COVER SHEET

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RESILIENT RESPONSE OF RECYCLED CONCRETE ROAD AGGREGATES

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ABSTRACT: This paper presents the results of a recent investigation on the perfor
concrete aggregates (RCAs). The materials, obtained by crushing concrete with com
from 15 MPa to 75 MPa, were reconstituted to satisfy the grading requirements for
specimens were tested under repeated loading one day after compaction. It appears
compressive strength, the amount of softer material in the RCA, and the flakiness
significantly affect the resilient modulus. Degradation is mostly related to the
materials within the aggregate matrix. In this regard, the Ten Percent Fines test
as it does not impose an excessive force on the RCA. The overall results indicate
as a subbase or base course material if it can be produced to consistently meet p

INTRODUCTION

For many years since the end of the Second World War, the recycling of concrete has been practiced on a large scale in Europe and Japan. In Australia, due to the increasing shortage of suitable landfill sites and the spiraling cost of tipping fees, considerable effort is being put into utilizing waste products, such as recycled crushed aggregate (RCA) for road pavements. The difficulty with nonstandard materials of this kind is the limited information available regarding their performance, particularly under the
variability of the materials may affect the reliability of the prediction of their future in-service performance.

USE OF RCA IN AUSTRALIAN ROADS

Several municipalities in Melbourne and Sydney began recycling concrete at their
and Warwick 1996). Since then, a number of demolition companies have started comm
purposes. At present, it is estimated that approximately 400,000 tonnes of concrete are recycled annually in Sydney and approximately 350,000 tonnes in Melbourne.

Until now, RCA has been used in several road construction projects around the Melbourne metropolitan area. While RCA was initially used as drainage backfill material and bedding layer for footpaths, it soon found application as a subbase material. In 1992 the
developed standard specification clauses for the production of both upper and lower subbase materials (Paul and Warwick 1996). Table 1 shows the grading and test requirements for a 20 mm RCA.

While current data are still insufficient to prove that RCA can be produced to consistently meet the above requirements, research is continuing in many road organizations and universities to further def
with regard to its behavior under traffic loading.

In line with the current practice in mechanistic pavement design procedure, and in agreement with Nunes et al. (1996), the present authors have used repeated loading to evaluate the resilient modulus and durability of four RCAs.

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EXPERIMENTAL WORK

The RCA materials consist of one commercial aggregate (herein named AF aggregate, 15 MPa estimated compressive strength) and three other aggregates (concrete compressive strength of 18.5, 49, and 75 MPa), which were produced inhouse by crushing concre

It was found that the crushed concrete tends to be flakier as the compressive strength is higher (Table 2). While the Los Angeles Abrasion (LAA, B and K gradings) and aggregate crushing value (ACV) test results suggest that the commercial aggregate has the lowest hardness (containing traces of bricks), the tests are clearly unable to differentiate the quality of the other three aggregates (most likely due to the severity of the tests). On the other hand, the Ten Percent Fines test results show that concrete compressive strength may be directly related to hardness of th the Ten Percent Fines test is a variation of ACV test in which the load in kN required to produce 10% fines (minus 2.36 mm particles) is determined (Minty et al., 1980).

All aggregates were prepared and mixed through a trial-anderror procedure to prod

TABLE 1. Grading and Test Requirements for RCA

	Upper Subbase[a]		Lower Subbase[b]
Sieve size (mm)	Target grading	Grading limits	Grading limits
26.5	100	100	100
19.0	100	95–100	—
13.2	85	75–95	—
9.5	75	60–90	—
4.75	59	42–76	42–76
2.36	44	28–60	—
0.425	19	10–28	10–28
0.075	6	2–10	2–14

Note: Australian test methods: LL (AS 1289.3.1.1), PI (AS 1289.3.3.1), CBR (AS 1289.6.1.1), LAA (AS 1141.23).

[a] Test LL, % (max) = 35; PI, % (max) = 10; CBR, % (min) = 30; Los Angeles Abrasion (LAA), % (max) = 35.

[b] Test LL, % (max) = 40; PI, % (max) = 20; CBR, % (min) = 15; LAA, % (max) = 40.

TABLE 2. Basic Properties of RCA Aggregates

Properties	AF	18.5 MPa	49 MPa	75 MPa
LAA(B),%	30	22	25	21
LAA(K),%	27	24	21	24
ACV,%	24	23	22	22
10% fines, kN	149	158	166	187
Flakiness index	6	12	9	14

Note: LAA = Los Angeles Abrasion.

