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RECYCLED CONSTRUCTION RUBBLE AS AGGREGATE

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RECYCLED CONSTRUCTION RUBBLE AS AGGREGATE

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Abstract

The ready availability of good quality virgin aggregates for concrete is reducing in some areas of the country, especially Auckland.

This paper discusses the initial results of an investigation into the properties of concrete made using recycled construction rubble as concrete aggregate. The aim of the work is to see if it would be possible to replace virgin aggregate with recycled rubble to reduce the drain on premium aggregate supplies.

It concludes that the use of recycled construction rubble as coarse aggregate for concrete is a viable proposition.

Introduction

In some areas of New Zealand cheap, readily accessible supplies of good quality concrete aggregate are starting to become a rare commodity. This is perhaps best demonstrated in Auckland where the author has heard of aggregates having to be trucked one and a half hours from the quarry to the ready mix plant. This is a result, generally, of current supplies running out, and any possible new sites, which are relatively close to ready mix plants, having been overtaken by urban sprawl. Hence, to get a site where it is also possible to get a resource consent to quarry rock, aggregate suppliers have had to move further out of Auckland.

This paper looks at the possibility of using recycled demolition concrete as coarse aggregate for new concrete for certain situations where a high quality concrete aggregate is not necessary. Why use the same quality aggregates that went into the Sky Tower, say, for making the concrete that will go into a residential driveway? Recycled aggregate concrete is used successfully overseas to conserve virgin aggregate supplies (Buck).

Different properties of concrete made with two different sources of recycled concrete aggregate are investigated. These are compared with control mixes to observe their comparative behaviours.

Experimental Method

The project was carried out in three stages. The first was making and testing a control concrete. These mixes are denoted with by the letters RA. During the second stage, the crushed control concrete was used as coarse aggregate for new concrete. These mixes are denoted by the letters RC. The third and final stage used crushed concrete supplied from an Auckland demolition company as coarse aggregate for new concrete. The letters ROC denote these mixes.

Before each stage, the coarse aggregate properties were determined. These included determination of saturated surface dry (SSD) density, oven-dry (OD) density and absorption to NZS 3111: 1986, Section 12, and crushing resistance to NZS 3111: 1986, Section 14.

For the second and third stages the aggregate was graded to the same grading as the virgin aggregate used in the control mix. This was done to prevent any variation in the grading having an effect on the mix properties.

Stage 1: Control Mix

The design for the control mix is given in Table 1, below. It was designed to have a strength of 17.5 MPa. This was chosen as it was felt that this would give a reasonably low strength concrete to use as aggregate, representing typical recycled concrete in the strength range 17.5 - 28.0 MPa. This mix design was designated RA230.

Material	SSD Weight kg/m^3
19 mm crushed greywacke aggregate	545
13 mm crushed greywacke aggregate	545
River Sand	818
GP Cement	230
Water reducer	0.550
Air entrainer	0.100
Target air	5.5%
Total water	170

Table 1: Control Mix Design

The concrete was weigh batched and mixed in a 100 litre pan-type mixer. Four 75 litre mixes were made, each targeting a slump (as measured to NZS 3112: Part 1: 1986) of 100 mm. Samples for fresh and hardened concrete testing were taken from each batch. Samples were made for compressive strength testing to NZS 3112: Part 2: 1986, flexural tensile testing to NZS 3112: Part 2: 1986, drying shrinkage to AS 1012.13, and modulus of elasticity testing to ASTM C469. The remaining concrete was cast into slab moulds for crushing into aggregate to be used for the RC mixes.

The concrete cast as slabs was well compacted in the mould, and kept moist overnight. The next day the slabs were stripped and transferred into a fog room. The environment in the fog room is maintained at 21°C and 100% relative humidity. At an age of 28 days they were removed from the fog room and placed in the main laboratory, which does not have any environmental control. The period when this took place was December, so the ambient conditions were reasonably warm and dry.

After the slabs had dried out (they were left approximately one month), they were crushed in a laboratory jaw crusher. The resulting rubble was sieved into discrete sizes such that it could be graded the same as the virgin aggregate used for the control mix. The sizes were material retained on the 16.0 mm, 13.2 mm, 9.5 mm, 6.7 mm and 4.75 mm sieves. This new recycled aggregate appeared to mainly be pieces of virgin aggregate with some paste on the outside. There were very few large pieces which were mainly paste.

All material passing the 4.75 mm sieve was discarded. Only the coarse recycled aggregate was used. This was done as a literature study undertaken before the project indicated that, whilst the fine material could be used, it tended to have a highly variable and large absorption making the required water demand difficult to predict (Buck, Hansen and Narud). It also decreased the workability thereby increasing the water demand. A sample of fine recycled aggregate tested during this program had an absorption of over 8.0% compared with a normal concreting sand which will have an absorption of 1.0 - 1.5%.

