

WASTE CONCRETE AS A SOURCE OF AGGREGATE FOR NEW CONCRETE

F. O. Okafor

Department of Civil Engineering,
University of Nigeria, Nsukka.
Email: fidelis.okafor@unn.edu.ng

ABSTRACT

Three concrete mixes of widely differing water cement ratios were made using crushed waste concrete as coarse aggregate. The properties investigated include the physical properties of the recycled aggregate, the compressive and flexural strengths of the concrete. These properties were compared with those of similar concrete specimens made with conventional natural aggregate. Also tested was the compressive strength of concrete cubes cut from the waste concrete. Results of the tests suggest that the strength of concrete made from recycled waste concrete aggregate is dependent on the strength of the original concrete from which the recycled aggregate is derived. It is concluded that recycled aggregate can be used to produce quality concrete when the strength of concrete required is not greater than the strength of the original concrete from which the recycled aggregate is derived.

KEYWORDS: Waste Concrete; Recycled Aggregate; Workability, Compressive Strength.

INTRODUCTION

Several comprehensive studies during the past years [1-13] have dealt with the subject of aggregate supplies and needs and the possible use of waste materials as aggregates for concrete. Critical shortage of natural aggregate for concrete production is developing in many regions. The needs for better methods of solid waste disposal and probably energy conservation have contributed to the increased interest in this technology.

In Nigeria and most other third world countries where technological development is still growing, some regions especially large urban areas already have a problem in obtaining adequate aggregate supplies at reasonable cost. At the same time, increasing quantities of demolished concrete from obsolete structures are expected to be generated as a waste material in these areas. It would therefore be desirable if demolished concrete could be processed to yield quality aggregate for production of new concrete.

Buck [5] and Frondistion-Yannas [6] have shown that it is possible to produce new

concrete from crushed concrete, but that recycled concrete may be expected to have lower strength than concrete made with similar aggregate not previously used. de Juan and Gutiérrez [12] studied the effect of attached mortar content on the properties of recycled concrete aggregate. It was observed that the properties of recycled concrete aggregate adversely affected by attached mortar content are the density, water absorption and Los Angeles abrasion. Khatib [13] examined the effect of fine recycled aggregate on the properties of concrete. The results showed that there is strength reduction of 15 – 30% for concrete containing fine recycled aggregate and that more shrinkage and expansion occur in these concretes.

Most work on recycled aggregate in concrete has focused mainly on the effects of recycled aggregate on the strength properties of concrete. Therefore, the present study assesses the performance of a 12-year old demolished concrete recycled into aggregate and used in the production of new concrete. The strength of concrete which is made from the recycled waste concrete was compared

with both the strength of the original concrete and the strength of concrete made from conventional aggregate over a test period of 91 days.

EXPERIMENTAL DETAILS AND TEST RESULTS

Physical Properties of Natural Aggregates

The grading of the river sand in the tests conformed to the Zone 3 requirements of BS 882 [14]. The natural coarse aggregate used was crushed granite from Abakaliki. The physical properties of the coarse aggregate are shown in table 1. The tests were carried out in accordance with BS 812 [15].

Physical Properties of Recycled Coarse Aggregate

Recycled coarse aggregate was prepared by crushing concrete rubbles obtained from a 12-year old concrete slab from a demolished building at Abakaliki. Crushing was done using the conventional crusher used for crushing natural aggregates and the crusher fines below 4.8 mm were discarded. The physical properties of the recycled coarse aggregate are shown in table 1. The tests were also carried out in accordance with BS 812 [15].

Preparation of Specimens

Three mixes of varying proportions of ordinary Portland cement (OPC), river sand and recycled aggregate were used. In addition, three control mixes with natural aggregate were made having identical proportions by weight of cement, free water, fine and coarse aggregate as their respective mixes containing recycled aggregate. The mix proportions used for all mixes are shown in table 2.

All test specimens were demoulded after 24 hours and immersed in curing water at room temperature. The following properties of the hardened concrete were tested.

1. Compressive strength on 100 mm cubes, three being tested at each age.
2. Flexural strength on 100 mm H 100 mm H 500 mm beams, three being tested at each age.

The results of these tests up to an age of 91 days are represented in figures 1 and 2.

