THE DURABILITY OF RECYCLED AGGREGATES AND RECYCLED AGGREGATE CONCRETE

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Abstract

The physical and mechanical properties of two recycled aggregates, crushed concrete and clean, graded mixed debris, have been examined and compared with results obtained for a natural river gravel . Initial characterisation tests were performed on both the recycled and natural aggregates to determine their particle size distribution and particle shape, apparent relative density, water absorption and 10% fines value. Tests were then performed to compare t he workability, compressive strength, modulus of elasticity, and resistance to freeze/thaw conditions of concretes made with these aggregates. The results indicate that recycled aggregates have lower strengths and densities than natural aggregates. Despite this the durability of concretes manufactured with these recycled aggregates is similar to that of conventional concretes.

Key words: Recycled aggregate concrete, Durability, Youngs Modulus, Compressive strength, 10% fines value, Density, Workability.

1. Introduction

Aggregates for the production of new concrete must meet a number of requirements. Firstly, they must be sufficiently strong for the grade of concrete required and possess good dimensional stability. Secondly, the aggregate must riot react with cement or reinforcing steel. Finally the aggregate should have a suitable particle shape and grading to produce a mix with acceptable workability. Based on the results of laboratory investigations and field trials, Hansen (1986), it has been found that clean brick and concrete aggregate can produce a concrete with acceptable workability and strength.
In a previous study by Mulheron (1986) the physical/mechanical properties and durability of dry lean concretes manufactured with recycled aggregates were investigated. The results showed that recycled aggregates were capable of producing lean concretes meeting the compaction and strength requirements of current specifications.
In the experiments reported here, the aim was to extend this initial investigation and compare the performance of conventional mass concrete mixes made from natural and recycled aggregates.

2. Experimental methods

Tests have been carried out to assess the mechanical and physical properties of a number of recycled aggregates and concretes made using these aggregates . Additional tests have been carried out on both the loose aggregate and concrete specimens to assess their durability when exposed to freeze/thaw conditions. Tests were also performed on control samples of a natural aggregate and equivalent concrete mixes made with this aggregate.

2.1 Materials under investigation

2.1.1 Aggregates

In this report two types of recycled aggregate have been studied, and their performance compared with that of a natural gravel. The aggregates were;
i). Clean graded concrete,
ii). -Clean graded mixed debris, and
iii). Thames valley gravel (and sand)- this irregular flinty gravel was chosen as a 'control' because it had been extensively characterised in previous testing programs.

2. 1. 2 Concrete

In these experiments the aim was to compare the performance of conventional concrete mixes made from natural aggregates with similar mixes incorporating recycled aggregates as the coarse aggregate. The decision to use only the coarse fraction of the aggregate was based on the finding that the use of recycled aggregate below 2 mm produces inferior quality concrete.

The mix design was formulated to produce a control concrete mix which would allow the water/cement ratio to be varied over the range 0.4 to 0.6 whilst maintaining a workable and cohesive mix. For this reason the aggregate/ cement ratio was fixed at 5:1 and the ratio of fine, medium and coarse aggregate was set at 2:1:2. Two mixes were made with each aggregate. The first was designed to be a stiff mix with reasonably low water/cement ratio, w/ c=0.45, and having a strength of 55 MPa. The second mix was designed to be more workable, w/c=0.54, with a strength of 40 MPa.

Table 1.1. Mix design, showing quantities of materials used.

Aggregate type	Thames Valley	Crushed concrete	Demolition debris
Coarse (nominal 20 mm)	16.0 Kg	15.70 Kg	14.98 Kg
Medium (nominal 10 mm)	8.0 Kg	7.88 Kg	7.20 Kg
Fine (<5 mm [sand*])	17.0 Kg	17.00 Kg	17.00 Kg
Total aggregate	41.0 Kg	40.58 Kg	39.18 Kg

Cement content = 8.0 Kg (Ordinary Portland cement)
Free water/cement ratio = 0.45 or 0.54
Aggregate/cement ratio = 5:1
* The sand used in ALL the mixes was a Thames Valley gravel

Having graded the aggregates into batches of nominal 20 and 10 mm particle size, it was necessary to adjust the weight of coarse and medium aggregate added to the mix to allow for lower density of the recycled aggregates compared to the Thames Valley control. By manufacturing the recycled aggregates to a specific grading based on equivalent volumes of coarse and medium aggregate a more exact comparison of the control and test mixes could be achieved. The weights of coarse and medium crushed concrete and demolition waste used in the mixes are shown in Table 1.1.

