Sustainable Aggregates for Unbound Granular Pavements

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ABSTRACT

Research has been underway at the University of South Australia since 2009 into the potential use of recycled concrete (RCA) and recycled (fired) clay masonry (RCM) as construction material for unbound granular pavements. Specifications both within and outside of Australia have been reviewed and recycled products have been compared with these specifications. The products generally meet existing specifications in terms of basic engineering properties and exceed resilient modulus requirements. In particular, properly compacted RCA should be employed in basecourses. The addition of RCM to RCA (10 to 30% by mass) generally leads to greater strains under repeated loading, and so the material is probably more suited to subbases. This paper presents the basis of these recommendations and includes studies into shrinkage strains, hydraulic conductivity and the influence of matric suction on shear strength.

Keywords: recycled concrete aggregate, recycled clay masonry, matric suction, resilient modulus, unbound granular material

1 INTRODUCTION

It would seem to make perfect sense in today's world to recycle building materials wherever possible and re-use the materials in new construction. Recycled aggregates can supplement overall aggregate demand, but in Europe is unlikely to ever exceed 10 to 15% of total demand (Meininger and Stokowski 2011). Likewise in Australia it will supplement supply of aggregate from quarries.

Countries devastated during World War II found they had few resources and re-used what they could in the re-building process. Other countries are resource poor in terms of source rock for aggregates. So countries, like the Netherlands, Belgium, Germany and Japan, have led the way in recycling Construction and Demolition (C&D) waste. In the UK there has been a greater acceptance recently of recycled aggregates with the adoption of performance based specifications, which removed the need to know the source material (Andrew Dawson, University of Nottingham, *pers. comm*.). Unfortunately the European experience cannot be simply adopted as it is based on the range of climates, pavement construction practices and geology in those areas. Furthermore the great majority of pavements in Australia are thinly surfaced. Nonetheless the long experience from the northern hemisphere can provide direction for road authorities in other countries, like Australia.

In both Australia and America, recycling of C&D waste has been much slower to progress and there would seem to be a reluctance to change specifications for aggregates to accommodate the recycled C&D waste. Why take the risk on largely unproven materials for projects? So there has been a concerted effort around southern Australia to evaluate the stockpiles of industrial waste for suitability for roads and to a lesser extent, concrete production. Curtin University and Swinburne University of Technology have active research programs, while the University of South Australia's School of Natural and Built Environments has been involved in this area of research for approximately 3 years.

Much of the work to date has been limited to the laboratory. Obviously wheel tracking tests or field trials on road structures would be more valuable than laboratory evaluations, provided the tests/trials are adequately instrumented. A few field trials of roads constructed with C&D waste have been conducted (Ecocycle 1997 and Bowman & Associates 2009a and 2009b). ARRB's Accelerated Loading Facility has been booked for testing of pavements consisting of recycled aggregates in Victoria in the near future. The combination of laboratory and field data is a potentially powerful mix which should fuel numerical analyses of Unbound Granular Material (UGM) behaviour and lead to improvements in pavement design generally.

This paper summarizes the work undertaken at the University of South Australia (UniSA) to evaluate aggregate produced from local recycled C&D waste, which consisted chiefly of crushed concrete and fired clay masonry. All products were nominally 20 mm sized maximum aggregate. In the paper, the aggregates produced from crushed concrete are referred to as RCA (Recycled Concrete Aggregate) and RCM (Recycled Clay Masonry). RCM is used generally in combination with RCA. DTEI-SA permit up to 20% by mass in RCA of “foreign material” consisting of clay brick tile, crushed rock and masonry for base course and subbase applications. Gabr and Cameron (2011) reported that most European standards for bases limit RCM to less than 10%.

DTEI also stipulates minimum resilient modulus and maximum rate of permanent strain for Class 1 bases, based on a simplified, single stress stage Repeated Load Triaxial Test (RLTT). These performance based specifications are unique in Australia if not worldwide. In parts of Scandinavia, specifications require back-calculated resilient modulus from a falling weight deflectometer or Young’s modulus from a plate bearing test.

