WASTE CONCRETE AS FINE AND COARSE AGGREGATE FOR NEW CONCRETE

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ABSTRACT

The effects of using crushed concrete as coarse and fine aggregates upon strength, elasticity and drying shrinkage of concrete are reported and compared with conventional concrete. The effects of using recycled concrete aggregates instead of natural aggregates in concrete are; reduction in compressive strength and modulus of elasticity by about 22 and 33 percent respectively; lower tensile and flexural strengths and about double amount of drying shrinkage. Fresh concrete properties were only marginally affected by the use of recycled aggregates. Available methods of predicting the modulus of elasticity on the basis of compressive strength for natural aggregate concrete overestimate the modulus of elasticity for recycled-aggregate concrete.

INTRODUCTION

There is critical shortage of natural aggregate for production of concrete in many urban areas. At the same time, increasing quantities of demolished concrete from deteriorated or obsolete structures are generated as waste material in the same areas. Most demolished concrete can be processed to yield aggregates for production of new concrete. Recycling concrete as aggregates for new concrete has attracted many researchers and the relevant literature has been reviewed by Nixon [1] and Hansen [2]. Most of the reported investigations have been into the properties of concrete using recycled coarse aggregate only. However, during the process of crushing waste concrete, about 30% of the product is fine material passing a 5mm standard sieve. Ravindrarajah [3] found that recycled-aggregate concrete made with fine and coarse recycled aggregate had up to 10 and 30 percent reduction in compressive strength and modulus of elasticity respectively. He also found that drying shrinkage of recycled-aggregate concrete at 90 days is about twice that for the natural aggregate concrete. Hasaba *et al* [4] found drying shrinkage of recycled aggregate concretes produced with both coarse and fine recycled aggregate to be 70 percent larger than that of the control concretes.

The purpose of the present investigation is to study the properties of concrete having recycled concrete of different quantities as fine and coarse aggregates. The results are compared with those for concrete of similar mix composition made with natural aggregates. The scope of this work is limited to recycled aggregates which were produced in the laboratory and therefore be considered as free of unsound materials and contamination. such clean concrete can be obtained from testing laboratories, precast concrete plants, and ready- mixed concrete plants.

EXPERIMENTAL DETAILS

Materials

Ordinary Portland cement conforming to BS-12 [5] was used in the investigation. The fine and coarse aggregates used in the control mixes were natural sand conforming to grading zone 2 of BS-882 [6] and crushed lime stone of maximum size 20 mm, respectively. Recycled fine and coarse aggregates were prepared by crushing demolished concrete by a hammer in the laboratory. Crushed products were screened into different seize fraction by using a sieve shaker. Product retained on a 20 mm BS sieve was recrushed to produce additional concrete fines. The crushed products were recombined to obtain similar grading to those of sand and lime stone natural aggregate.

Concrete Mix Proportions

Two series of tests were carried out. Table (1) summarizes the compositions of the concrete mixed used. The coarse and fine aggregates used in series 1 and 2 were natural and recycled aggregates, respectively. The water/cement ratio by weight was varied between 0.30 and 0.70. The aggregate/cement ratio by weight were 5.46 and 5.1 for the concrete with natural and recycled aggregates, respectively. However, the volume fraction of aggregate in both types of concrete was approximately the same, because of the low specific gravity of the recycled aggregates compared to that of the natural aggregates.

Table 1. Mix proportions of control and recycled aggregate concretes.

Series	Mix	Mix Composition (kg/m^3)			W/C	A/C
		Cement	Aggregate	Water		
I	NN1	371	2026	111	.30	5.46
	NN2	360	1966	144	.40	5.46
	NN3	351	1917	176	.50	5.46
	NN4	343	1873	206	.60	5.46
	NN5	337	1840	236	.70	5.46
II	RR1	371	1892	111	.30	5.1
	RR2	360	1836	144	.40	5.1
	RR3	351	1790	176	.50	5.1
	RR4	343	1749	206	.60	5.1
	RR5	337	1719	236	.70	5.1

Table 2. Properties of control and recycled aggregate fresh concretes

Mix	Slump-mm	Compacting factor	Wet density-kg/m3
NN3	70	.95	2410
NN4	80	.96	2370
NN5	110	.96	2340
RR3	60	.94	2290
RR4	70	.96	2240
RR5	110	.97	2220

Test Details

All specimens were made and cured according to ASTM C192-76, "Standard Method for Making and curing Concrete test specimens in the laboratory. The test specimens were demoulded at 24 hours after casting and were subsequently water cured at 20°C. Standard workability tests were carried out on fresh, natural and recycled aggregates, concrete in accordance with BS 1881 [7] with slump and compacting factor up to 2 hours after mixing.

