Sustainable Use of Crushed Concrete Waste as A Road Base Material

Narantuya Batmunkh[1], Komsun Siripun[2], Peerapong Jitsangiam[3] and Hamid Nikraz[4]

[1]PhD candidate, Department of Civil Engineering, Curtin University of Technology, P.O. Box U1987, Perth, WA, Australia 9845; PH (61) 8 9266-7609; FAX (61) 9266-2681 ;
e-mail: narantuya.batmunkh@postgrad.curtin.edu.au ;
[2]PhD candidate, Department of Civil Engineering, Curtin University of Technology, P.O. Box U1987, Perth, WA, Australia 9845; PH (61) 8 9266-7609; FAX (61) 9266-2681 ;
e-mail: komsun.siripun@postgrad.curtin.edu.au ;
[3]Lecturer, Department of Civil Engineering, Curtin University of Technology, P.O. Box U1987, Perth, WA, Australia 9845; PH (61) 8 9266-4527; FAX (61) 9266-2681;
e-mail: p.jitsangiam@curtin.edu.au ;
[4]Professor, Department of Civil Engineering, Curtin University of Technology, P.O. Box U1987, Perth, WA, Australia 9845; PH (61) 8 9266-7609; FAX (61) 9266-2681;
e-mail:h.nikraz@curtin.edu.au ;

Corresponding author/Presenter: Mr.Komsun Siripun: komsun.siripun@postgrad.curtin.edu.au

ABSTRACT

Crushed concrete waste is a by-product from building demolition and constitutes a principal component of municipal solid waste consisting of concrete, sand, brick, rock, metals and timber. Over 50% of this waste is commonly sent to land-filled sites, resulting in the impact on the limited capacity of land-filled sites. Nowadays, the sources of virgin natural aggregates are depleted by increases in demand of using a virgin material in building and infrastructure construction and maintenance facilities. This depletion leads to the utilisation of crushed concrete waste to replace natural aggregates in road and highway construction. Of key significance of this study is to present alternative materials for road and highway construction on the production of the proper guideline for road base by using crushed concrete waste. Sophisticated tests were conducted to investigate the mechanical responses of compacted crushed concrete subjected to applied loads simulated from traffic loads. Unconfined compressive strength, shear strength parameters and the resilient modulus of such material were determined. Our findings showed that crushed concrete waste is able to be utilised as a road base material. The results of this study will enhance increased use of crushed concrete waste in road and highway construction and will, therefore, alternatively reduce consumption and costs in manufacturing virgin aggregates.

Introduction

In recent times there has been an increasing shift towards finding more environmentally sustainable practices in an effort to tackle modern challenges related to climate change, population growth and pollution. This study presents the latest research in the performance of recycled construction and demolition material as a road building material in Western Australia and recommends new technology for this growth industry. Local Governments and industry are encouraged to be development leaders with more sustainable road building practices and materials. The objective of this report is to investigate crushed concrete waste material as a pavement material with sufficient background information to enable interested parties constructing roads to understand how utilisation limits were derived. The study investigates properties and performance characteristics to enable practitioners to confidently make use of recycled construction and demolition materials in the construction of road pavements.

Existing road construction material specifications for recycled products were generally derived from specifications of virgin rock aggregates, and modified slightly to allow for the different properties of the recycled products (Austroads 2004). The materials used as sources for the manufacture of recycled roadbase stem from the construction and demolition industry. The term commonly used to describe this material is construction and demolition (C&D) waste. A literature review was undertaken of Australian and international test methods to analyse the performance of pavement materials. There seemed to be gaps in previous research undertaken into the performance and characterisation of recycled materials. A significant amount of laboratory characterisation of recycled materials and virgin quarried aggregates has been undertaken by Curtin University which has enabled a greater understanding of the characteristics of recycled roadbase sourced from construction and demolition materials and how these relate to newly quarried materials. The test results were compared, and indicated that the materials produced in Western Australia are comparable in performance to those in other parts of Australia and the world.

It seems that where recycled products are used, they are generally considered second class material suitable for a subbase generally or a base material for low volume roads. There are some interesting new test methods which could be applied not only to recycled materials but also to virgin aggregates used for road construction. From field trials using recycled concrete products an increase in stiffness was observed after one to two years of service. There is the potential for recycled concrete products to rehydrate and re-cement with time. This process of rehydration has not been fully investigated and may result in a material that is too stiff and brittle. If rehydration continues and creates a bound material, the pavement then may be subject to fatigue failure of the basecourse. Further research is needed to study the effects of blending other materials such as clay bricks and tiles, reclaimed asphalt pavement (RAP) and small amounts of clay material with the crushed concrete to minimise the effects of rehydration.

