Continental J. Engineering Sciences 3: 30 - 36, 2008

INFLUENCE OF RECYCLED CONCRETE AGGREGATE (RCA) ON COMPRESSIVE STRENGTH OF PLAIN CONCRETE

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ABSTRACT
This paper presents the findings of an investigation on the influence of recycled aggregate concrete (RCA) as a substitute for virgin coarse aggregate in the compressive strength of `plain concrete. Recycled aggregate concretes were produced together with virgin coarse aggregates and subjected to empirical tests which include grading, specific gravity, bulk density, water absorption, aggregate impact value (AIV) and aggregate crushing value (ACV) to ascertain their performances. Mix design was carried out for grade 30 concrete according to DoE (1975) and RCA percentages of 0, 25, 50, 75, and 100 were used in replacing the virgin aggregate proportion in the mix. The test results showed that the use of recycled concrete aggregate (RCA) reduces the compressive strength and this reduction increases with the increase in percentage of the RCA. Maximum decrement of about 33% in strength or about 67% of compressive strength development occurs when 100% of RCA was used as substitute to virgin coarse aggregate. It also reveals that about 25% of virgin coarse aggregate can be replaced with RCA in structural concrete work with out compromising the characteristic strength of the concrete. This result will not only eliminate the development of waste stockpiles of concrete as recycled material but also elicit the use of RCA in concrete work, thus providing environmentally friendly and economically viable solution as substitute for virgin aggregate as well as provide savings in the final cost of projects.

KEY WORDS: Cement, Concrete, Virgin aggregates, Recycled concrete aggregates (RCA), compressive strength.

INTRODUCTION
The need and importance of concrete in construction industry is ever increasing since its discovery. Lomborg (2007) reported that the use of concrete is more than any other man made material on the planet. As about 2005, six billion cubic meters of concrete are made each year with countries like China currently consuming about 40% of world cement production, (Wikipedia, (2007).

Most of the times, facilities constructed using concrete materials need to be repaired or replaced with passing time either because their end of service life is reached or the original design no longer satisfy the needs due to the growth in population or traffic or even an error in construction. These activities have always led to construction, demolition and excavation waste. The waste materials does not only constitute environmental problem but also put pressure on the available constituent materials used in concrete production- like the aggregate. The facts have remained how do we satisfy the growing demand for construction aggregates and, secondly how do we take care of the ever increasing amount of construction waste. FHWA (2004), report shows that two billion tonnes of aggregate are produced each year in the United States and production is expected to increase to more than 2.5 billion tonnes per year by the year 2020. This has raised concerns about the availability of natural aggregates and where they will find new aggregate sources.

Generally, millions of aggregate tonnes are produced each year in developing countries and is expected to increase tremendously in the future as more concrete material is used. This has raised concerns about the availability of natural aggregates and where to find new aggregate sources.

Table 1: Grading Table for Fine Aggregate (sharp Sand)

Sieve Numbers (BS)	Opening Size of Sieve (mm)	Cumulative Fraction Passing (%)
3/8''	10.00	99.60
3/16''	5.00	99.15
5	3.35	96.03
7	2.36	90.07
14	1.18	80.52
25	0.600	68.02
36	0.425	60.94
52	0.300	51.90
72	0.212	45.06
100	0.150	44.12
200	0.075	38.93

On the other hand, the report also confirmed that the construction waste produced from building demolition alone in US is estimated to be 123 million tonnes per year.

Table 2: Grading Table for Virgin and Recycled Coarse Aggregates

Sieve Numbers (BS)	Opening Size of Sieve (mm)	Cumulative Fraction Passing (%) (Virgin Aggregates)	Cumulative Fraction Passing (%) (RCA)
2”	50	100	100
11/2”	37.5	100	100
1”	20	76.6	73.6
-	14	18.1	15.20
3/8”	10	6.8	3.65
-	6.3	3.05	1.60
4	5	2.8	1.40
5	3.35	0.3	1.25
8	2	0.17	1.20
Pan	Pan	0.0	0.0

Historically, the most common method of managing this material has been through disposal in landfills. As cost, environmental regulations and land use policies for landfills become more restrictive, the need to seek for alternative uses of the waste material increases. This situation has led State Agencies and the aggregate industry in the US to begin recycling concrete debris as an alternative aggregate. The report further said that commercial construction industry has been leading the reuse of this debris, but with the State

Transportation Agencies (STA) recognizing the engineering, economical and environmental benefits that can be achieved for using recycled concrete aggregates (RCA), prompting its use for highway work to be on the increase. Also several studies by Wilburn, and Goonan (1998); Kerkhoff and Siebel (2001); Sagoe-Crentsil,(2001); Katz, (2002); Olorunsogo and Padayachee(2002) and Salem, et al (2003), show that RCA

Table 3: Aggregates Result of Mechanical Properties.

