptance of the material has been slow. Specifications currently in use have been modified from specifications for new quarried products, and there has been some doubt about the long term performance and quality control of recycled products. This paper analyses the performance of recycled concrete pavements that have been constructed in Western Australia, and details the extensive laboratory testing programme undertaken to model the product and compare its performance to conventional quarry products. The relative performance of blends of concrete and clay brick and tile has also been studied. The laboratory and field testing demonstrates good quality control and performance superior to conventional quarry products. However laboratory testing has not fully described the high insitu stiffness, and the paper outlines areas of further research proposed

Keywords: shear recycled crushed concrete, specification, performance.

1. Introduction

This report documents WA experience in the use of recycled roadbase sourced from demolition materials and investigates the properties and performance characteristics of both recycled products and new quarried roadbase to enable a comparison of performance. It is only a summary of the work undertaken, and readers are referred to listed references [1-3] for greater detail. A specification for recycled products is developed in [1].

The following terms are used in this paper. The company identifier is only used when reference to a specific source is required.

- Crushed granite roadbase company X = CGRB (X)
- Crushed recycled roadbase containing concrete only company Y = CCRB (Y)
- Crushed recycled roadbase containing mixed demolition materials company Z = CDRB (Z)

2. Western Australian Experience with Recycled Roadbase

The have been two major field investigations using recycled crushed demolition materials in Western Australia:

- Gilmore Ave, Town of Kwinana constructed January to April 2003 [3]
- Welshpool Road, City of Canning constructed November 2007 to February 2008 [2]

These are not considered trials in the true sense, as there is sufficient evidence that recycled demolition materials can be successfully used to construct pavements. These field investigations were undertaken to refine the knowledge base surrounding the use of these products and to refine the specification and design methods applicable to pavements constructed using these materials.

Further investigation has been undertaken on a third section of road, Warton Rd, City of Gosnells constructed March 2009 was undertaken following concerns during construction of excessive stiffness.

In addition, an extensive survey was undertaken in Western Australia in 2007/2008 [4] to determine the consistency of roadbase manufactured from recycled demolition materials in WA.

A major study into the properties of CCRB and CDRB compared to CGRB was undertaken by ARRB Group and Curtin University in 2010 [1]. This study found that the recycled products performed as well or better that quarried roadbase. Details of these studies are detailed in the following sections.

2.1 Gilmore Ave

Gilmore Avenue is a district Distributor Road joining Thomas Road (Primary Distributor) in the north and Mandurah Road in the south. The 20 year design traffic was estimated at 4.5 x 10^6 ESA. Based on a subgrade design CBR of 12% the following pavement profile was required:

- Dense graded Asphalt = 30mm
- Base Course (crushed granite roadbase (CGRB) crushed demolition roadbase (CDRB)) = 125mm
- Subbase Course (Limestone) = 150mm

Trial sections of 400m length each were constructed using a base course of CRB and CRC, with similar surfacing and subbase throughout. Whilst not stated in the report, it appears from photographs and test results that the CDRB may have contained some clay brick and tiles, but also contained a significant proportion of structural grade concrete which may be an important factor as will be discussed later. Significant aspects of testing both during and post construction are covered in the following sections.

An important note is that at sealing, the moisture content in the pavement was high at 86% OMC. The significance of this will be discussed later.

2.1.1 Deflection Testing

Initial deflection testing on Gilmore Ave was undertaken using the Benkelman Beam. Results are shown in Table 1. Further deflection testing was undertaken in October 2010 using a Falling Weight Deflectometer (FWD). A summary of the test results is shown in Table 2.