Various test on hardened concrete specimens were carried out in accordance with BS 1881 [7]. Compressive strength of 150mm cubes was determined at 3, 7, 28, and 90 days. At 28 days tensile splitting strength of 150mm diameter and 300mm long cylinders, and flexural strength of 150*150*750mm prisms, were determined. The reported strengths at any particular age are the average of three specimens.

Static modulus of elasticity was measured on 150mm diameter and 300mm long cylinders at 3, 7, 28, and 90 days. The results reported are the average measurements on two specimens.

The drying shrinkage of concrete was measured o 100*100*500mm prisms. After an initial water curi period of 3 days, the specimens were allowed to dry o in the laboratory at an average temperature of about 25 and relative humidity of about 70%. Shrinkage w measured using a demec mechanical strain gauge over gauge length of 200mm. The readings were taken up to 9 days and the average of the readings from two prisms a reported.

RESULTS AND DISCUSSION

Fresh Concrete Properties

Slump, compacting factor and wet density tests we carried out according to BS 1881 [7] on freshly mix control and recycled aggregate concretes and the resul are presented in Table (2). The results show that the us of coarse and fine recycled aggregates seems to have litt influence on initial workability of the concrete. Figure (1) shows the variation of the slump for the control and recycled aggregate concretes (water/cement ratio of 0.70) with elapsed time. It is evident that the workability of both types of concretes decreased with elapsed time. Recycled aggregate concrete showed higher workability loss with time than the control concrete. This may be due to the higher absorption characteristics of recycled aggregates. Table (2) also shows that the wet density of recycled aggregate concretes was lower than that of the control concretes. This may be due to lower density of old mortar coating the recycled aggregates particles.

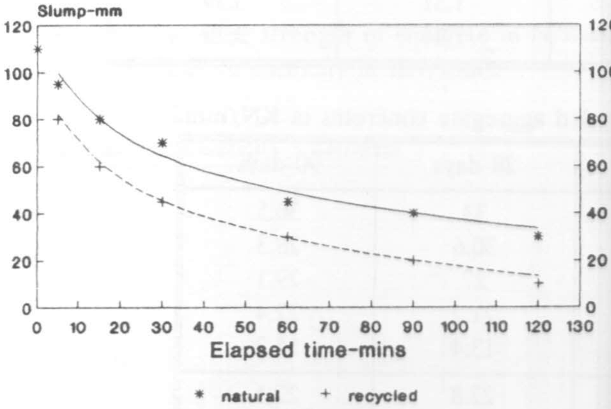


Figure 1. Relationship between slump and elapsed time for control and recycled aggregate concretes with W/C=0.70.

Compressive Strength

The strength of the control and recycled aggregate concretes in compression was determined on 150mm cubes according to BS 1881 [7]. The results are summarized in Table (3) and in Figures (2) and (3). Figure (2) shows the effect of water/cement ratio on compressive strength for control and recycled aggregate concretes at the age of 28 and 90 days. Figure (3) shows the effect of aggregates on the compressive strength development with age.

In general the recycled fine and coarse aggregate concretes showed a lower strength at 3, 7, 28, and 90 days than those for control concretes of similar composition. The use of recycled aggregate concrete reduces the compressive strength by about 22 percent than the control concrete. The results reported by Ravindrarajah [3] showed a reduction in compressive strength by about 10 percent. The observed reduction in the compressive strength of recycled aggregate concrete may be attributed to the amount of weak bond areas in the recycled aggregate which have a double effect between the aggregate and old or new mortar.

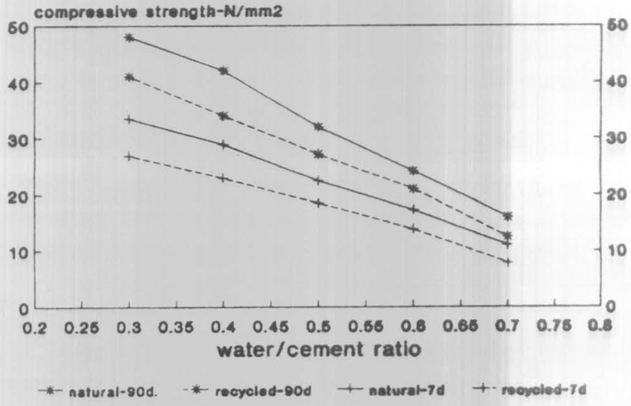


Figure 2. Compressive strength as a function of water/cement ratio for control and recycled aggregate concretes.