Stage 2: Recycled Concrete Mixes

The coarse aggregate obtained from crushing the control mix concrete was used to make three different mixes. The first, RC230, had an identical mix design to RA230 given above except that the mass of the aggregates was lighter due to the lower density of the recycled concrete aggregates. This mix was done to provide a direct comparison to the control mix.

The second mix, RC250, had 250 kg/m^3 of cement and slightly less sand. This mix was carried out to try and determine what level of cement increase would be necessary to obtain an equivalent strength to the control concrete.

RC320, the third mix, had 320 kg/m^3 of cement. The mix design used is given in Table 2 below. This is a structural mix design, the results of which are to be compared with control concretes from work carried out previously (designated here as RA320).

Material	SSD Weight kg/m^3
19 mm new recycled aggregate	545
13 mm new recycled aggregate	545
River sand	818
GP cement	320
Water reducer	0.800
Target air	2.5%
Total water	165

Table 2: RC320 Mix Design

For each of the mixes the wet concrete properties were tested to NZS 3112: 1986, Part 1, and samples were made for testing compressive strength, flexural strength, drying shrinkage and modulus of elasticity.

Stage 3: Recycled Old Concrete Mixes

The concrete rubble received from the demolition company had been crushed to some extent, and was in pieces from about 150 mm down. There was some contamination with small pieces of wood and dirt, as one would expect from a demolition site. Care must be taken with any aggregate supply of this type to ensure that contamination is kept to a minimum.

A representative sample was put through the jaw crusher such that enough aggregate was obtained to carry out the required mixing. Again this aggregate was sieved out and recombined to have the same grading as the virgin aggregate. All material passing the 4.75 mm sieve was discarded. Like the new recycled aggregate described in Stage 2 above, the old recycled aggregate was mainly made up of pieces of rock with some paste attached.

The mix designs from stage two were repeated with this aggregate such that there were mixes ROC230, ROC250 and ROC320.

Wet concrete properties were tested, and samples were again made for testing compressive strength, flexural strength, drying shrinkage and modulus of elasticity.

Some large pieces of concrete that had not been crushed were also sent with the recycled old concrete. From these cores were taken to determine the strength of the concrete and its density before crushing. This testing was done to NZS 3112: Part 2: 1986

Results

Aggregate Properties

Table 3 gives the results of the testing carried out on the coarse aggregates.

Property	Virgin Greywacke Aggregate	New Recycled Aggregate	Old Recycled Aggregate
SSD Density	2660 kg/m^3	2490 kg/m^3	2570 kg/m^3
OD Density	2650 kg/m^3	2400 kg/m^3	2450 kg/m^3
Absorption	0.5%	3.8%	4.8%
Crushing Resistance	360 kN	170 kN	110 kN

Table 3: Coarse Aggregate Properties

Results of the core testing from the old concrete are given in Table 4 below.

	Strength (MPa)	SSD Density (kg/m^3)
Old Concrete	61.5	2590

Table 4: Old Concrete Properties

Approximately 25% by mass of the concrete was discarded after crushing. This was the material that passed the 4.75 mm sieve. This was the case for both the new and old recycled concretes.

Wet Concrete Test Results

Table 5 gives the wet concrete results for all of the mixes.

Mix	Slump (mm)	Air Content (%)	Wet Density (kg/m^3)	Yield	Measured w/c*	Total Water (l)
RA230	100	7.0	2270	1.008	0.67	153
RC230	100	5.5	2220	1.006	0.71	163
ROC230	80	7.6	2210	1.012	0.66	150
RC250	100	5.5	2220	1.008	0.64	159
ROC250	90	7.0	2230	1.007	0.61	152
RA320	100	2.3	2410	1.002	0.53	170
RC320	90	2.5	2290	1.022	0.55	172
ROC320	90	3.7	2310	1.023	0.53	164

* w/c: water to cement ratio
RA: Control mixes
RC: Recycled new aggregate concrete
ROC: Recycled old aggregate concrete