Table 1. Benkelman Beam test results

Deflection parameter	Type	May 2003		October 2003		June 2004		September 2004	
		Curv. (mm)	Max. defl'n (mm)	Curv. (mm)	Max. defl'n (mm)	Curv. (mm)	Max. defl'n (mm)	Curv. (mm)	Max. defl'n (mm)
Mean	CGRB	0.153	0.425	0.109	0.410	0.103	0.328	0.142	0.429
Std dev		0.047	0.079	0.040	0.087	0.025	0.060	0.050	0.094
90th %ile		0.209	0.507	0.158	0.517	0.138	0.403	0.205	0.535
No tests		108	108	108	108	107	107	108	108
Mean	CDRB	0.071	0.413	0.071	0.413	0.039	0.261	0.053	0.377
Std dev		0.031	0.053	0.031	0.053	0.023	0.064	0.026	0.065
90th %ile		0.113	0.469	0.113	0.469	0.065	0.324	0.083	0.443
No tests		76	76	76	76	75	76	72	72

Table 2. FWD test results at 7 years

Deflection parameter	Type	October 2010	
		Curv. (mm)	Max. defl'n (mm)
Mean	CGRB	0.125	0.343
Std dev		0.028	0.068
90th %ile		0.168	0.443
No tests		54	54
Mean	CDRB	0.086	0.373
Std dev		0.027	0.071
90th %ile		0.128	0.509
No tests		44	44

The results between the Benkelman Beam and the FWD are not directly comparable, but the results do indicate that the recycled base is significantly stiffer than the granite roadbase given the significantly lower curvature values.

2.1.2 Particle Size Distribution and Atterberg Limits

Testing for particle size distribution showed that the recycled material was slightly deficient in fines, but that Atterberg limits were within the specification when compared to the MRWA specification 501 which is the defining specification generally adopted in WA.

2.1.3 Unconfined Compressive Strength (UCS)

In testing for unconfined compressive strength (UCS) in Gilmore Ave, the mean UCS was found to be in the order of 0.85 MPa. The acceptable range of UCS values for laboratory specimens is 0.4-1.0 MPa. The results suggest that the UCS of the CDRB is well below the upper limit of 1 MPa and therefore requires no pre-treatment such as wetting and drying cycles at the plant site [3]. This assumption will be discussed later as some cementing has been noted in subsequent years.

2.2 Welshpool Road

Welshpool Road is a major arterial road linking Albany Hwy to Leach Hwy and Roe Hwy and further to Kalamunda. Llocated in an industrial area it carries a significant number of heavy vehicles including road trains and extra wide low loaders serving several heavy engineering construction companies.

The pavement under consideration is an 860m section of Welshpool Road from west of Sevenoaks St to Leach Hwy in Welshpool. The 4 lane undivided road, was widened to include a 6m median, wider lanes and turn pockets. This involved a 4.5m widening each side or the existing pavement. The road carries approximately 8,030vpd in each direction with 15% heavy vehicles giving a design traffic of approximately 20 million standard axles over a 30 year design life.

Four pavement sections were constructed as follows:

- 250mm CDRB subbase with 150mm CGRB base (control section)
- 250mm CDRB subbase with 150mm CDRB base
- 250mm CDRB (50) subbase with 150mm CCRB base
- 250mm CCRB with 150mm CCRB base

All sections are on sand subgrade with design CBR of 10% and were surfaced with 30mm 10mm/75blow Marshal asphalt. The CDRB (50) was a special run of 50mm all in recycled demolition material (i.e. containing brick and tile).

Details of the more significant tests are discussed in the following sections.

2.2.1 Repeat Load Triaxial Testing (RLTT)

Repeat load triaxial testing is considered to be one of the better indicators of performance for unbound granular materials [5]. Samples of the three base course materials were tested by ARRB Group laboratories in Melbourne and are detailed in Table 3.

Table 3. Repeat load triaxial test results for Welshpool Rd base material

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

The results show that the CCRB and CDRB are stiffer than the CGRB and are less moisture sensitive. The control material CGRB (new quarried roadbase) failed the test at the higher moisture contents, and it should be noted that the minimum dryback requirement in MRWA Specification 502 is 60%. The straight recycled concrete (CCRB) is stronger that the commingled CDRB.

2.2.2 *Falling Weight Deflectometer Testing (FWD)*

FWD testing was undertaken at both the subbase and base course levels as well as the completed surface. FWD test results for testing undertaken on the top of base are shown in **Error! Not a valid bookmark self-reference.**. Curvature values indicate that the CCRB and CDRB are stiffer than the CGRB, confirming the RLTT results.