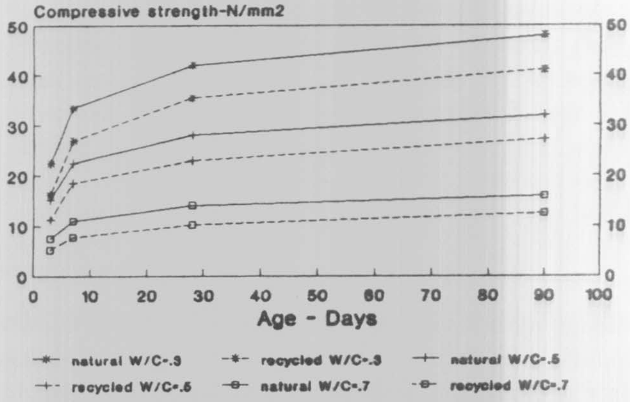


Figure 3: Development of compressive strength with age for control and recycled aggregate concretes.

Tensile Strength

The strength of the control and recycled concretes in indirect tension and in flexure at the age of 28 days were determined according to BS 1881 [7]. The results are summarized in Table (3) and in Figure (4). The tensile and flexural strengths are lower for recycled aggregate concrete than for control concrete. The results also show that the water/cement ratio have significant influence on compressive strength than on tensile strength.

Table 3. Strength of control and recycled aggregate concretes.

Mix	Compressive Strength-N/mm^2				Splitting Tension-N/mm^2 at 28 days	Flexural Strenght-N/mm^2 at 28 days
	3 days	7 days	28 days	90 days		
NN1	22.5	33.5	42	48	2.91	5.51
NN2	19.6	28.9	35	42	2.48	5.28
NN3	15.2	22.5	28.1	32	2.17	4.73
NN4	11	17.3	22.9	24.2	1.74	3.63
NN5	7.5	11	14.1	16	1.62	3.42
RR1	16.2	27	35.5	41	2.54	4.98
RR2	13.7	23	30.5	34	1.99	4.25
RR3	11.3	18.5	23	27.2	1.87	4.16
RR4	7.8	13.9	17.8	21	1.51	3.39
RR5	5.2	7.8	10.2	12.5	1.44	2.79

Table 4. Modulus of elasticity of control and recycled aggregate concretes in KN/mm2

Mix	3 days	7 days	28 days	90 days
NN1	22.6	27.5	33	30.5
NN2	22	25.5	30.6	28.3
NN3	14	21.5	27	29.1
NN4	10.5	15.4	21.2	22.4
NN5	10	13.3	13.4	15.2
RR1	15.6	18.7	22.8	22.5
RR2	14.4	17.3	19.8	17.6
RR3	10.2	14.4	16.3	18.3
RR4	7.4	10.5	12.5	13.9
RR5	6.9	8.8	9.8	11.4

Similar observations were reported by Malhotra [8], who reported a lower flexural strength for recycled aggregate concrete than for the corresponding control concrete.

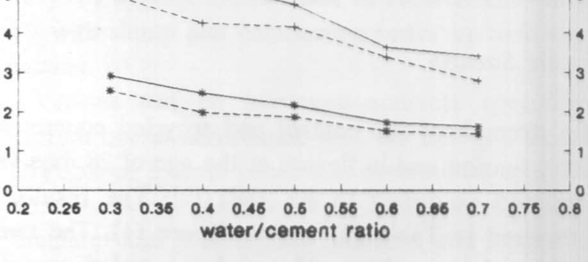


Figure 4. Relationship between tensile strength and water/cement ratio for control and recycled aggregate concretes.

Modulus of Elasticity

Static modulus of elasticity for the control and recycled aggregate concretes at the age of 3, 7, 28, and 90 days were determined according to BS 1881 [7]. The results are summarized in Table (4) and in Figure (5). Figure (5) shows the relationship between the modulus of elasticity and compressive strength for control and recycled aggregate concretes. On the basis of equal cube strength, the static modulus of elasticity of recycled aggregate concrete is on average about 67 percent that of the control concrete. This confirms earlier finding by Ravindrarajah [3] who reported that the modulus of elasticity of recycled fine and coarse aggregate concrete is on the average about 70 percent that of the control. Frondistou-Yannas [9] found that the modulus of elasticity of concrete with recycled coarse aggregate and natural sand was 15 to 40 percent lower than that for natural aggregate concrete.

This reduction in the modulus of elasticity is expected because the recycled aggregate has a lower modulus of elasticity than the natural aggregate.