Australian test methods: LAA (AS 1141.23), ACV (AS 1141.21), 10%

Fines (RTA T215), Flakiness Index (AS 1141.15).

FIG. 1. Variation of 10% Values with Concrete Compressive Strength

FIG. 2. Particle Size Distribution of RCC Aggregates

p = 100 (d/D)n (1)

where p = percent passing; d = sieve size; D = maximum particle size; and n = grading exponent, between 0.5 and 0.6 in this particular case. (A grading with n value of about 0.5 normally produces better compactibility.) Fig. 2 shows the particle distribution

A compaction test (modified energy) was performed on the reconstituted AF aggregate, which resulted in a maximum dry density of 2.0 t/m3 and an optimum moisture content of 9.5%. Because of the grading similarities, all triaxial specimens were prepared at a moisture content of 8.5%, using the same compactive energy. All tri before conducting repeated load triaxial (RLTT). However, a limited number of specimens were cured for 7 days to establish the uniaxial compr aggregates.

While repeated load triaxial testing of the AF aggregate was carried out in a separate investigation using a large (200-mm diameter . 400-mm height) triaxial cell (see Nataatmadja and Parkin, 1990), the three other aggregates were tested using servo-controlled pneumatic equipment that can accommodate 100-mm diameter specimens. To simplify the test procedure, air pressure was used to apply constant confinement. The use of air pressure may be dangerous for high-pressure application; however, in this values were kept below 175 kPa. The repeated load triaxial testing was conducted with the drainage open.

Tests on 100-mm diameter specimens were carried out using

external strain measurement, because it was found that, with extra care, this technique could produce reasonably accurate modulus values. Note that the repeated deviator stress in the RLTT was kept well below the maximum stress associated with the static shear envelope to avoid a premature failure. Under the application of a constant confining pressure, the resilient modulus (Mr) is simply the ratio of the repeated axial stress and the recoverable (resilient) axial strain.

REPEATED LOAD TRIAXIAL TEST RESULTS

Resilient Response

It is known that the resilient modulus is a stress dependent parameter. Until recently, the resilient modulus variation has been frequently modelled using the well-known K-Theta model (Hicks 1970):

Mr = K1(u)K2 (2)

where Mr = resilient modulus; . = sum of the principal stresses; and K1 and K2 = experimental coefficients. Fig. 3 shows a typical resilient modulus variation of the RCA with the sum of the principal stresses.

Despite its simplicity, the K-Theta model is not an accurate or correct model, because the resilient modulus is not only dependent on the sum of the principal stresses but also significantly affected by of more accurate models have since been proposed (Lekarp et al. 2000), among which, a simple model developed by the first

FIG. 3. Resilient Modulus Variation According to K-Theta Model

FIG. 4. Resilient Modulus Variation According to Two-Parameter Model

author has been found to be very useful for ranking granular materials (Nataatmadja 1992)

Mr =(u/qr)(A . Bqr) (3)

where Mr = resilient modulus; . = sum of the principal stresses; qr = repeated deviator stress; and A and B = experimental coefficients.
resilient modulus of the RCA using the two-parameter model.

Comparison with Typical Road Aggregates

To evaluate the performance of the RCAs, it is necessary to compare the RCA modulus variations with those of typical fresh (nonrecycled) road aggregates. Table 3 presents the tabulated values of coe
coefficient of determination (r2). It is seen that because of the inaccuracy of the model, it is difficult to comment on the performance of the RCA
above material are compared, it is apparent that the RCAs is as good as if not better than the fresh base-course aggregates, although the 75 MPa RCA produced rather low A and B values due to the higher flakiness index (Table 4). In this case, it is worth mentioning that the 7-day uniaxial compressive strength of compacted RCA aggregates was found in the order of 1.5–2.5 MPa. This suggests that the residual cement within the RCA materials may have a significant role in affecting their resilient performance.

