Durability And Performance Characteristics Of Recycled Aggregate Concrete

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Summary: In recent years, the recycling of concrete to produce aggregates suitable for non-structural concrete applications is emerging as a commercially viable and technically feasible operation. In this paper, we report on performance and durability tests carried out to determine the fresh and hardened properties of concrete made with commercially produced coarse recycled concrete aggregate and natural fine sand. Test results indicate that the difference between the characteristics of fresh and hardened recycled aggregate concrete and natural aggregate concrete is relatively narrower than reported for laboratory-crushed recycled aggregate concrete mixes. For concrete without blast furnace slag, having similar volumetric mix proportions and workability, there was no difference at the 5% significance level in concrete compressive and tensile strengths of recycled concrete and control normal concrete made from natural basalt aggregate and fine sand. Water absorption rates and carbonation of recycled concrete and reference concrete were comparable. However, the abrasion loss of recycled aggregate concrete made with ordinary Portland cement increased by about 12% compared to normal concrete, while the corresponding drying shrinkage was about 25% higher at one year.

Long-term performance results generated from field case studies involving the construction of a 120 m long bicycle/footpath with a 40 m recycled aggregate concrete (RC) segment are discussed. The paper further discusses observed fresh and hardened concrete properties of both recycled and conventional aggregates, and examines specific implications for satisfactory performance of the recycled product for recreational and non-structural construction applications.

Keywords: Aggregates, compressive strength, concrete, durability, recycling.

1 INTRODUCTION

Intensive global R&D effort conducted over the last few decades demonstrates the potential viability of recycled concrete aggregate (RCA) as a concreting material (Hansen 1992; Sri Ravidrarajah *et al*. 1987; Sagoe–Crentsil *et al*. 1996). Notwithstanding what has been achieved, there still exists a scarcity of durability performance and engineering data on the serviceability of construction works incorporating recycled aggregates. This situation has arisen because, until recently, the use of crushed concrete derived from building demolition has been restricted to granular sub-base layers in road pavements, and drainage or excavation fill applications, rather than the production of new concrete. However, the emergence of new crusher technologies, including rubble processing, grading and aggregate washing equipment, together with tighter regulation of the recycling industry (Topcu 1997), have contributed to significant improvements in the quality of recycled concrete aggregate products.

While studies on the engineering properties of concrete made with laboratory-crushed recycled concrete aggregate abound (Frondistou–Yannas 1980; Hansen & Narud 1983), only limited data is available on commercial grade recycled concrete aggregate, including concrete mix proportions, fresh concrete performance and durability characteristics. Technical consideration for the use of recycled aggregates in premix concrete production, however, is strongly dependent on achieving satisfactory fresh and hardened concrete performance. Thus, this paper evaluates aspects of recycled concrete durability and field performance based on commercial production of N25 (25 MPa) grade premix concrete for recreational construction works.

2 LABORATORY TESTS

A single source of commercially graded unwashed coarse RCA and natural fines was used in all recycled concrete mixes. The natural coarse aggregate used in the reference mixes was a nominal 14 mm crushed basalt. The grading of the basalt and the coarse RCA conformed to the requirements of AS 2758.1 (Standards Australia 1998), as shown in Table 1. A fine to coarse aggregate ratio of 46:54 was kept constant throughout the test program for all concrete mixes. The RCA was batched in the as-received state. Details of the physical properties of both aggregates are shown in Table 2.

Ordinary Portland cement (Type GP) and blast furnace slag cement (Type GB) comprising 65/35 Portland cement/blast furnace slag were used in the investigations. The slag blend was used partly to assess the possible improvements in fresh concrete cohesion, workability and concrete performance.

2.1 Concrete mixes

Several preliminary trial mixes were prepared to evaluate water requirements for a nominal 25 MPa concrete. Mix proportion data is given in Table 3. The unit water content of the concrete was corrected for free moisture in the aggregates. However, the recycled aggregate was presaturated for 10 minutes in the mixer and brought to room temperature prior to mixing the concrete. The mixes were proportioned to have a nominal binder content of 240 kg/m^3 for mixes C0912A, C0912B and C1212A, while mix C1212B contained an additional 5% cement to assess the effect of increased cement content. Slag cement was used in mix C1212A.

The water/binder ratio (W/B) of all mixes was adjusted to achieve comparable consistency and a nominal slump of 80 ± 15 mm. A reduction in the water requirement was attained by using a lignosulfate-based water-reducing admixture at nominal doses recommended by the manufacturer. The recycled concrete mixes contained 100% recycled aggregate and natural fine sand, while the normal concrete mixes contained all natural coarse and fine aggregates.