The following equations were found to fit the observed results for control and recycled aggregate concretes:

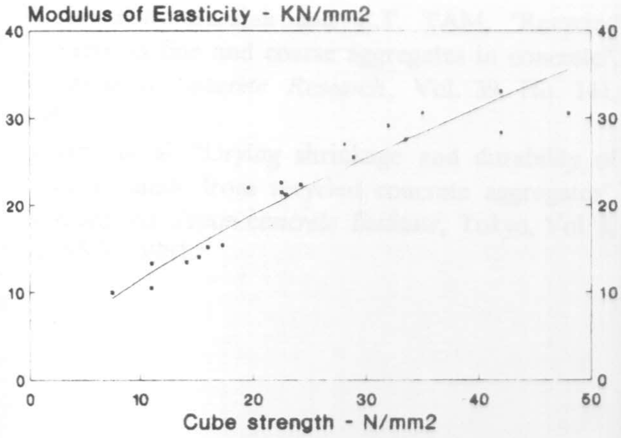
Natural aggregate concrete:

$$E = 2.19\ f_{cu}^{.72} \tag{1}$$

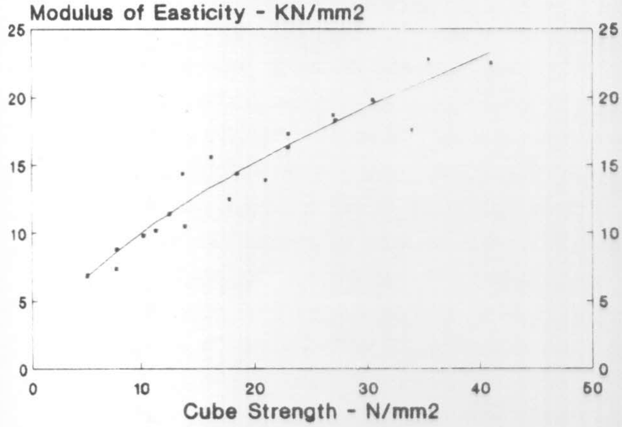
Recycled fine and coarse aggregate concrete:

$$E = 2.51\ f_{cu}^{.6} \tag{2}$$

where f_{cu} is the cube strength of concrete in N/mm^2 and E is the modulus of elasticity in KN/mm^2.



(a) Control Concrete



(b) Recycled Concrete

Figure 5. Relationship between modulus of elasticity and compressive strength for control and recycled aggregate concretes.

Teychenne et al [11] described this relationship by the equation:

$$E = 9.1\ f_{cu}^{.33} \tag{3}$$

BS 8110 [10] recommends the following equation for the relationship between the static modulus of elasticity and cube strength at 28 days for normal-weight concrete:

$$E_{c,28} = 20 + 0.20\ f_{cu,28} \tag{4}$$

where $f_{cu,28}$ is the cube strength of concrete at the age of 28 days in N/mm^2, and $E_{c,28}$ is the static modulus of elasticity of concrete at the age of 28 days in KN/mm^2.

A comparison of equations 2, 3, and 4 shows that, for a given compressive strength, the static modulus of elasticity of recycled aggregate concrete is significantly lower than that for the natural aggregate concrete.

Drying Shrinkage

Tests were carried out with 100*100*500mm prisms to determine the influence of recycled fine and coarse aggregate upon the drying shrinkage of concrete. Gauge points were attached to two opposite sides of each specimen with a guage length of 200mm. The test specimens made from the control and recycled aggregate concrete were initially water cured for 3 days before drying out in the laboratory environment 25°C and 70% R.H. Table (5) summarizes the drying shrinkage date, and the typical development of shrinkage with time is shown in Figure (6).

The recycled aggregate concrete showed significantly higher drying shrinkage than the control concrete. At the end of 90 days, the drying shrinkage of recycled aggregate concrete was about 85 to 110 percent higher than that of control concrete. It was reported by Hasaba *et al* [4], that the drying shrinkage of recycled aggregate concrete, made with fine and coarse aggregate to be 70 percent larger than drying shrinkage of control concrete. However it was found by Ravindrarajah [3] that the drying shrinkage of recycled aggregate concrete was about twice that for the natural aggregate concrete. The results obtained from this experimental study show a good agreement with those of Ravindrarajah [3], but were somewhat higher than those reported by Hasaba *et al* [4].

For recycled aggregate concrete, the increase in drying shrinkage may be due to the combined effects of lower aggregate modulus and additional shrinkage caused by old mortar around the aggregate. Further research is needed to investigate the effect of water/cement ratio on the drying shrinkage of recycled aggregate concrete.