This study provides pavement material characterisations for use by Local Governments and Industry for the supply of recycled concrete based roadbase, subbase and fill materials. The limit use however, has been developed based on the results of laboratory testing and the field performance of pavements constructed using recycled materials. Laboratory characterisations of three sources of recycled materials (All Earth, C&D Recycling and Capital Demolition) and two sources of virgin quarried aggregates (Boral and Cemex) have been undertaken by Curtin University. These results were used to give a greater understanding about the characteristics of recycled materials sourced from construction and demolition materials and how these materials compared to local virgin materials. The tests results were also compared to those in selected engineering papers and indicate that the materials produced in Western Australia are comparable in performance to those in other parts of Australia and the world. The laboratory test results show that the constituents of the source material are significant to the long-term performance of pavement material. Where it contains only structural concrete crushed from the demolition of reinforced concrete structures, rehydration of the cement within the material may produce an excessively stiff material likely to fatigue with time. The blending of small amounts of crushed clay bricks and tiles appears to help minimise the risks of excessive rehydration of recycled structural concrete. The possible effect of cement reacting with bitumen where cement fines may be pumped by traffic action into the seal coat has been noted and will require further research.

Laboratory Results and Discussion

Maximum dry density and optimum moisture content

Maximum dry density (MDD) and optimum moisture content (OMC) tests were undertaken and the compaction curves are shown for C&D Recycling in Figure 1, All Earth in Figure 2 and Capital Demolition in Figure 3 (Main Roads Western Australia 2007).

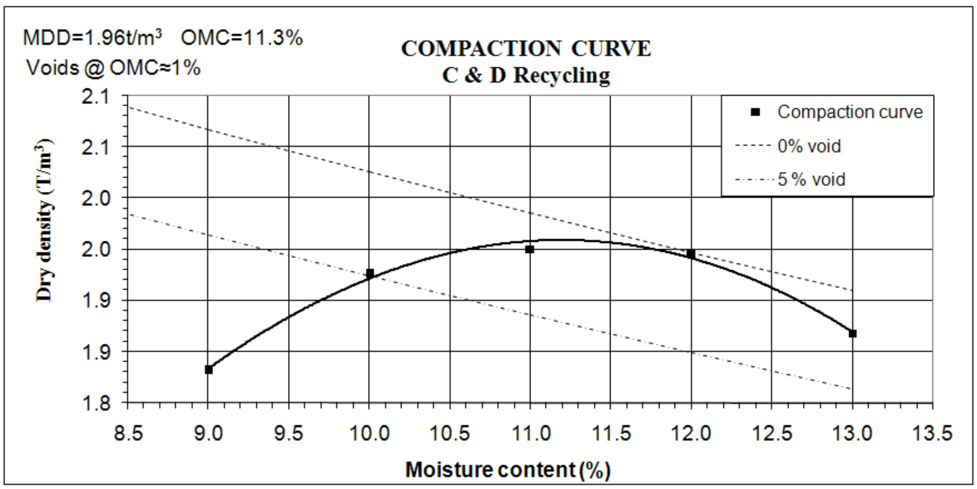


Figure 1: The C & D Recycling compaction curve.