2 MATERIALS AND RANGE OF TESTS

Two RCA basecourse products, A and B, were tested, along with a comparable product (A20) of RCA with 20% by mass of RCM. Further materials were made at UniSA by blending product B with RCM to 10%, 20% and 30% (B10, B20 and B30). Finally a virgin quartzite aggregate (Q) was evaluated, which is commonly used in Adelaide for construction of Class 1 bases.

The particle size distributions of the materials fell within DTEI specifications for Class 1 base. All the materials were well-graded gravel and sand mixtures with silty gravel; GW-GM according to the Unified Soil Classification System (USCS). Material A lay close to the coarse specification limit, while Material B20 crossed between the limits and had a fairly high proportion of fine sand-sized particles. The fines content of the two RCA products, A and B were just 5% and 7% respectively, while the quartzite base material (Q) had 11%.

Tests were conducted in line with the requirements of current Australian specifications. These included plasticity of fines, aggregate strength tests, Los Angeles abrasion, CBR tests on 4 day soaked samples and RLTT to DTEI protocol. In addition, falling head permeability tests and shrinkage tests were conducted. Some interest has been expressed relating to the propensity of RCA to exhibit some cementation upon wetting and compaction. This self-cementation of RCA materials can produce increase of strength with time, but also the possibility of reduced permeability (AASHTO 2002) and of course shrinkage. Therefore shrinkage was investigated.

3 MATERIAL PREPARATION

3.1 Falling Head Permeability, CBR and Unconfined Compressive Strength (UCS),

All samples were dynamically compacted to the target density DDR of 98%. For the falling head permeability tests, the moulding moisture contents were 100 and 80% of OMC. Materials tested were A20, B10, B20 and B30. For CBR testing, duplicate samples were prepared at various target moisture contents. Results for the samples prepared at 80% of OMC are presented herein. In South Australia, materials are commonly compacted at 80% of OMC and are allowed to dry back to 60% of OMC. For the CBR test, a 2.3 kg metal surcharge was mounted on the sample after compaction and the specimen was soaked 4 days in a water tank prior to testing. Duplicate samples for the UCS testing program were prepared at OMC, and then cured for 7 days at 65ºC (accelerated curing).

3.2 Drying Shrinkage

Triplicate samples of materials A and B, and duplicate samples of A20 and B20, were prepared using static compaction at the target DDR of 98% of MDD for Modified compactive effort. The target moisture content was OMC which was reduced to 90% OMC if the material was found to be too fragile (e.g. samples B & B20). Samples were 200mm high by 100 mm diameter. After compaction, the samples were extruded from the mould and sealed in plastic bags to cure for 7 days; the samples were then stored in a curing room (temperature 23±2°C and relative humidity 55±5%).

3.3 Undrained Triaxial and RLTT Testing

Duplicate samples were prepared using static compaction at the target Dry Density Ratio (DDR) of 98% of Maximum Dry Density (MDD). The resilient modulus and permanent deformation behaviour of RCA mixtures were investigated at different levels of moulding moisture contents, as was the undrained shear strength. Generally just one day of curing occurred before de-moulding and testing.

4 RLTT TEST METHODS

In Australia, there are two standard approaches to Repeated Load Triaxial Testing (RLTT); multi-stage stress testing and single-stage stress testing, e.g. the Department for Transport, Energy and Infrastructure (DTEI (now DPTI), South Australia) approach. DTEI specify application of a constant confining stress of 196 kPa and a vertical deviator stress of 460 kPa, pulsed over 50,000 loading cycles. AUSTROADS established a multi-stage stress RLTT under drained conditions to determine the permanent deformation and resilient modulus properties. Space requirements prevent further discussion of AUSTROADS style tests in this paper.

In the RLTT program conducted at UniSA, deformations were measured with two pairs of inductance coils (“Emu” coils, Janoo et al., 1999) mounted on the sample.