The workability and total water content of each batch of fresh concrete were determined prior to specimen manufacture to ensure that no errors had occurred during the batching process. Cube and prism specimens were then prepared using standard methods and cured at 100% relative humidity and 20°C for a minimum of 24 hours. Further curing of the specimens was carried out in water baths held at 20°C.

2.2 Tests on aggregates

2.2.1 Physical properties

Prior to testing the aggregates were graded by dry sieving following the method described in BS 812 Part 103 (1985). Having obtained the particle size distribution for each aggregate the material was re-combined into the following fractions; Coarse (10-20mm), Medium (5-10mm), and Fine (<5mm).

(a) Relative density

The relative densities of the coarse and medium fractions of each aggregate were determined following the method described in BS 812 Part 2: (1975). In this paper the relative density on an oven-dried basis and the apparent relative density are reported since the ratio of these two values reflects the volume fraction of open voids in the aggregate which can be directly related to the moisture absorption of the aggregate in the saturated surface dry condition.

(b) Moisture absorption

The moisture absorption of an aggregate is defined as the mass of water absorbed into the capillary pores of the saturated surface dry aggregate as a percentage of the dry mass of the aggregate. The weight of water absorbed into the capillary pores of the aggregate can be used to give an indirect measure of the volume fraction of pores present in the aggregate.

(c) 10% fines value

The 10% fines value for the recycled and natural aggregates were determined in accordance with BS 812 Part 3: (1975). This value is the load, in kiloNewton (kN), required to produce 10% fines, defined as material below 2.3 mm, from aggregate particles in the size range 10 to 14 mm. Values in excess of 100 kN are usually required for aggregates for the production of conventional concrete with values in excess of 150 kN being necessary for the production of concrete for hard granolithic floor slabs. Aggregates with a 10% fines value of less than 50 kN would be unacceptable for the production of any cement bound layer or material.

2.2.2 Durability

The durability of the coarse and medium fractions of each aggregate, when subjected t o freeze-thaw condition s , was monitored using the following simple test. A known weight of saturated surface-dry aggregate was sealed into a plastic bag with an excess of water and subjected to alternate freezing at -25 °C for 24 hours followed by thawing under water at 25°C. After 7 cycles the aggregate was removed from the plastic bag and sieved over a 2 .5 mm size sieve and re-weighed. This process was repeated and the weight of aggregate retained on the sieve was monitored as a function of the number of freeze-thaw cycles.

2.3 Tests on concrete

2.3.1 Assessment of fresh concrete

Tests were carried out on each batch of fresh concrete to assess its workability. The properties measured were slump, compaction factor and Vebe time. All tests were performed in accordance with BS 1881 (1983). It should be noted that each of these tests measures a different aspect of the workability of the fresh concrete.

To ensure that the water available to the cement was correct the total water content of each batch of concrete was measured using the 'frying pan' method. By comparing this measured value with the theoretical value from the mix design it was possible to get an indication of the accuracy of the hatching and mixing process.

2.3.2 Physical/mechanical properties of hardened concrete

(a) Compressive strength

Testing of the compressive strengths of the concrete cubes was carried out in accordance with BS 1881 Part 116: (1983). The compressive strength was determined on specimens cured for 7 and 28 days. The results reported here are an average of five separate determinations.

(b) Density

The densities of the 28- day old cubes were determined using the method outlined in BS 1881 Part 114: (1983).

(c) Elastic modulus

The dynamic modulus of elasticity, Ed, of the 28 day old concrete prisms was determined by measuring the natural frequency of the specimen when excited using a variable frequency oscillator. The full method being described in BS 1881 Part 5: (1983). In addition the static elastic modulus, Es, was determined following the method described in BS 1881 Part 121: (1983) .

2.3.3 Durability of hardened concrete

Testing of the durability of the concrete was carried out using a n accelerated freeze-thaw test • Testing was limited to the concretes made with a water/cement ratio of 0.54 since these exhibited the lowest strengths, moduli, and densities they would be most likely to suffer deterioration under freeze-thaw conditions. The test consisted of repeated 48-hour cycles in which saturated surface-dry cubes ~ere sealed into plastic bags containing 1 litre of distilled water or saturated sodium chloride solution and placed into a freezer at - 25°C for 24 hours followed by immersion in a water bath at 20°C for a further 24 hours.