Table 4. Welshpool Rd FWD test results on top of base

Pavement construction	Deflection @ 700 kPa			Curvature @ 700 kPa		
	Mean (mm)	Std dev. (mm)	95th %ile (mm)	Mean (mm)	Std dev. (mm)	95th %ile (mm)
250 mm co-mingled recycled / 150 mm roadbase	0.59	0.06	0.65	0.21	0.03	0.25
400 mm co-mingled recycled	0.46	0.05	0.53	0.15	0.02	0.17
250 mm 50 mm co-mingled recycled / 150 mm recycled concrete	0.46	0.05	0.51	0.13	0.02	0.16
400 mm recycled concrete	0.49	0.05	0.57	0.15	0.03	0.20

2.3 *Warton Road*

Warton Road is an arterial road in City of Gosnells, linking Nicholson Road in the south to Albany Hwy in the north. The road carries significant heavy traffic, but traffic counts are not available at this time. City of Gosnells staff expressed concern regarding the apparent stiffness of the recycled base. Investigation revealed that the source material was straight recycled crushed concrete sourced from mainly structural grade concrete (CCRB (A)). Pavement construction details are:

- 30mm asphalt
- 200mm CCRB
- 350mm limestone
- sand subgrade

Details of FWD and RLTT testing follows.

2.3.1 *FWD Testing*

FWD test results after construction are shown in Table 5. These results indicate a strong and stiff pavement structure.

Table 5. Warton Rd FWD test results on finished pavement

Pavement construction	Deflection @ 700 kPa			Curvature @ 700 kPa		
	Mean (mm)	Std dev. (mm)	95th %ile (mm)	Mean (mm)	Std dev. (mm)	95th %ile (mm)
30mm AC/250 mm CCRB (A) / 350 limestone	0.200	0.019	0.226	0.052	0.019	0.090

2.3.2 *Repeat Load Triaxial Testing*

Repeat load triaxial testing was undertaken on samples extracted from Warton Rd. The results are shown in Table 6. This result indicates a strong material.

Table 6. Repeat load traixial testing on Warton Road material

Material constants after regression					Modulus (MPa) at specific stress state σ_1, σ_2			
Material	**% OMC**	**K_1**	**K_2**	**K_3**	**σ_1 kPa**	**200**	**400**	**240**
					σ_2kPa	**50**	**50**	**94**
CCRB (A)	60	432.5	0.5860	0.0327		440	600	540
CCRB (A)	80	351.1	0.2893	0.4113		440	610	480

2.4 Curtin University SWIS Research

Curtin University successfully applied for a grant under the Strategic Waste Initiative Scheme (SWIS) to further research the properties of recycled roadbase materials and compare the properties to conventional quarried road base.

Three sourced of recycled products, either CCRB (concrete only) and CDRB (comingled concrete, brick and tile) were examined from companies A, B and C and two compared to two quarried granite road base materials sourced from companies D and E. Company A supplied the material for Warton Road and Company B supplied the material for Welshpool Road. The company that supplied for Gilmore Ave no longer produces, as is the case for company B which ceased production in 2010.

A comparison of modulus values of recycled concrete roadbase and new quarry products confirmed the WA findings that the recycled materials outperform newly-quarried products. (Andrews 1998). Details of the more significant tests are given in the following sections.

2.41 Repeat Load Triaxial Testing

Repeat load triaxial testing was undertaken on three samples of each material at 60%, 80% and 100% OMC and analysed using a regression analysis to determine the material constants k_1, k_2, k_3. The results are shown in Table 7 and indicate a clear strength (modulus) variation between very stiff (CCRB), stiff (CDRB) and marginal (CGRB)