5 INDEX VALUES AND OTHER BASIC PROPERTIES

The plasticity of fines of the various materials is indicated in table 1. The DTEI 2008 specifications call for a maximum Liquid Limit of 25% for Class 1 and 28% Class 2, and so A20 would fall into Class 2, while all other materials would be acceptable on this basis for Class 1 applications.

Los Angeles Abrasion Value (LAA or LAV) may be used to evaluate the abrasion resistance/toughness under traffic loading. The LAA values of the South Australian RCA examples ranged between 37% and 39%, which failed to meet the maxima of 30% proposed by DTEI. The values for RCM blends were higher (refer table 1).

Average shrinkage curves with time are provided in figure 1 for the four materials that were tested. Interestingly, shrinkage strains were similar for the RCA products, as they were for the blends (20% RCM); however, the addition of crushed masonry resulted in an appreciable drop in shrinkage. In the case of product B, a reduction of almost 60% was observed.

The permeability of blended recycled material when prepared at OMC was approximately 2 x 10^{-8} m/sec for blends based on RCA product B, but it was observed that A20 was ten times more permeable. Compaction to the same density but at just 80% OMC increased the permeability of all materials generally by a factor of approximately three.

A study was undertaken on materials A20 and B20 of the matric suction–moisture content relationship, or soil water characteristic curve (SWCC). Initial matric suction was determined by the contact filter paper method for samples of 100 mm diameter prepared over a range of initial moisture contents and compacted to 98% of MDD by static compaction. The sample height was just 100 mm. An air dry filter paper, 85 mm in diameter and sandwiched between two 90 mm filter papers, was placed between the two halves of the sample after breaking the soil along the interface between the two compaction stages. The sample was then placed in an airtight container, sealed and placed in a constant temperature room (22°C). After 7 days, the central filter paper was recovered and weighed. More details of this test procedure are given by Cameron, Azam and Rahman (2011). The two SWCC plots are provided in figure 3. Degrees of saturation have been plotted rather than gravimetric moisture contents. As a reference, the degree of saturation was 89% for A20 and 79% for B20, respectively, when prepared at OMC and 98% MDD.

Table 1: Selected properties of the recycled aggregate blends

Material	A	A20	B	B10	B20	B30	Q
Liquid Limit of fines (%)	26	27	23	24	23	23	18
Plastic Index of fines (%)	2	2	1	3	3	2	3
LAA (%)	39	42	37	42	43	45	25