Workability measurements were carried out on all mixes by two of three BS 1881 [16] standard test methods (slump and compacting factor). The results of the workability test are shown in table 2.

Table 1: Physical Properties of Coarse Aggregate.

Physical Property	Aggregate	
	Natural	Recycled
Specific gravity	2.65	2.49
Water absorption, (%)	0.21	3.67
Aggregate crushing value, (%)	22.52	29.86
Grading (% by weight passing sieve size stated)		
25.4 mm	100	100
20.0 mm	70	81
12.7 mm	20	35
9.5 mm	15	19
6.4 mm	4	10
4.8 mm	1	1

Table 2: Mix Proportions and Workability Results for All Concretes.

Type of coarse aggregate	Mix	Proportion by weight ^a			Free water cement ratio	Cement content (kg/m ³)	Workability	
		OPC	Aggregate				Slump (mm)	Compacting factor
			Fine	Coarse				
Natural	N1	1.00	1.20	2.71	0.45	465	30	0.87
	N2	1.00	1.62	3.40	0.54	390	45	0.91
	N3	1.00	2.05	4.10	0.63	330	50	0.94
Recycled	R1	1.00	1.20	2.71	0.45	465	15	0.85
	R2	1.00	1.62	3.40	0.54	390	20	0.85
	R3	1.00	2.05	4.10	0.63	330	35	0.89

^aon saturated surface dry basis.

Compressive Strength of Original Concrete

An estimate was also made of the compressive strength of the original concrete from which the recycled aggregate was derived. This was achieved by testing concrete cubes sawn from the 125 mm thick slab of the demolished building. The cubes were cut in sizes of 125 mm and were soaked in water for 7 days before testing. In all, five such cubes were tested and an average compressive strength of 41.3 MPa was obtained.

DISCUSSION OF TEST RESULTS

Properties of Natural and Recycled Aggregates

It is evident from the results shown in table 1 that compared to natural aggregate, recycled aggregate has lower specific gravity, higher water absorption and higher aggregate crushing value. Thus, all conventional quality indices for aggregate indicate that recycled aggregates are inferior in quality to natural aggregate. This is in agreement with the observations of de Juan and Gutiérrez [12] and is attributed to the considerable amounts of old mortar which always remain attached to the aggregate particles in recycled aggregate.

Properties of Fresh Concrete

The results of workability tests presented in Table 2 show that recycled aggregate concrete is less workable than natural aggregate concrete for the same free water-cement ratio. This low workability of recycled concrete is indicated by all two test methods used. Attempt was made to achieve the same workability for both types of concrete and it was observed that the recycled aggregate concrete generally required about 7% more water for nominally equal slump.

It is believed that the higher water requirement of recycled concrete was as a result of higher proportion of recycled aggregate particles that is less than 12.7 mm. From table 1, 35% by weight of recycled aggregate consist of particles less than 12.7 mm as against 20% for the natural aggregate thus, resulting in increased specific surface and higher water requirement. Improvement in workability may be achieved by adjusting the particle size distribution of the recycled aggregate.

The workability of concretes made from the recycled aggregate was also observed to decrease relatively faster with time after mixing than the workability of natural aggregate concretes. This is probably because recycled aggregates continue to absorb water

after mixing is completed due to its higher water absorption capacity.