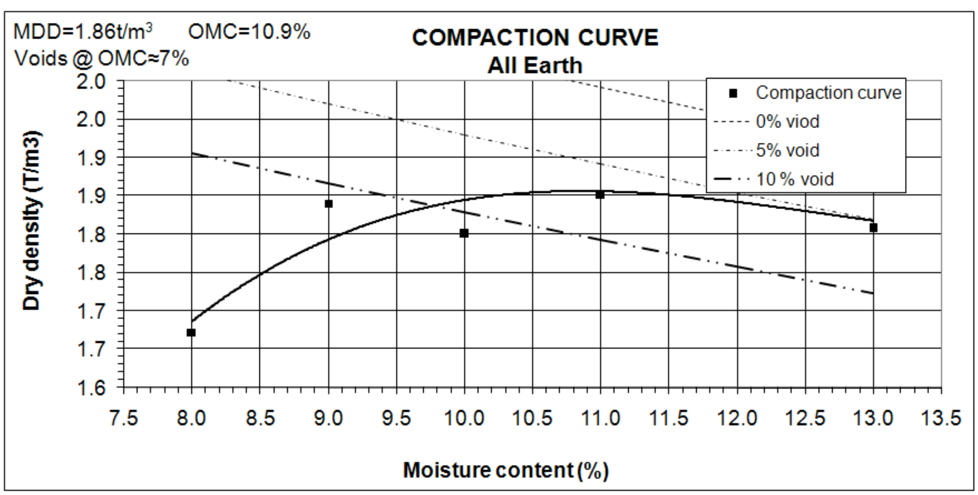


Figure 2: The all Earth compaction curve.

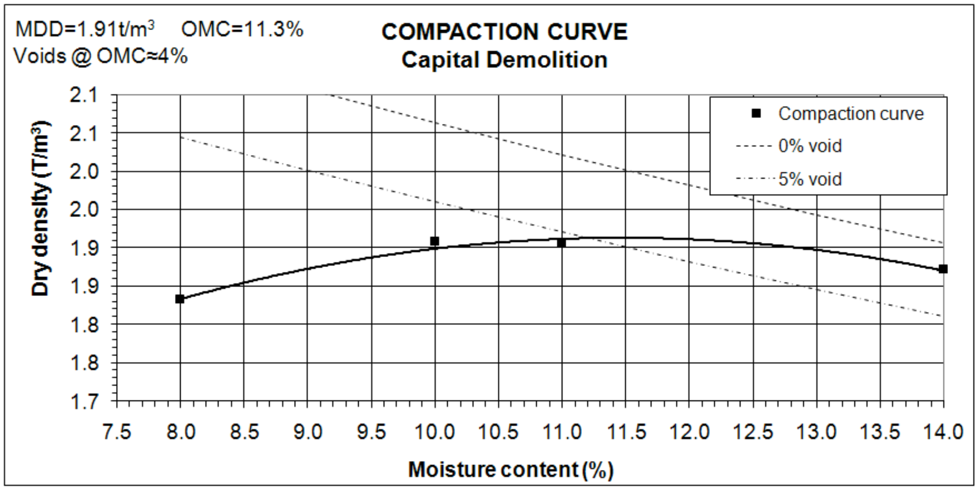


Figure 3: The Capital Demolition compaction curve.