To monitor the effect of the freeze-thaw cycles the ultrasonic pulse velocity was recorded at regular intervals using the method described in BS 188 1 Part 203: (1986). The direct transmission method was used with the emitter and detector mounted on opposite faces of the cube as this is the most sensitive method for measuring the speed of the pulse travelling through the concrete. To obtain a measure of the overall damage in each cube, the average was taken of the pulse velocity readings taken from all three faces of the cube.

3 Discussion of results

3.1 Aggregates

3.2.1 Physical properties

(a) Relative density

According to Hansen (1986) the density of recycled aggregates can be expected to be somewhat lower than that of equivalent natural aggregates due to the presence of lightweight materials such as old mortar and brick. This is confirmed by the results of the tests performed in this study, Table 3.1. It can be seen that the apparent relative densities of the coarse and medium sized recycled crushed concrete aggregates are some 6% lower than those of the Thames valley grave l while those of the recycled demolition debris are 18% lower.

(b) Moisture absorption

Much larger amounts of water are absorbed by the recycled aggregates than the Thames valley gravel, Table 3.1. These results are in close numerical agreement with those of Hansen and Narud (1983) who measured water absorptions for coarse recycled aggregates ranging from 3.7% to 8.7% as compared to the 5.3% to 8.3% obtained here.

Table 3.1 Physical properties of aggregates

	Thames Valley Gravel		Crushed Concrete		Demolition Waste	
	Medium	Coarse	Medium	Coarse	Medium	Coarse
Relative Density (Oven-dried)	2.46	2.52	2.16	2.23	1.89	1.96
Apparent Relative Density	2.55	2.65	2.40	2.48	2.10	2.18
Water Absorption (% of dry mass)	3.1	1.5	8.3	5.4	5.3	5.9
10 % fines value (kN)	180	-	108	-	80	-

Medium = 10 mm; Coarse = 20 mm

(c) 10% fines value

The 10% fines value of the recycled concrete aggregate, Table 3.1, is significantly lower than that of the Thames Valley gravel but still exceeds 100 kN. This indicates that the aggregate has sufficient strength to be viable as an aggregate for the production of mass concrete. The somewhat lower value of 80 kN determined for the recycled mixed debris is less encouraging and would suggest that the use of such aggregates in the production of anything other than low strength concretes would result in the strength of the concrete being limited by the strength of the aggregate.

3.2.3 Durability

The cumulative percentage weight loss of the recycled and natural aggregates are shown in Figure 3.1. The deterioration of the demolition debris aggregate is thought to result from the presence of soft, clay bricks. Such bricks are known to have little resistance to freeze-thaw conditions when tested in the saturated condition. Not all bricks exhibit this behaviour since well burnt, hard bricks are known to be extremely resistant to such damage. The crushed concrete aggregate shows a similar behaviour to that of the Thames Valley gravel but at longer times does show some sign of breaking down.

3.3 Concrete

3.3.1 Assessment of fresh concrete

(a) Workability

The results of the tests to assess the workability of the concrete mixes are shown in Table 3.2. As might be expected increasing the water content in each mix produced an overall increase in workability resulting in an increase in the values of slump and compaction factor and decrease in Vebe time.

The affect of the two recycled aggregates on the workability of the mix can be seen to be quite different. The crushed concrete aggregate produced slightly harsher and less workable mixes than the equivalent control mix as is evidenced by the lower values of compaction factor and slump and longer Vebe times. It is thought that this is a consequence of the particle shape and texture of the crushed concrete aggregate which was both more angular and rougher than the Thames Valley gravel resulting in an increased amount of inter-particle interaction and 'locking'. In contrast the demolition debris derived aggregate produced concrete mixes of similar workability to the control. Interestingly, the individual particles in this aggregate were considerably rounder and less abrasive than the crushed concrete aggregate. This appears to confirm the suggestion that it is the shape and texture of the aggregate particles which is controlling the workability of the fresh concrete.

(b) Total water content

The measured values of total water content in the individual mixes are shown in Table 3.2 along with the theoretical values obtained from the mix design calculations. It can be seen that in all cases there is good agreement between the theoretical and measured values indicating that the hatching process employed has been successful in producing concretes with a well-controlled free water content.