Table 1. Sieve analysis of coarse RCA and basalt aggregate

Coarse aggregates	*Percentage of mass passing through sieve (mm)*						
Maximum size (mm)	*19*	*13.5*	*9.5*	*6.7*	*4.75*	*2.36*	*150 mm*
RCA	100	91.4	28.7	7.6	5.4	0.2	0.5
Basalt	100	84.0	43.7	5.6	2.1	1.0	0.2

Table 2. Properties of RCA and basalt aggregate

Property	*RCA*	*Basalt*
Aggregate crushing value (%) (AS 1141.21)	23.1	15.7
Bulk density (kg/m^3) (AS 1141.6)	2394	2890
Water absorption (%) (AS 1141. 6)	5.6	1.0
Impurity level (%) (AS 1141. 32)	0.6	<0.1
LOI (%)	4.9	1.3

Table 3. Mix designation and mix details of concrete specimens

Mix designation	*Binder loading (kg/m^3)*	*Binder type*	*W/B*	*Slump (mm)*	*Wet density (kg/m^3)*	*Entrapped air content (%)*	*Coarse aggregate*
C0912A (*OPC/basalt*)	242	Type GP	0.76	90	2466	2.4	Basalt
C0912B (*OPC/recycled*)	240	Type GP	0.73	75	2335	2.4	Recycled
C1212A (*Slag/recycled*)	238	Type GB	0.74	95	2321	1.8	Recycled
C1212B (*OPC+5%/recycled*)	254	Type GP	0.70	80	2335	2.3	Recycled

Specimens were cast from each mix to assess compressive strength, drying shrinkage, expansion, splitting tensile strength and abrasion resistance. Unless otherwise specified, all specimens, upon their removal from the moulds, were stored under standard moist curing conditions of 23°C and >95% RH until required for testing. Hardened concrete testing was performed in accordance with the requirements of AS 1012.

2.2 Laboratory tests – results and discussions

Based on visual inspection, the surface texture of the RCA appeared characteristically grainy compared to the basalt. This is partly a result of the residual cement mortar attached to the RCA particles, and is also responsible for the characteristic lower density and corresponding higher aggregate crushing values compared to the basalt aggregate (Hansen 1992; Frondistou–Yannas 1980).

As indicated in Table 2, RCA also has a comparatively high water absorption value at 5.6%. Although the water absorption of the recycled aggregate is relatively high compared to the reference basalt aggregate, there was no difficulty in achieving the desired consistency and subsequent compaction of concrete.

Compressive strengths were determined on concrete cylinders continuously stored under moist conditions for up to 365 days. As shown by the mean compressive strength results plotted in Fig. 1, there is no significant difference between the strength of Portland cement concretes, as a function of aggregate type, for the grade of concrete investigated.

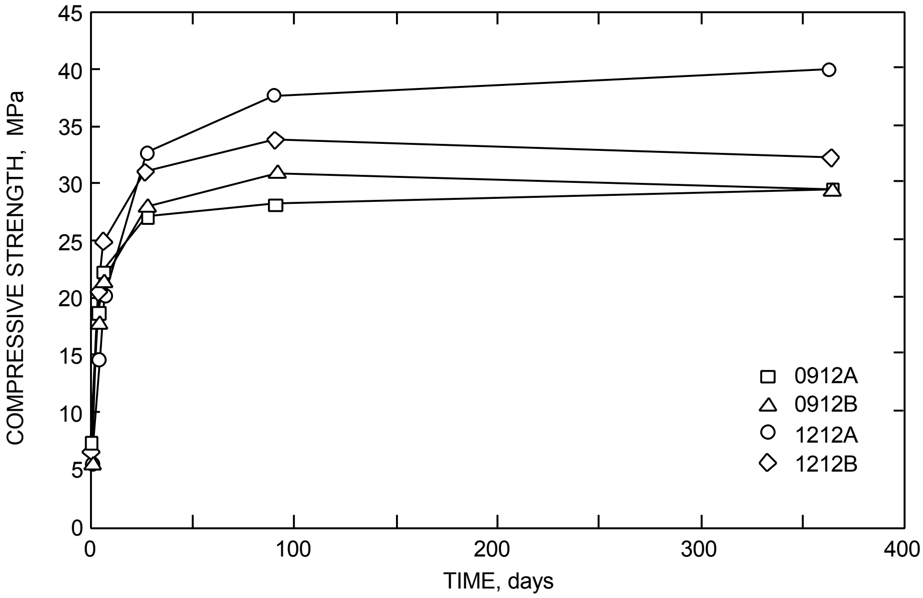

Figure 1. Development of concrete compressive strength with age

The corresponding increase in strength gain of the slag cement concrete from 20.2 to 32.6 MPa between 7 and 28 days is significantly higher than the equivalent nominal 6 MPa average increase for the Portland cement concretes. As noted in Fig. 1, the strength gain for recycled concrete made with Portland cement remains virtually unchanged at the 5% significance level beyond 28 days.