Property	Virgin Aggregates (Crushed Rock)	Recycled Concrete Aggregates (RCA)
Specific Gravity	2.70	2.47
Aggregate Impact Value(AIV) %	23	23
Aggregate Crushing Value(ACV) %	20	25
Bulk Density (Kg/m^3)	1641.10	1502.20
Water Absorption (%)	0.38	4.04

is a valuable resource, and by proper engineering, it can be used for pavement aggregate base, and other miscellaneous concrete work.

They inferred that the material is too valuable to be wasted, and landfill. The report identified that some of the best aggregates used for highway, bridge, and building construction are already in use in most of the highways and bridges, and effective recycling is a means to re-use these materials.

Despite the obvious benefits derivable from the use of recycled concrete, as is practiced in developed and developing countries, Nigerian construction industry is yet to adopt the practice of RCA as aggregate substitute in structural grade concrete, although in some cases, they use has been established for roadwork as sub-base or base, backfills and/or flooring. Considering the ever increasing construction work coupled with the antecedent demolition/failure of structures in major cities of the country resulting in large tonnes of concrete debris an investigation on the effect of RCA on structural concrete becomes necessary. This paper reports the findings of an investigation on the suitability of use of recycled concrete aggregates (RCA) as substitute to virgin aggregates in structural concrete work.

Aggregates constitute about 75% by weight of concrete and it is considered to not only influence the volume stability, strength and durability of the composite material but also makes it more economical in value (Neville, 2003).

JUSTIFICATION:

The use of recycled concrete aggregates (RCA) in new construction work will eliminate the development of waste stockpiles of concrete as recycled material can be used within the same metropolitan area; this can lead to a decrease in energy consumption from hauling and producing aggregate, and can help improve air quality through reduced transportation source emissions.

Also the supply of virgin aggregates in many areas in the country is becoming limited; the use of recycled concrete aggregates will serve as an environmentally friendly and economically viable solution as substitution of RCA for virgin aggregate can provide savings in the final cost of projects.
The reuse of concrete demolition will eventually reduce unsightly stockpiles of concrete rubble, animal infestation of stockpiles, and an overall environmental improvement.

MATERIALS AND METHODS:
Materials:

1. Cement: The cement used for the research is the ordinary Portland cement manufactured by Ashaka cement company Plc. Care was taken to ensure that it was of recent supply and free from adulteration.

2. Aggregates: The fine aggregates used are clean sharp sand, graded to be of zone 2 and the virgin coarse aggregates are crushed granite of maximum size of 20mm, both obtained from supplies for laboratory work in Civil Engineering department of Bayero University Kano.

3. Recycled Concrete Aggregates(RCA):
The recycled concrete aggregates were obtained from a demolished building structure located along old Bayero University Road, Kano. The old concrete lumps were broken into smaller pieces on the site. This was further broken down to pieces manually using sledge hammer and the steel reinforcements, dowels and tie bars removed after which sieving was carried out using 5mm BS sieve to remove the unwanted recycled fines. Further sieving using 20mm sieve was done to ensure the maximum aggregate size of 20mm.

4 Water: The water use for the research is portable water fit for drinking

Table 4: Compressive Strength Test Result on RCA Concrete Specimens

RCA Replacement (%)	Average Compressive Strength N/mm^2					
	3 days	Change in Strength %	7days	Change in Strength %	28days	Change in Strength. %
0	25.20	-	30.10	-	40.10	-
25	24.90	-1.19	29.48	-02.06	38.83	-03.17
50	24.59	-2.42	28.74	-04.52	37.50	-06.48
75	22.96	-8.89	25.93	-13.85	34.07	-15.04
100	18.82	-25.30	25.32	-15.88	27.11	-32.29

Methods:
Both the virgin and recycled aggregates were subjected to mechanical tests in accordance to British Standards: BS 812 (1975); BS 882 (1992).These are aggregate Impact value (AIV), aggregate crushing value (ACV), specific gravity, water absorption and bulk density as well as grading test. Mix design was carried out for concrete grade 30 using the procedure for the design of normal concrete mixes (DoE, 1975). The virgin coarse aggregates proportion of the mix design is partially replaced with RCA of 0%, 25%, 50%, 75% and 100% by weight respectively. The 0% replacement with RCA served as control test. The constituent materials were batched by weight, mixed thoroughly, and cast into 150mm x 150mm x 150mm cube moulds and compacted mechanically to the required density. A total of Forty five (45) concrete cubes were cast. Three (3) cubes each were tested for compressive strength at 3, 7, and 28 days of curing in clean water and 24 hours of air drying in the laboratory and at various percentages of replacement of virgin aggregates with RCA. The compression test was done in accordance to BS 1881(1983), using Avery Denison universal testing machine with maximum capacity 2000KN. The machine applied load axially on the cube specimen at a constant rate until a maximum load, which correspond to the ultimate compressive load is reached at failure point.