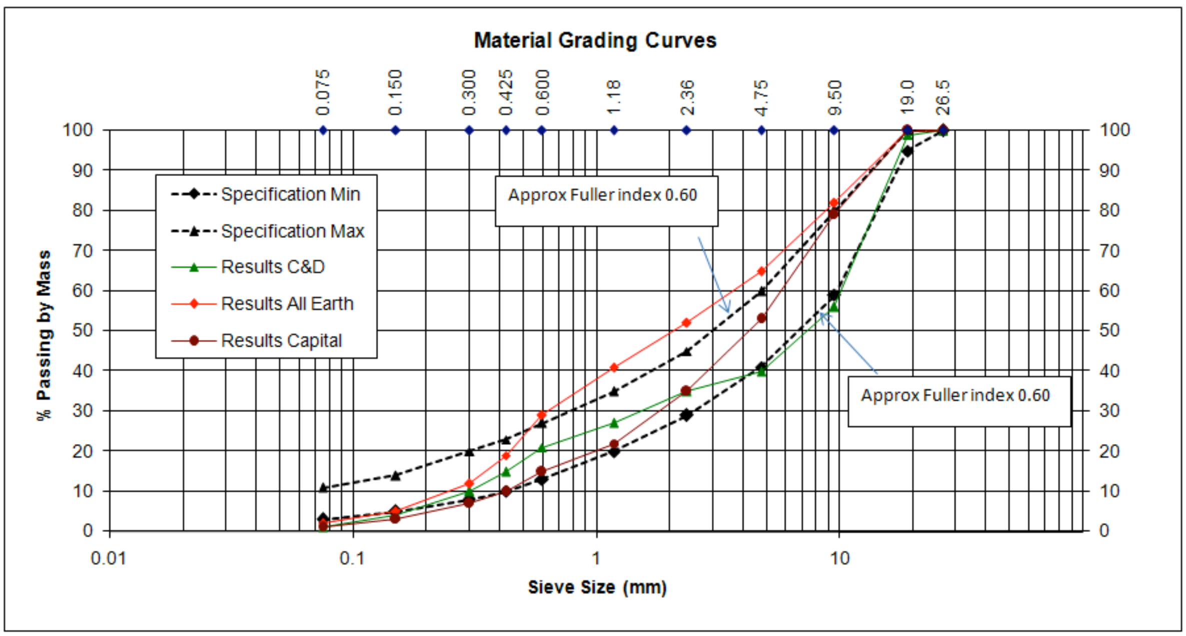


Figure 4: Particle size distributions for recycled materials.

Particle size distribution

Particle size distributions are shown in Figure 4 (Main Roads Western Australia 2007). The grading shows that all materials are low in fines, and that for these samples at least, the grading of the All earth material is well out of specification on the fine side, and the grading for C&D Recycling is slightly out of specification on the coarse side. The coefficient of curvature and Coefficient of Uniformity for each material are shown in Table 1. Whilst the grading is out of specification for All Earth, the coefficient of uniformity and coefficient of curvature for all materials are within a tolerable range.

Table 1: The grading properties of recycled materials.

Property	Results		
	C&D	All Earth	Capital
D_{60}	10	3.5	5.6
D_{30}	1.5	0.65	1.8
D_{10}	0.3	0.23	0.425
Coefficient of Curvature	33.3	15.2	13.2
Coefficient of Uniformity	0.8	0.5	1.4

Unconfined compressive strength (UCS)

Tests were undertaken on samples on day 1 and then after 28 days curing as shown in Table 2. These results show that there is some degree of cementing action for recycled materials, and that there is considerable variability between suppliers. A limit is applied to UCS to prevent excessive brittleness of a granular pavement material. This testing confirms that there is a gradual increase of strength with time, and should this strength gain be related to the rehydration of cement bonds as suspected, the strength gain will be very dependent on the curing regime. As pavements are typically dried back before sealing, ideal curing conditions will not be established as is the case in the test conditions. In practice, the increase in strength with time should not be as marked as that in the laboratory.

Capital Demolition sources its concrete from structural concrete beams and columns, but the samples collected for testing were only concrete. All Earth and C&D Recycling receive supplies of material from a wide range of sources, and much of the concrete is non-structural house pads, paving and kerbing from roadworks. There is also a blend of other products mainly brick, tile, sand, aggregate and asphalt. Whilst there is a significant difference between C&D Recycling and All Earth, this should not be viewed as a difference in process, rather an indication of the potential variation in materials. MRWA specification 501 requires a 7 day UCS value of 0.6 MPa to 1.0 MPa. Based on the results in Table 2, it is likely that the 7 day value for UCS will be potentially in the range of 0.37 MPa to 1.2 MPa (Main Roads Western Australia 2006). Further testing is required, and the extraction of cores from existing road pavements will be undertaken by Curtin as part of ongoing research.

It is recommended that further research be undertaken to investigate the potential for recycled pavement materials to rehydrate and under what conditions rehydration occurs. There has been little research into the rate of rehydration of crushed concrete and the assumption that 90% of the potential rehydration is achieved in 28 days is not supported from field trial testing. Further UCS testing of specimens cured in a condition that represents the as-constructed pavement for 60, 90, 180 and 360 days should be undertaken and if necessary the specification reviewed.