As shown in Table 4, the splitting-tensile/compressive strength ratios of recycled concretes are comparable to results obtained for conventional concretes made with natural aggregates. This ratio provides an indication of the resistance of a concrete to tensile strain and is dependent on type and size of coarse aggregate particles, voids in the concrete, and curing and test conditions. Calculated splitting-tensile to compressive strength ratio values ranged from 0.89 to 1.21 for recycled concrete, compared to 0.8 to 1.4 for standard aggregate concretes.

The variation of drying shrinkage strain with time for both recycled and reference concretes is shown in Fig. 2. The drying shrinkage of test specimens increased with time and stabilised at about 91 days, following similar trends reported by several researchers (Sri Ravindrarajah *et al*. 1987; Topcu 1997) for laboratory-crushed recycled concrete, although the absolute shrinkage values are slightly lower in the present case. While both natural and recycled aggregates display similar trends with regard to the rate of shrinkage, strains associated with recycled concrete made with slag cement at 365 days are over 35% higher than the reference mix, and closer to typical published values of 30–70% (Hansen 1992; Sri Ravindrarajan *et al*. 1987). In contrast, only a 15% increase in shrinkage strain is obtained for Portland cement specimens for the same curing conditions. However, there appears to be a much less significant effect on drying shrinkage as a result of the 5% difference in cement content.

Table 4. Ratios of splitting-tensile (f_t) and compressive strength (f_c) of concretes

Concrete mix	f_t/f_c		
	7 days	*28 days*	*365 days*
C0912A (*OPC/basalt*)	1.19	1.07	0.99
C0912B (*OPC/recycled*)	1.19	1.20	0.94
C1212A (*slag/recycled*)	1.21	0.98	0.96
C1212B (*OPC+5%/recycled*)	1.08	0.97	0.89

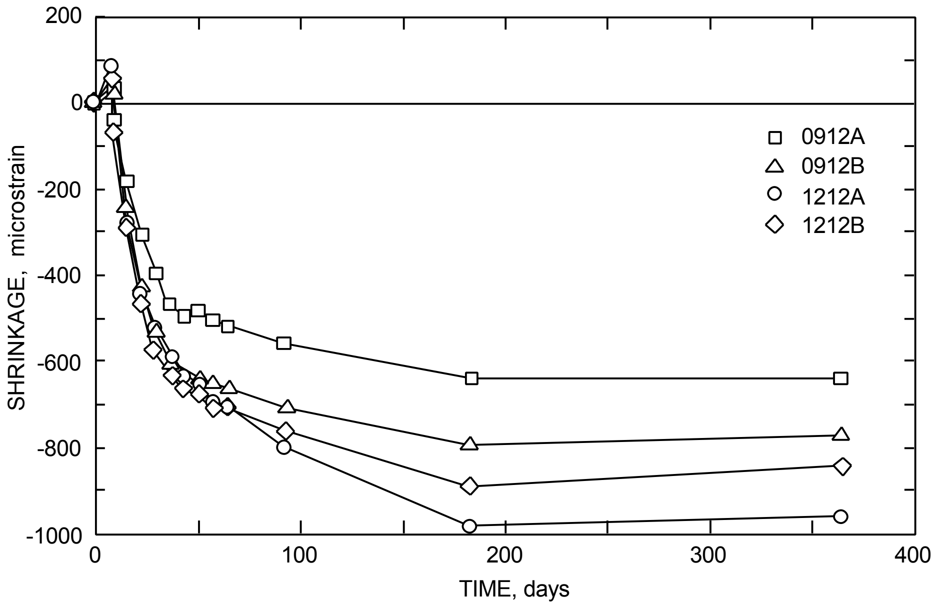

Figure 2. Relationship between drying shrinkage strain of recycled and reference concrete with time

It is evident from Fig. 2 that RCAs display higher drying shrinkage values compared to the reference normal concrete mixes, possibly partly due to the lower restraining capacity of recycled aggregate particles compared to basalt. Currently, AS 3600 (Standards Australia 1994) recommends a basic shrinkage limit of 700 microstrain at 56 days.