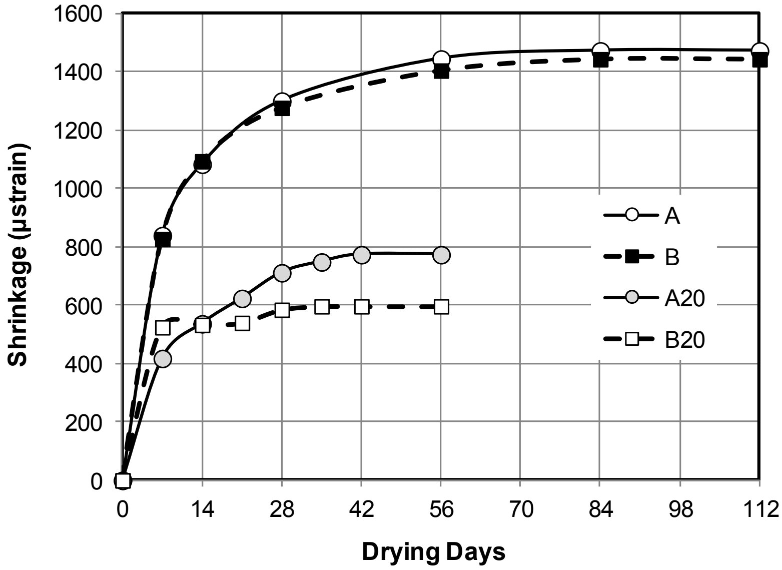

Figure 1. Shrinkage strain development

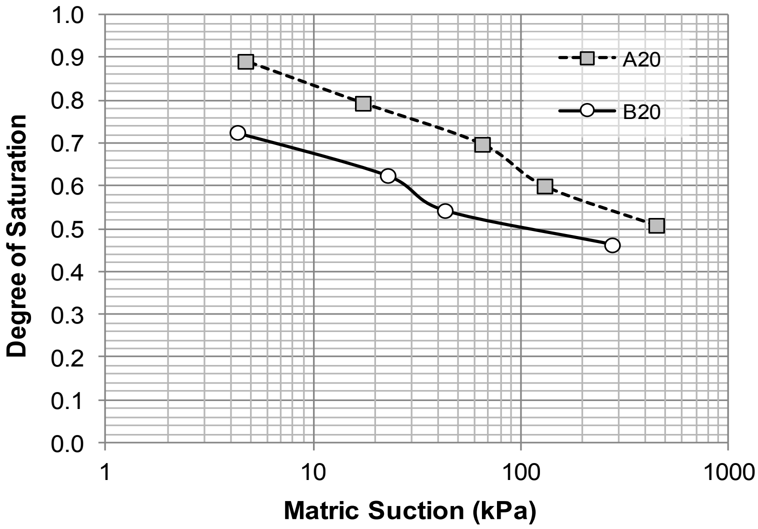

Figure 2. SWCC of materials, A20 and B20

A20, with a higher plasticity of fines than B20 as evidenced by respective liquid limits, had the greater water retaining ability. Accordingly residual suction was higher; 130 kPa compared with 43 kPa.

Generally CBR values are required to be a minimum of 80 or 100%, although DTEI (2008) does not have a CBR specification for either grading based or performance based specifications. Samples prepared at 80% OMC generally met this requirement as shown in table 2. It can be seen from the B materials that the inclusion of masonry reduced the CBR significantly. The two “A” materials don’t reflect this trend suggesting that on site blending of A20 may involve other components or fillers.

Authorities such as Road Transport Authority (NSW) require UCS of unbound base materials to be less than 1 MPa. Table 3 presents average values for the materials. All except A20 met this target easily; this material was borderline at 1.00 MPa.

6 TRIAXIAL TESTING RESULTS

Undrained shear strength parameters are given in table 3 for material prepared at a target of 80% OMC. Shear strength tended to increase with matric suction up to the residual suction (at approx 70%

OMC), as discussed by Cameron et al. (2012). Assuming a normal stress of 100 kPa, the shear strength of A20 and B20 increased by 13 and 16% relative to strength at OMC, respectively.

The resilient modulus of the RCA products (materials A and B), prepared to a dry density ratio of 98% and over a range of moisture contents was found to vary between 500 and 950 MPa (refer figure 3), clearly surpassing the DTEI (2008) requirement of 300 MPa. Generally resilient modulus decreased with moisture content although product A had a fairly constant modulus of approximately 600 MPa. The rate of permanent strain with load repetitions over the last 30,000 load cycles was generally acceptable when compared with DTEI specification for Class 1 (refer figure 4); just one of the 16 test results did not meet the Class 1 base requirement. In contrast, the quartzite material failed to make the DTEI limit when prepared at 80% OMC or wetter. It was also more susceptible to moisture content.

The materials blended with crushed masonry performed well with respect to resilient modulus. Even material B30 had a minimum modulus of more than 400 MPa. However the rate of permanent strain development was generally far greater than the comparable RCA product (figure 3). Nonetheless, under DTEI specifications, these products still meet the Class 2 requirement.