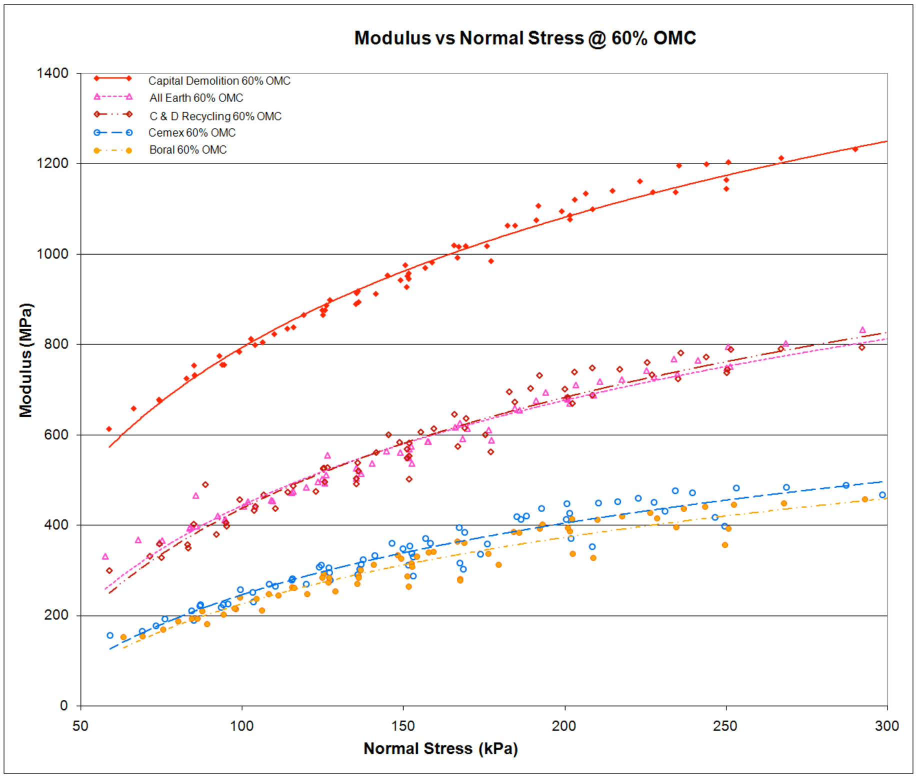
Table 2: The results of UCS testing.

Supplier	UCS 1 day cure (kPa)	UCS 28 day cure (kPa)
Capital Demolition	668	1625
C&D Recycling	220	474
All Earth	541	1323

Repeat load triaxial testing (RLT)

RLT tests were undertaken on triplicate samples of recycled demolition roadbase sourced from the three suppliers, All Earth, Capital Demolition and C&D Recycling, and two samples of new quarried roadbase from Cemex and Boral (Voung and Brimble 2000). The relationships between the modulus and normal stress for the various materials tested at 60% and 80% OMC are shown in Figure 5. In this figure, AE represents All Earth, CAP represents Capital Demolition and CD represents C&D Recycling, all of which are the recycled materials. CEM represents Cemex and BOR represents Boral, both of which are high quality quarried and crushed granite roadbase materials (CGRB). The highest modulus values were obtained by Capital Demolition, with All Earth and C&D Recycling showing similar values. Both Boral and Cemex roadbase also showed very similar values. All of the recycled materials showed significantly higher modulus values than that obtained from the CGRB materials.

The Capital Demolition roadbase, which is predominantly structural grade concrete with no brick and tile clearly showed the highest modulus values. The All Earth and C&D Recycling roadbases which contained predominantly non-structural concrete with some brick and tile, estimated to be between 10% and 15% by weight, showed good modulus values significantly higher than the values shown by the new CRB of Boral and Cemex.