3 FIELD TRIAL

3.1 Project description

The field trial involved the construction of a bicycle/footpath facility located at Duncans Road, Werribee South, Victoria, Australia. The project involved the construction of a 120 m long, 2 m wide and 100 mm thick bicycle/footpath, a section of which is shown in Fig. 3. A segment, about 40 m long, was constructed with recycled aggregate concrete(RC), and normal grade concrete(NC) for the remainder. Normal base course preparation was employed. Both concrete types contained polypropylene fibres. No steel mesh was used. The Council supplied both RC and NC from a commercial batching plant and the contractor completed placement of both types of concrete over a two-day period. Both concrete types were formulated to the same mix design and were supplied by a local premix concrete producer.

Concrete compressive strength measurements and shrinkage tests were carried out on in-situ cored samples, as well as field- and laboratory-exposed specimens made from the supplied concrete batches. The specified concrete strength was 25 MPa.

3.2 Observations

The measured concrete slump was 75 mm and 115 mm for the RC and references (NC) mixes respectively. The air temperature on the day of casting for the RC was 11°C and 18°C for NC. Placement and finishing for both types of concrete presented no difficulties for the contractors.

3.3 Field trials – results and discussion

3.3.1 Compressive strength

As shown in Figs 4 and 5, the 28-day fog cylinder compressive strengths of RC and NC concrete were 27.0 MPa and 28.1 MPa respectively – well above the specified 25 MPa cylinder strength. The corresponding 28-day strengths of field-cured concretes with a length to diameter ratio of ~1:1 were 20.1 MPa for RC and 23.2 MPa for the NC concrete. The core sections were taken from experimental concrete test strips cast adjacent to the path, as shown in Fig. 3. Concrete strengths at six months were comparable.

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Figure 3. Completed footpath showing section of experimental test strip

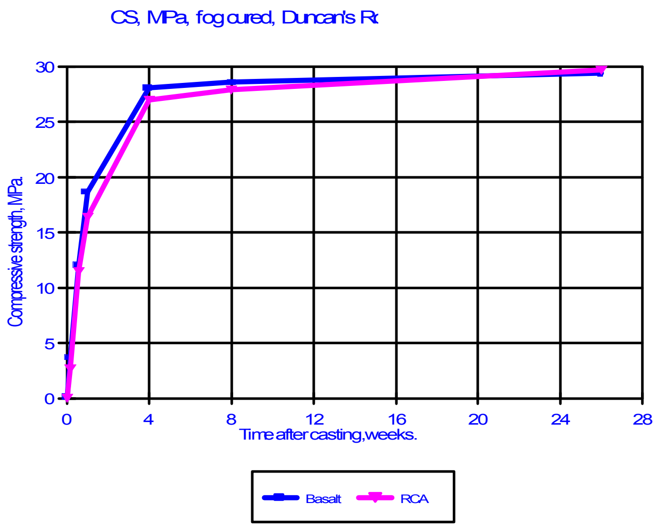

Figure 4. Fog-cured compressive strengths of RC and NC concretes

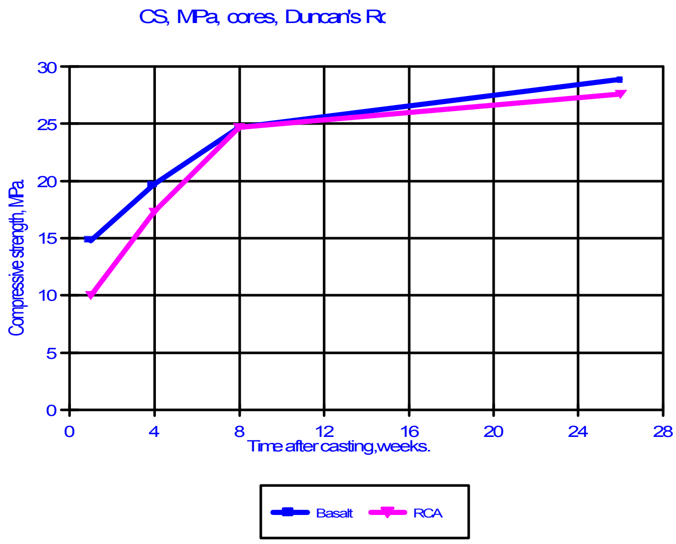

Figure 5. Core compressive strengths of RC and NC concretes

The 26-week compressive strength development of 95 mm diameter cored sections was of the same order for NC and RC concretes. It is conceivable that the difference in ambient temperatures at the time of casting may be partly responsible for the marginally lower initial strength of RC specimens, particularly given that Type GB cement was used.