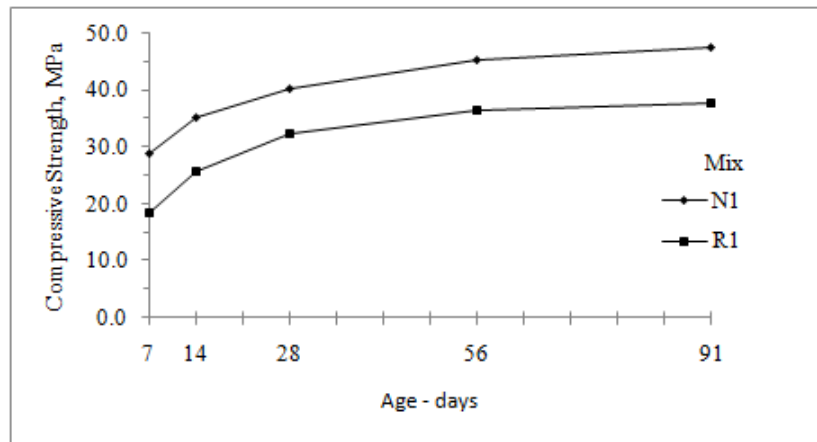
Properties of Hardened Concrete

From the results of the development of compressive and flexural strengths represented in figures 1 and 2, it is evident that in every case, the strengths continue to increase with age and that, for the given water-cement ratio, concretes made from the natural aggregate have higher strengths than those from recycled aggregate at all ages. The difference in strength is however seen to decrease rapidly with increase in water-cement ratio and that at water-cement ratio of 0.63, the strength of natural aggregate concrete is approximately equal to that of recycled aggregate concrete at all ages.

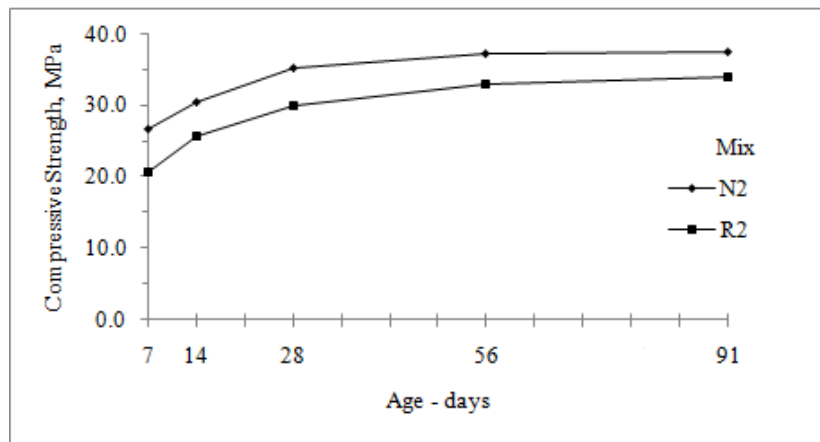
A closer examination of figures 1a and 1b reveals that the strength of recycled aggregate concrete remained almost unaltered despite the reduction of the water-cement ratio suggesting that no further improvement in strength may be achieved by reducing the water-cement ratio below 0.54. In this case the maximum compressive strength attained by adjusting the cement content and water-cement ratio was 37.7 MPa for the recycled aggregate concrete at 91 days which was lower than 41.3 MPa being the strength of the original concrete from which the recycled aggregate was derived. This trend may be explained by arguing that the strength of recycled aggregate concrete is governed primarily by the strength of old mortar which always remains attached to the recycled aggregate particles and initiates failure at a

compressive stress some what below the compressive strength of the old concrete. This fact was confirmed by an examination of the failure surface of the broken cubes. With the recycled concrete mix, failure was dominated by a breakdown in the bond between the aggregate and the paste without any apparent crushing of aggregate while for the natural aggregate concrete of similar mix crushing of aggregate was more prominent. It may then be reasoned that the strength of recycled concrete will be equal to or lower than the strength of the original concrete from which the recycled aggregate is derived.

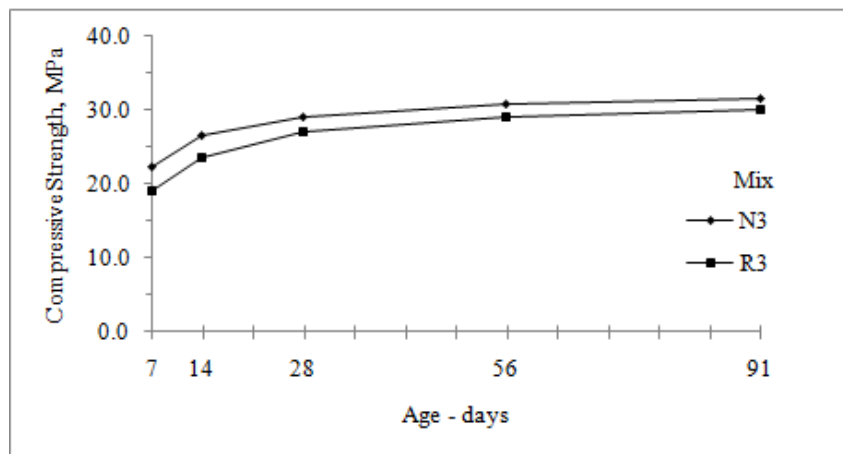
The performance of the two types of concrete is also compared in figures 1c and 2c but the concrete in this case have been made with significantly higher free water-cement ratio of 0.53. A closer examination of figures 1b and 1c shows that, unlike the previous case, both concretes show a reduction in strength with the increased water-cement ratio, the natural aggregate concrete exhibiting the greater reduction. This trend is similar for the flexural strength represented in figure 2. It is clear then that, with such a high water-cement ratio the strength of the paste has been reduced to a figure below that of the old mortar which remains attached to the recycled aggregate particle. Failure of the concrete made from recycled aggregate is now governed by the strength of the new mortar as with the natural aggregate concrete, and hence their strengths are almost equal. In this case, no apparent crushing of aggregate was noticed in both concrete.