Table 7. Repeat load triaxial testing on various base course materials

Material	% OMC	K_1	K_2	K_3	σ_1 kPa	200	400	240
					σ_2 kPa	50	50	94
CDRB (B)	60	432.5	0.5860	0.0327		440	600	540
CDRB (B)	80	351.1	0.2893	0.4113		440	610	480
CCRB (A)	60	762.0	0.4192	0.0559		790	1000	910
CCRB (A)	80	631.9	0.3527	0.1197		670	850	760
CDRB (B)	60	375.2	0.5311	0.2164		420	610	510
CDRB (B)	80	355.6	0.3287	0.3344		430	580	480
CGRB (D)	60	173.4	0.4463	0.5123		230	360	270
CGRB (D)	80	177.1	0.4662	0.4430		220	350	260
CGRB (E)	60	154.9	0.4095	0.5631		210	330	240
CGRB (E)	80	150.6	0.3783	0.6027		210	330	240

2.4.2 Unconfined Compressive Strength

Unconfined compressive strength was only undertaken on the recycled products in order to determine if excessive rehydration of cement was occurring. The results in Table 8 indicate that high UCS values are probable. MRWA Specification 501 limits UCS to 0.6MPa to 1 MPa at 7 days. However the test does not allow for rehydration of cement bonds, and as is shown, the trend in UCS indicated that rehydration may be on-going beyond 7 days.

Table 8. Unconfined compressive strength with curing time

Material	UCS 1 day cure (kPa)	UCS 7 day cure (kPa)	UCS 28 day cure (kPa)
CCRB (A)	668		1625
CDRB (B)	220		474
CDRB (C)	541		1323
	625	979	1023

3. Site Conditions in January 2011

3.1 Visual Inspection

Detailed visual inspections were undertaken in January 2011, and further FWD testing was undertaken in October 2010 (Gilmore Ave) and January 2011 (Welshpool Road and Warton Road). The following observations are relevant:

- Gilmore Ave: The control section constructed with conventional CGRB has generally minor rutting of 10-20mm throughout with some significant areas of fatigue and 30mm rutting, some sections so severe patching has occurred. This is attributable to the high moisture content at sealing. For CGRB, a dryback of 60% is recommended. The sections using CDRB have isolated minor rutting < 10mm, but do exhibit extensive fine block cracking on an approximate grid of 1.5m.
- Welshpool Road: There is no rutting or cracking evident in any section of Welshpool Road.
- Warton Road: There is no rutting in Warton Road, but transverse cracking has commenced and this is predicted to extend ultimately to block cracking on a 2m grid. Cracks are wider in Warton Road that at Gilmore Ave.

3.2 FWD Testing

FWD test results are summarised in Table 9. The results show that the CCRB (A), the material used in Warton Road and showing signs of block cracking is indeed very stiff, although due to variations in pavement thickness, direct comparisons cannot be made between the three pavements. However Welshpool Road, which has a lower curvature value, and intuitively stiffer that Warton Rd, is not cracking, despite being two years older. It is apparent that the recycled materials are stiffer than quarried roadbase.

Table 9. Summary deflection and curvature values

Material	Welshpool Road		Warton Road		Gilmore Ave	
	Mean Deflection	Mean Curvature	Mean Deflection	Mean Curvature	Mean Deflection	Mean Curvature
CGRB	0.33mm	0.08mm			0.34mm	0.12mm
CDRB			0.19mm	0.03mm	0.37mm	0.09mm
CCRB (A)	0.14mm	0.01mm				
CDRB (A)	0.20mm	0.03mm				

4. Conclusion

Based on the research undertaken in WA, the following generalized observations are provided:

- Recycled roadbase materials sourced from recycled demolition materials can provide a good quality high strength base for roads.
- Recycled base material are likely to give an increased asphalt fatigue life, but some minor block cracking may be the compromise.
- The source of concrete in recycled materials may have a significant effect on rehydration and subsequent excessive stiffness and block cracking.
- It is probable that the addition of brick, tile and or sand as a fine material into the recycled product may control excess stiffness and limit the effects of rehydration
- Rehydration may not be adequately described by a 28 day UCS.
- Further research into the rehydration effects of recycled roadbase is required
- Further research into the source of the concrete and its effect on stiffness is required
- Further research into the effect of the source of fines on the long term stiffness of recycled materials is required.

5. References

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