3.3.2 Dimensional stability

Shrinkage data is shown in Figs 6 and 7. A separate set of specimens was stored in a conditioned room at 23°C and 50% RH, after 7 days of fog cure. Measured shrinkage of field-exposed specimens 56 days after casting are–0.122% for RC and –0.098% for NC respectively. Equivalent results of field-exposed samples were –0.021% and –0.020% respectively for RC and NC specimens.

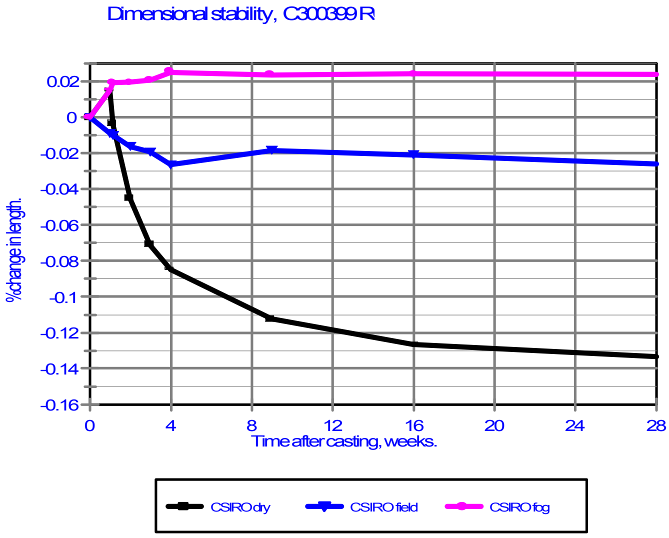

Figure 6. Drying shrinkage of RC concretes

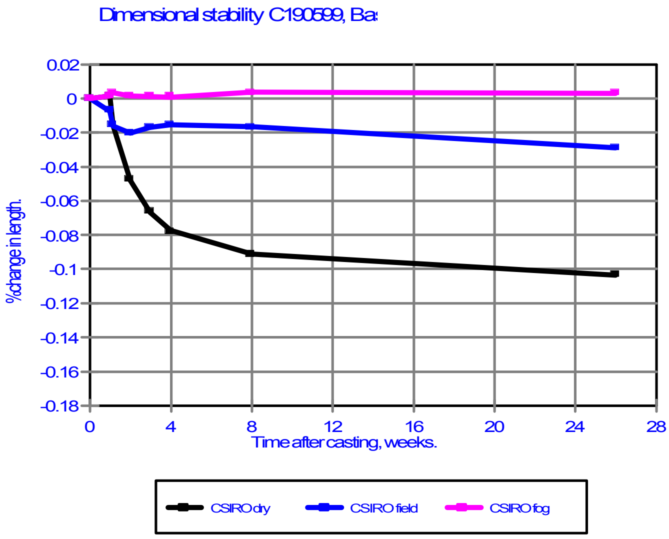

Figure 7. Drying shrinkage of NC concretes

4 CONCLUSIONS

The satisfactory demonstration of a real-life constructed facility, as reported in this paper, provides a preliminary indication of the technical performance of recycled aggregates, whilst promoting consumer awareness of waste minimisation and recycling in the construction sector. The results of the trials specifically indicate the potential for partial or full replacement of virgin aggregates with recycled material in non-structural construction applications. The preliminary findings of the project further indicate the following.

1. The quality of commercially produced coarse RCA and the performance of premix recycled concrete are, possibly, at a level where uniform concrete quality is achievable.
2. The same equipment and procedures used for concrete containing conventional aggregate may be used to batch, mix, transport, place and finish recycled premix concrete, including curing requirements. Initial trialing of recycled concrete mix designs are, however, recommended should there be a need for appropriate minor adjustments to achieve the desired performance.
3. Over the six-month test period, recycled premix concrete typically exhibits comparable characteristics similar to those of conventional concrete, and generally satisfies nominal specification requirements for concrete performance.

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4. Similar performance trends exists in RC and NC concretes for both the fresh and hardened states, including the response to conventional mix design methods, except for differences in measured drying shrinkage values for two of the three grades of concrete investigated, i.e. 15 and 25 MPa concretes.

5 REFERENCES

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