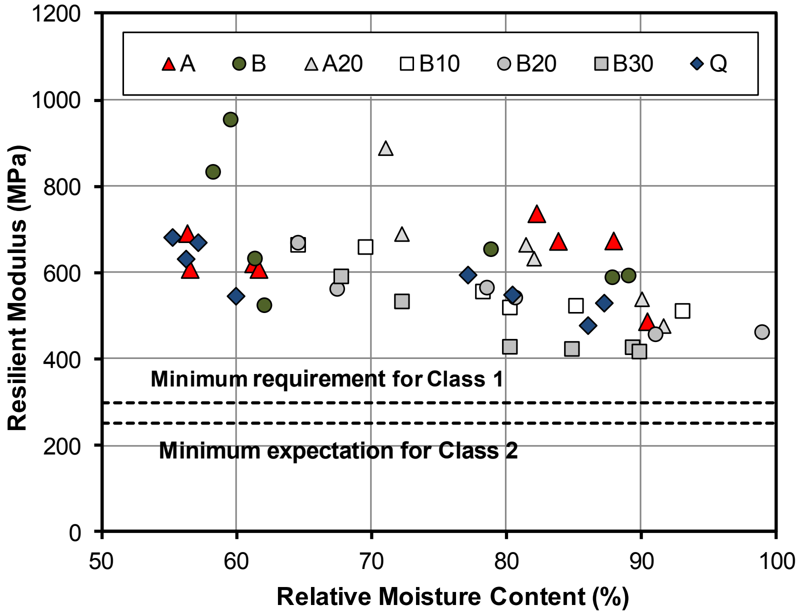

Figure 3. Resilient modulus as a function of initial moisture content

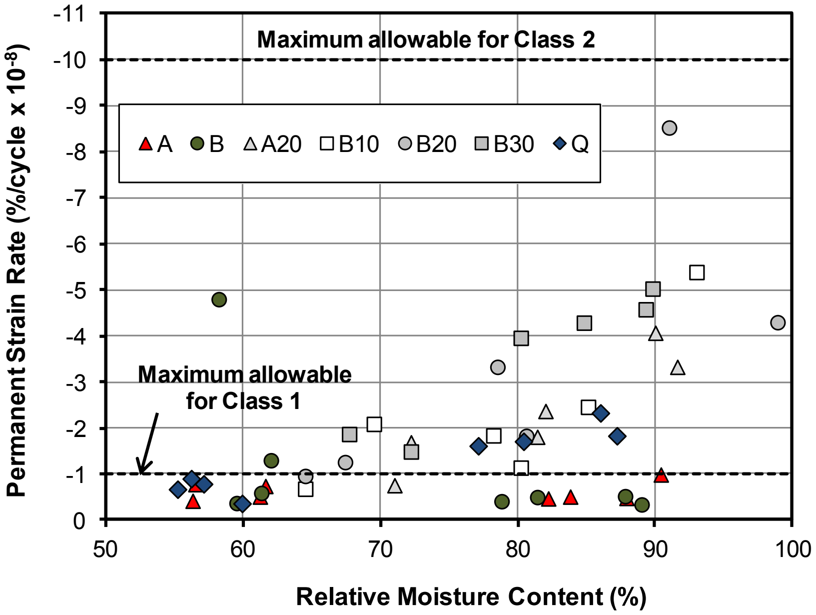

Figure 4. Permanent strain rate as a function of initial moisture content

7 CONCLUSION

Performance based specifications centred around shear strength and RLTT testing indicate that recycled aggregates such as RCA and RCM can be used as pavement materials. RCA products can out-perform virgin aggregate, although of course the ultimate test will be on the road. Grading based or other specification systems dependent on basic engineering properties may unnecessarily restrict the application of recycled materials. Recycled C&D waste materials are not fresh from the quarry and contain construction matter such as cement and lime from either concrete or masonry, and so tend to have higher LAA values and greater water avsorption.

From the evidence presented, the RCA productss could be used as Class 1 base, while the blended products are more suited to Class 2 applications or subbase. More evidence will be provided with AUSTROADS style test results in subsequent publications (e.g. 2nd International Conference on Road Transport Geotechnics, Hokkaido, Japan, Sept 2012).

Table 2: CBR and UCS of RCA-RCM

Material	B	B10	B20	B30	A	A20	Q
CBR (%)	200-210	103-127	99-123	77-91	90 -120	149-170	135-150
UCS (MPa)	0.30	0.15	0.38	0.21	0.79	1.00	NA

Table 3: Shear strength data for 80% OMC

Material	B	B10	B20	B30	A	A20	Q
cohesion (kPa)	41	9	46	0	163	134	30
Friction angle (°)	60	53	44	53	48	55	53

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