Table 5: Wet Concrete Properties

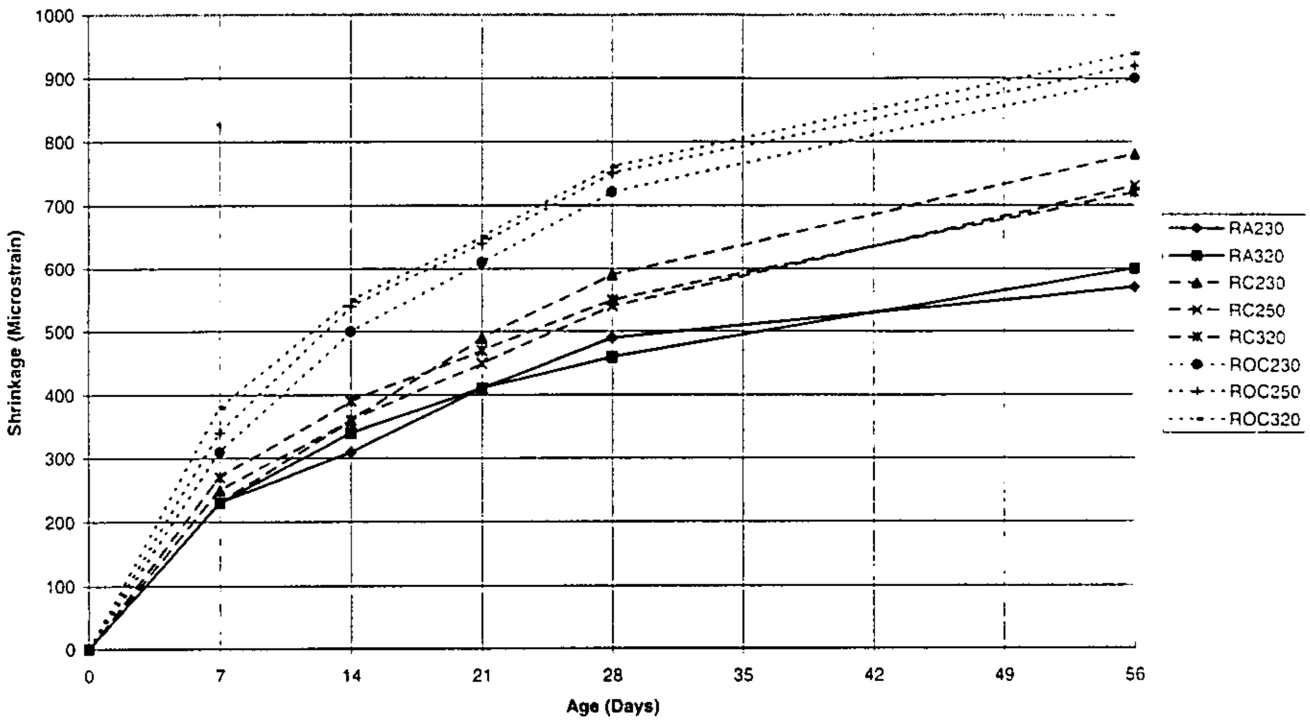
Hardened Concrete Test Results

Table 6 shows the results of the hardened concrete tests. The results of the drying shrinkage are also given graphically in Figure 1.

Mix	28 Day Strength (MPa)	Hardened Density (kg/m^3)	Flexural Tensile Strength (MPa)	56 Day Drying Shrinkage (microstrain)	Modulus of Elasticity (GPa)
RA230	28.5	2350	4.2	570	37.1
RC230	21.5	2260	3.0	780	26.0
ROC230	24.0	2270	3.4	900	28.2
RC250	27.0	2270	3.6	730	Not Tested
ROC250	28.0	2270	3.8	920	29.5
RA320	43.0	2430	Not Tested	600	Not Tested
RC320	39.0	2330	4.4	720	33.8
ROC320	43.5	2350	4.4	940	28.8

Table 6: Hardened Concrete Properties

Figure 1: Drying Shrinkage



Discussion

Aggregates

All of the parameters measured in the coarse aggregate testing showed differences between the virgin coarse aggregate and the recycled coarse aggregates. Firstly, the density is significantly greater for the virgin aggregate. This is not surprising given the fact that the density of the concrete crushed up to make the recycled aggregate was 2350 kg/m^3 for the virgin aggregate concrete, and 2590 kg/m^3 for the old concrete. The higher density for the old concrete was due to the fact that the aggregates used to make it were Auckland basalt, which has a higher density than greywacke.

The high absorption values in the recycled aggregates come from the air voids in the original concrete. The RA230 mix had an air content of 7.0%. This gives the resulting new recycled aggregate more pores, and hence a higher absorption. The new recycled aggregate had an absorption of 3.8%. A typical greywacke aggregate has an absorption of approximately 0.5 - 0.7%. In the case of the old concrete, the basalt, upon observation, appeared quite vesicular. That is, the aggregate used to make the original concrete had a lot of pores already in it. This, plus any other air voids in the paste of the old concrete, gives the reasonably high absorption figure of 4.8%. A typical basalt aggregate has an absorption of approximately 3.5 - 4.0%.

These high figures do not make the aggregate unsuitable for concrete, but it is important that if these types of aggregates are to be used, then the aggregate stockpiles must be kept wet to keep aggregates above SSD and thereby prevent problems with mixing.