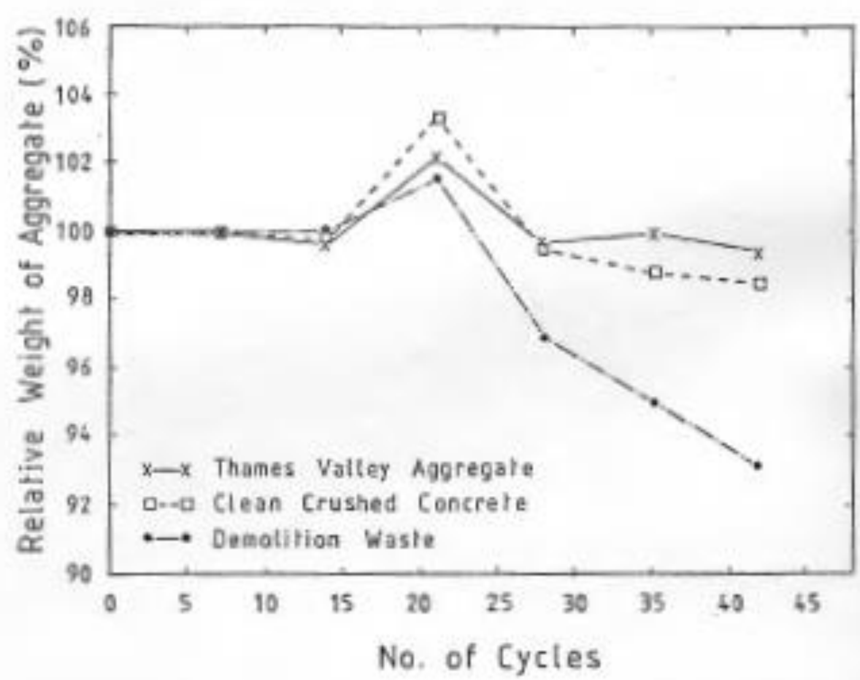

Figure 3.1 Relative weight loss of aggregates as a function of freeze-thaw cycles.

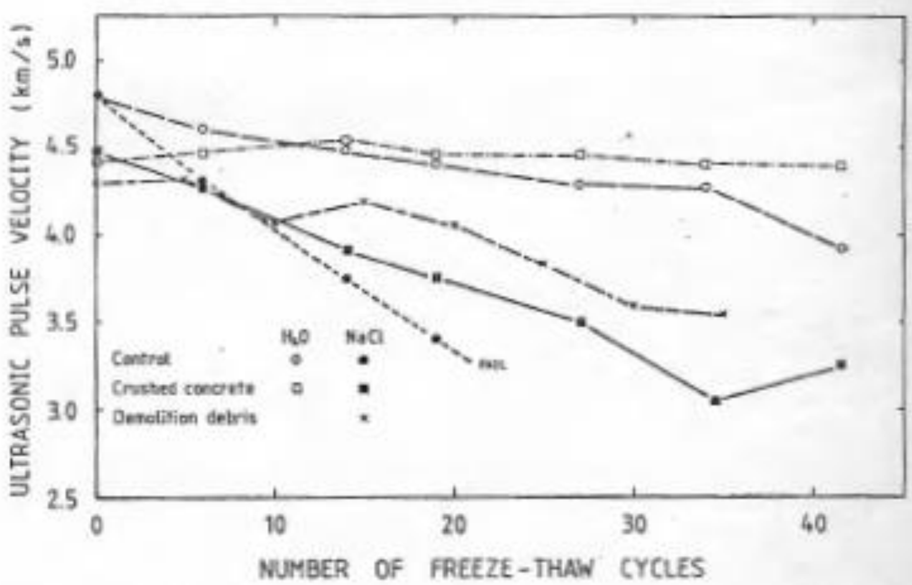

Figure 3.2 Ultrasonic pulse velocity of hardened concrete specimens subjected to alternate freezing and thawing.

4. Conclusions

4.1 Recycled aggregates

1) The physical properties of the recycled concrete and demolition debris aggregates are dissimilar to those of the natural aggregate having properties somewhere between those expected of conventional and lightweight aggregates.

2) The durability of the recycled aggregates exposed to severe freeze-thaw conditions is poor when compared to a natural gravel.

4.2 Recycled aggregate concrete

1) Suitably graded recycled aggregates can be used to produce concretes that satisfy the strength and density requirements of current specifications.

2) The physical and mechanical properties of concrete manufactured using recycled aggregates reflect the porous, low density, low modulus materials present in such aggregates. Thus, when compared to a control concrete, concrete manufactured using recycled aggregates has a lower elastic modulus, lower density, and lower strength.

3) The durability of lean concrete made using recycled aggregates, when subjected to freeze-thaw conditions, appears to be better than, or similar to, an equivalent control concrete made with natural

gravel. Further long-term testing is required to confirm this result.

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