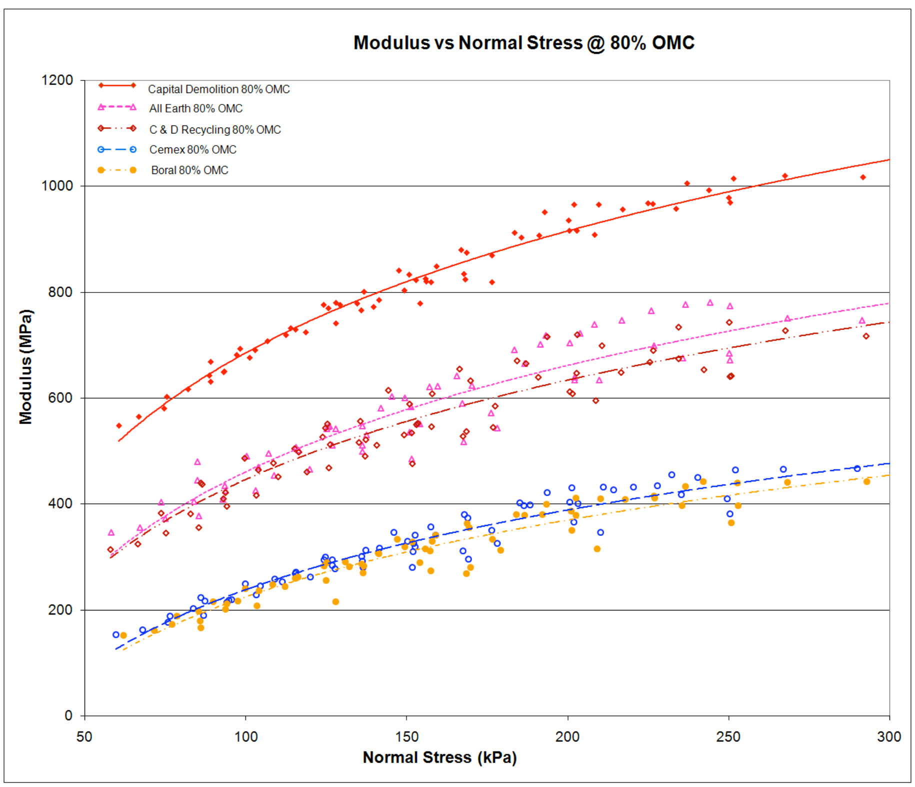


Figure 5: Modulus vs. normal stress for recycled and quarried roadbase materials.

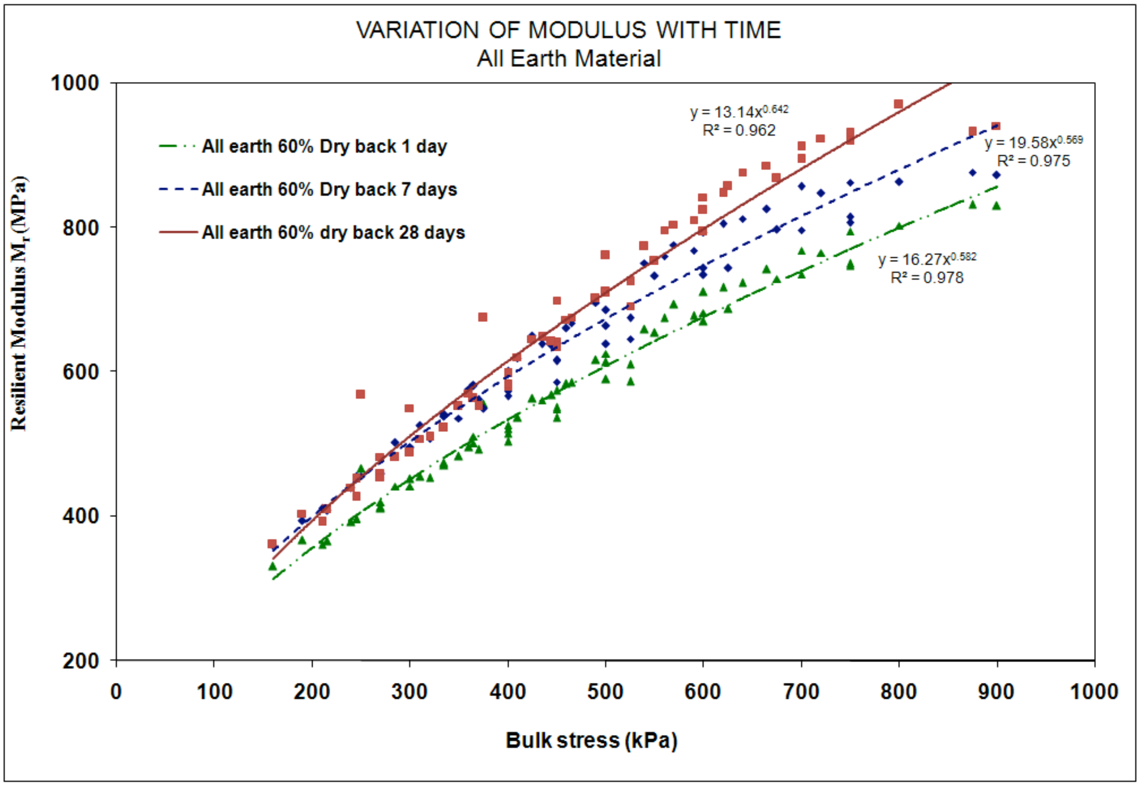


Figure 6: The All Earth resilient modulus at 1, 7 and 28 days.

The above tests were undertaken without curing, and in order to assess the potential changes of modulus with time, one product was selected to undertake resilient modulus testing at 60% OMC over a period of 1 day, 7 day and 28 day curing. All Earth material was chosen, as it represents the middle range of the uncured performance testing. The results of this testing are shown in Figure 6, and indicate a clear increase in stiffness with time. In practical terms, a higher modulus value will result in lower curvature values and hence a longer fatigue life of an asphalt surface.