Degradation under Repeated Loading

Boyce (1980) noted that crushing is a significant mechanism contributing to permanent deformation. Hence, in this investigation, 100-mm diame
rubber-lined mould and loaded under repeated stress of 550 kPa to determine the level of degradation. This test was carried out in place of the RLTT test to avoid specimen failures. Particle size analysis

TABLE 3. Comparison of Performance Using K-Theta Model

Aggregate	K1	K2	r2
AF RCA	10,387	0.5939	0.8493
18.5 MPa RCA	16,712	0.5508	0.7599
49 MPa RCA	13,809	0.6087	0.8444
75 MPa RCA	14,338	0.5513	0.8802
Base course (Hicks 1970)	3,982	0.6951	0.9466
Dry Rhyolite (Nataatmadja and Parkin 1989)	5,104	0.67	0.9137
Uzan’s Dense Graded Aggregate (Nataatmadja and Parkin 1989)	40,681	0.3528	0.5619

TABLE 4. Comparison of Performance Using Two-Parameter Model

Aggregate	A (kPa)	B	r2
AF RCA	69,872	510	0.9777
18.5 MPa RCA	110,372	628	0.9198
49 MPa RCA	112,963	711	0.9781
75 MPa RCA	80,084	514	0.9814

Hicks’ base course (Nataat20,420 412 0.9691
madja and Parkin 1989)
Dry rhyolite (Nataatmadja and 24,200 560 0.9801
Parkin 1989)
Uzan’s dense graded aggregate 38,310 445 0.9500
(Nataatmadja and Parkin
1989)
Sandstone subbase (Nataat44,300 350 0.9593
madja 1994)

FIG. 5. Increase in Percent Passing after 50,000 Cycles of Repeated Loading

vealed that depending on the quality of the RCA, significant degradation of the sand-gravel fraction could result (Fig. 5). In this case, flakiness index may be the most important factor in affecting degradation characteristics of RCAs. Therefore, to avoid excessive permanent deformation while maximizing the resilient modulus, its value should probably be kept under 10% (although a value of around 35 is normally specified for fresh aggregates in Australia).

CONCLUSION

Based on the test results, it can be concluded that the performance of the RCA ma
course aggregates. The well-graded RCA may even produce a
higher resilient modulus under low deviator stresses, as compared with other mate
concrete compressive strength, the amount of softer material in the RCA aggregate, and the flakiness index of the RCA aggregate can significantly affect the resilient modulus and permanent deformation. In this regard, the Ten Percent Fines test may be suitable for estimating the compressive strength of the parent material.

REFERENCES

Boyce, J. R. (1980). ‘‘A non-linear model for the elastic behaviour of granular materials under repeated loading.’’ Proc., Int. Symp. on Soils under Cyclic and Transient Loading, Swansea, U.K., 285–294.

Hicks, R. G. (1970). ‘‘Factors influencing the resilient properties of granular materials.’’ PhD thesis, University of California, Berkeley, Calif.

Lekarp, F., Isacsson, U., and Dawson, A. (2000). ‘‘State of the art. I: Resilient response of unbound aggregates.’’ J. Transp. Engrg., ASCE, 126(1), 66–75.

Minty, E. J., Pratt, D. N., and Brett, A. J. (1980). ‘‘Aggregate durability tests compared.’’ Proc., 10th ARRB Conf., Australia Road Research Board, Sydney, Australia, 3, 10–20.

Nataatmadja, A. (1992). ‘‘Resilient modulus of granular materials under repeated loading.’’ Proc., 7th Int. Conf. on Asphalt Pavements, Univ. of Nottingham, Nottingham, U.K., 1, 172–185.

Nataatmadja, A. (1994). ‘‘On the response of granular unbound pavement materials under repeated loading.’’ Proc., 17th ARRB Conf., Australia Road Research Board, Gold Coast, Australia, 2, 99–114.

Nataatmadja, A., and Parkin, A. K. (1989). ‘‘Characterisation of granular materials for pavements.’’ Can. Geotech. J., 26, 725–730.
Nataatmadja, A., and Parkin, A. K. (1990). ‘‘Axial deformation measurement in rep

48.

Nunes, M. C. M., Bridges, M. G., and Dawson, A. R. (1996). ‘‘Assessment of second
environmental aspects.’’ Waste Mgmt., 16(1–3), 87–96.

Paul, R., and Warwick, R. (1996). ‘‘Use of recycled crushed concrete for
road pavement sub-base.’’ Proc., 18th ARRB Conf., Australia Road Research Board,

NOTATION Mr = resilient modulus;
The following symbols are used in this paper: n
p
=
=
grading exponent of Talbot equation;
percent passing;
A, B
D
=
=
experimental coefficients of two parameter model;
maximum particle size;
qr
r2
=
=
repeated deviator stress;
coefficient of determination; and
d = sieve size; . = sum of principal stresses = s1 . s2 . s3.
K1, K2 = experimental coefficients of K-Theta model;