(a) Cement content 465kg/m³; free water-cement ratio 0.45

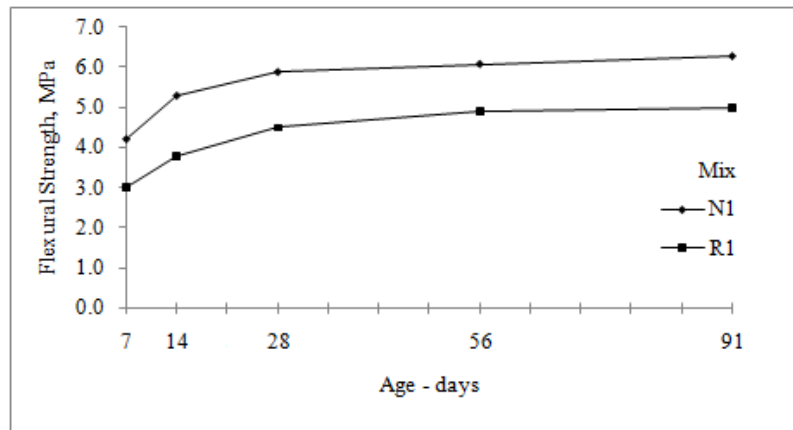
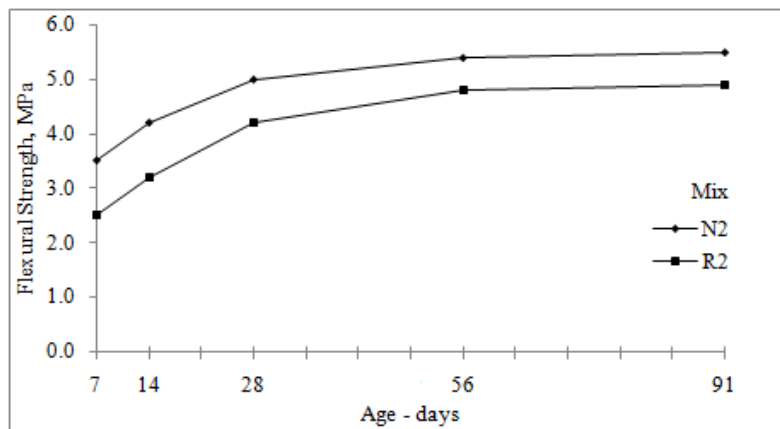
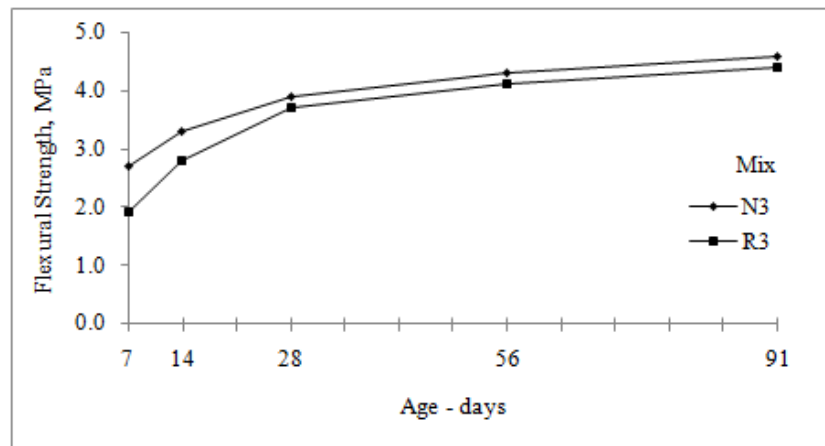