Conclusions

Test results have confirmed that the optimum moisture content for recycled crushed demolition roadbase (CDRB) materials is higher than for crushed granite roadbase (CGRB). It has also been determined by repeat load triaxial testing (RLTT) that the resilient modulus of the CDRB is superior to that of CGRB by a factor of two or more. The RLTT also showed that the source of material strongly influences the modulus of the recycled material.

In order to differentiate between products, new definitions should be included. It is proposed that the following definitions be used:

CGRB	– conventional new roadbase manufactured from virgin granite rock
CCRB(S)	– crushed concrete roadbase containing only structural grade concrete
CCRB(N)	– crushed concrete roadbase containing only non-structural grade concrete
CDRB(x)	– crushed demolition roadbase containing a mix of predominantly concrete with clay brick, tile and sand containing approximately x% concrete.

CCRB(S) may be too stiff in its raw state for a basecourse and could lead to premature shrinkage and or fatigue type cracking. CCRB(N) may be suitable for roadbase, as is CDRB(x) where x is yet to be determined. There may be a value of x suitable for base application, and a value for subbase application. The Capital Demolition material would fall into CCRB(S) class, and the RLTT shows a very stiff material. This may be suitable under thick layers of asphalt, or as a subbase for heavily trafficked pavements, however, it may be unsuitable for those with a thin asphalt cover due to possible fatigue cracking. The Capital Demolition material showed a modulus value of approximately 3 times that of the CGRB.

CCRB(S) can be blended with clay brick or tile to form CDRB(90), that is 90% concrete with 10% foreign material, which would make a good general-purpose base for heavy trafficked pavements.
The CDRB(x) which comprises the All Earth material and C&D Recycling material, where x is thought to be around 90%, showed very similar modulus values of about twice that of CRB. Particle size distributions (PSD) of the materials do not completely fall within the current MRWA specification, but this does not seem to affect the performance of the material in the RLTT. Unconfined compressive strengths were undertaken on all recycled materials, and here significant variations were observed. Tests were undertaken at 1 day and 28 day curing. The results are interesting in that in this test, the high modulus Capital Demolition material and the lower modulus All Earth material showed similar results, where as the C&D Recycling material which has a similar modulus to All Earth showed a much lower value. The All Earth material, considered to be the best compromise between modulus and UCS was subjected to more study using the RLTT and static triaxial testing at 1 day, 7 day and 28 day curing to determine if there was significant rehydration occurring in the material.

This investigation has considered Australian and international trends in the use, performance and specification for roadbase material sourced from construction and demolition materials. However, no specifications currently give limits for modulus, compressive strength. Therefore as a starting point, limits for these values have been estimated based on the results obtained from Curtin University's testing associated with this investigation. These values will need revision as more data becomes available, but by including them now in the specification and testing for these properties, a data base will be established which will allow a more critical review in the future.

References

Austroads (2004). Pavement Design-A Guide to the Structural Design of Road Pavements, Austroad Inc.2004.

Main Roads Western Australia. (2006). "A guide to the selection and use of naturally occurring materials as base and subbase in roads in Western Australia " Retrieved September, 2008, from http://standards.mainroads.wa.gov.au/NR/mrwa/frames/standards/standards.asp?G={E582C897-FF5E-4C02-8B46-51E88C1E5DD8}.

Main Roads Western Australia. (2007). "Dry density/moisture content relationship: modified compaction fine and medium grained soils." Retrieved September, 2008, from http://standards.mainroads.wa.gov.au/NR/mrwa/frames/standards/standards.asp?G={E582C897-FF5E-4C02-8B46-51E88C1E5DD8}.

Main Roads Western Australia. (2007). "Test Method (Aggregate)." Retrieved September, 2008, from http://standards.mainroads.wa.gov.au/NR/mrwa/frames/standards/standards.asp?G={E582C897-FF5E-4C02-8B46-51E88C1E5DD8}.

Voung, B. T. and R. Brimble (2000). Austroads Repeated Load Triaxial Test Method-Determination of Permanent Deformation and Resilient Modulus Characteristics of Unbound Granular Materials Under Drained Conditions. APRG DOCUMENT APRG 00/33(MA), Austroads.