Crushing resistance is given as the force needed to break a sample of aggregate passing a 13.2 mm sieve, but retained on a 9.5 mm sieve, such that 10% will pass through a 2.36 mm sieve. The virgin aggregate quite clearly has the highest crushing resistance with the recycled concrete second and the old recycled concrete third. This is interesting because the concrete which produced the old recycled concrete was twice as strong as the RA230 mix which produced the new recycled aggregate. What is believed to have caused this is that the old recycled aggregate may have been more prone to losing small pieces, whereas the new recycled aggregate, whilst it also broke down easily, it may have initially broken into larger pieces, thereby requiring more force to get 10% to pass a 2.36 mm sieve. The crushing resistance test values based on 10% fines for non-homogenous aggregate (eg recycled aggregate with mortar and virgin aggregate) may not be relevant for describing recycled aggregate fracture within concrete.

Wet Concrete

When used in concrete, the recycled aggregates appeared to behave very satisfactorily. This is also the observation of work carried out overseas (Frondistou-Yannas, Buck, Hansen and Narud). The only anomaly was a rather high air content in the ROC mixes. This is probably best explained by the vesicular basalt in the mix entrapping quantities of air.

The target slump was easily obtained with all of the mixes. It should be noted that all of the 230 and 250 mixes had a lower than design water content. This led to a lower w/c ratio, and hence, higher strengths. So the 17.5 MPa control mix, which should have had a strength of around 22.5 MPa, had a strength of 28.5 MPa instead. The 320 mixes were all fairly consistent.

Hardened Concrete

In general the recycled aggregates produced weaker concrete than the virgin aggregates. From the RA230 mix to the RC230 mix there was quite a significant drop in strength of 7.0 MPa, or 25%. The drop in strength from the RA 230 mix to the ROC230 mix was 4.5 MPa or 16%. Mixes RC250 and ROC250 with an extra 20 kg of cement were made to determine what level of cement increase would give a strength equivalent to the RA230 mix. The RC250 mix had a strength of 27.0 MPa and the ROC250 mix had a strength of 28.0 MPa. It can be seen therefore, that for these mixes, an increase in the cement content of the recycled aggregate mixes by 20 kg/m^3 brought the strength of the concrete back up to the level attained using virgin aggregate.

The 320 mixes all gained very similar strengths. The RC320 mix gained 39.0 MPa in 28 days compared with the 43.0 MPa gained by the RA320 mix. The ROC320 mix gained 43.5 MPa, more or less equalling the RA320 mix.

The hardened densities of the mixes made with recycled aggregates were lower than on those made with virgin aggregates. This is to be expected given the lower densities of the aggregates used in the mixes.

The flexural tensile strength of the recycled aggregate concretes was significantly lower than the virgin aggregate concrete. This is as a result of the weaker aggregates. Flexural tensile strength is loosely related to the compressive strength of the concrete, so the stronger the concrete in compression, the stronger the concrete in flexure. However, the effect of the weaker aggregate seems to have a marked affect on the performance of the recycled concrete in flexure. The 320 recycled aggregate mixes only just pass the RA230 mix for flexural strength.

The drying shrinkage of concrete made with recycled aggregate was markedly greater than that made with virgin aggregates. This correlates well with work carried out by Tavakoli and Soroushiam. This high level of shrinkage is again, probably due to the physical properties of the aggregate. The weaker aggregate, and in particular, the weaker mortar adhered to the aggregate, has a lesser restraining effect on shrinkage. This allows more shrinkage to take place. Care should be taken therefore, when using recycled aggregate concrete to ensure that allowance is made for any shrinkage that may occur.

The modulus of elasticity (MOE) measurements perhaps best display the difference between the virgin and recycled aggregate concretes. The virgin aggregates are just that much stronger, that much more rigid, giving the higher MOE results.

Concrete with the characteristics of the recycled aggregate concrete outlined above would be suitable for many situations, especially non-structural ones such as driveways, footpaths, foundations etc, where the higher shrinkage can be accommodated.

Overall, given the results of this test program, the use of recycled concrete as aggregate for new concrete is a practice that can be adopted as long as care is taken in handling the aggregates, ensuring that they are kept moist, and that they are not expected to perform as well as the same concrete made using virgin aggregates.

Future research in this topic will be looking at full scale field trials using recycled concrete as coarse aggregate for new concrete.

Conclusions

- Recycled aggregate concrete will be weaker than the same concrete made with virgin aggregates. This can be compensated for by adding extra cement to the mix.
- The hardened density of concrete made using recycled aggregates will be lower due to the lower density of the aggregate itself.
- The flexural tensile strength of concrete made using recycled aggregates will be lower than the same concrete made with virgin aggregates. This can not be as easily compensated for by adding cement as the loss in compressive strength could.
- There is a marked increase in drying shrinkage when using recycled aggregates in concrete. This must be allowed for when using this concrete in practice.
- The modulus of elasticity of concrete made using recycled aggregates is much lower than the same concrete made using virgin aggregates. This is due to the physical properties of the aggregates in question.

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