(b) Cement content 390kg/m³; free water-cement ratio 0.54



(c) Cement content 330kg/m³; free water-cement ratio 0.63

Figure 1: Relationship Between Compressive Strength and Age

(a) Cement content 465kg/m³; free water-cement ratio 0.45(b) Cement content 390kg/m³; free water-cement ratio 0.54(c) Cement content 330kg/m³; free water-cement ratio 0.63**Figure 2: Relationship Between Flexural Strength and Age**

CONCLUSIONS

The following main conclusions are drawn from the study:

- (1) Recycled aggregate has lower specific gravity, higher water absorption and higher aggregate crushing value than is typical of similar conventional aggregate.
- (2) Recycled concrete generally required about 7% more water for the same workability as a corresponding concrete produced with natural aggregate.
- (3) The strength of recycled concrete is equal to or lower than the strength of the original concrete from which the recycled aggregate is derived.
- (4) It is possible to produce recycled concrete of strength equal that made from similar natural aggregate, but the target strength of the new concrete may have to be lower than the strength of the old concrete from which the recycled aggregate is derived.
- (5) On the basis of this investigation, it is apparent that recycling of aggregate is feasible and may become a viable and routine process for the generation of aggregate for middle and low strength concrete.

REFERENCES

1. Wainwright, P. J. and Boni, S. P. K., "Artificial Aggregate from Domestic Refuse", *Concrete*, Vol. 15, No. 5, 1981, pp. 25-29.
2. Wainwright, P. J. and Boni, S. K., "Some Properties of Concrete Containing Sintered Domestic Refuse as a Coarse Aggregate". *Magazine of Concrete Research*, Vol. 35, No. 123, 1983, pp. 75-85.
3. Okafor, F.O., "Palm Kernel Shell as a Lightweight Aggregate for Concrete". *Cement and Concrete Research*, Vol. 18, No. 6, 1988, pp. 901-910.
4. Harrison, W. H., "Synthetic Aggregate Sources and Resources", *Concrete*, Vol. 8, No.11, 1974, pp. 41-44.
5. Buck, A. D., "Recycled Concrete as a Source of Aggregate". *ACI Journal*, Proc. Vol. 74, No. 5, 1977, pp 212-219.
6. Frondistou-Yannas, S., "Waste Concrete as Aggregate for New Concrete", *ACI Journal Proc.* Vol. 74, No. 8, 1977, pp. 373-376.
7. Tam, V. W. Y.; Wang, K. and Tam, C. M., "Ways to Facilitate the Use of Recycled Aggregate Concrete", *Proceedings of the ICE – Waste and Resource Management*, Vol. 160, No. 3, 2007, pp. 125-129.
8. Ryu, J. S., "An Experimental Study on the Effect of Recycled Aggregate on Concrete Properties", *Magazine of Concrete Research*, Vol. 54, No. 1, 2002. pp. 7-12.
9. Evangelista, L. and de Brito, J., "Mechanical Behaviour of Concrete Made with Fine Recycled Concrete Aggregates", *Cement and Concrete Composites*, Vol. 29, No. 5, 2007, pp.397-401.
11. Ann, K. Y.; Moon, H. Y.; Kim, Y. B. and Ryou, J., "Durability of Recycled Aggregate Concrete Using Pozzolanic Materials", *Waste Management*, Vol. 28, No. 6, 2008, pp. 993-999.
12. de Juan, M. S. and Gutiérrez, P. A., "Study on the Influence of Attached Mortar Content on the Properties of Recycled Concrete Aggregate", *Construction and Building Materials*, Vol. 23, 2009, pp. 872-877.
13. Khatib, J. M., "Properties of Concrete Incorporating Fine Recycled Aggregate", *Cement and Concrete Research*, Vol. 35, 2005, pp. 763-769.
14. BS 882: Part 2, "Specification for Aggregate from Natural Sources for Concrete", *British Standards Institution*, London, 1973.
15. BS 812: Part2, "Methods of Sampling and Testing Mineral Aggregates, Sand and Fillers". *British Standards Institution*, London, 1975.
16. BS 1881: Part 2: "Methods of Testing Fresh Concrete", *British Standards Institution*, London, 1970.