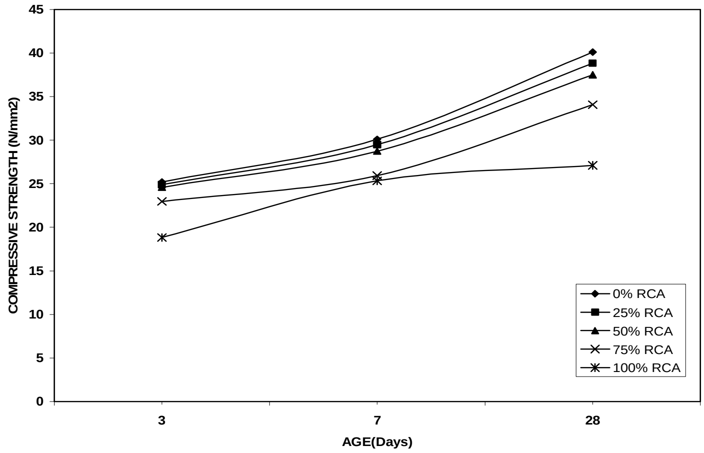

Fig.1: Compressive Strength of RCA Plain Concrete

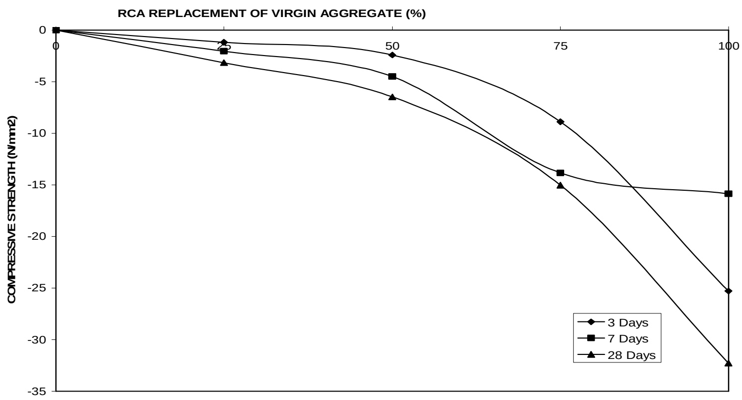

FIG.2 :PERCENTAGE REDUCTION IN COMPRESSIVE STRENGTH WITH INCREASE IN RCA

PRESENTATION AND DISCUSSIONS OF RESULTS

The physical and mechanical properties tests on the virgin and recycled concrete aggregates (RCA) are as in tables 1, 2, 3. Table1 revealed that the natural fine aggregates falls within zone 2 of BS 882 grading limits. This indicates that the sharp sand is of good grade for structural plain concrete. The grading table for virgin coarse aggregates and recycled concrete aggregates (RCA) in table 2 show that both aggregates contains similar size proportions with the RCA having more fines than the virgin aggregates. This indicates possibility of greater water absorption when RCA are implored in concrete making. Table 3 shows that the virgin coarse aggregate has Specific gravity, Aggregate impact value (AIV), Aggregate crushing value(ACV) and Bulk density of 2.7, 23%, 20% and 1641.10Kg/m^3 respectively while the RCA has its Specific gravity, AIV, ACV and Bulk density as 2.47, 23%, 25% and 1502.20Kg/m^3 respectively. These values are clearly within the BS 812 limits for aggregates needed for both highway and structural concrete work.

The result of workability test conducted with various percentages of RCA replacement of virgin aggregate in concrete specimen show that 0% RCA (control test) has slump of 28mm, while the slump values for

25%, 50%, 75% and 100% RCA are 22mm, 18mm, 13mm and 11mm respectively. These values show that as the percentage of RCA replacement of virgin aggregates increases the slump values decreases. This may not be unconnected with proportion of fines in RCA as seen in table 2. Also the presence of residual cementatious materials on RCA increases its water absorption potentials, hence the decrease in workability. This is also confirmed by the water absorption test presented in table 3, which show that the virgin aggregates has 0.38% as compared to 4.04 % of the RCA concrete.

The results of the compressive strength test presented in table 4, figures 1 and 2 show generally that the strength increases with age, which is expected. The 3, 7, 28 days average strength with 0 % RCA has the compressive strength of 25.20 N/mm^2, 30.10 N/mm^2 and 40.10 N/mm^2 respectively. This increase tends to decrease as the percentages of the RCA in the concrete increases from 0 -100%. For instance, the compressive strength of specimens with 25 %, 50%, 75% and 100% RCA at 28 days age of curing are 38.83N/mm^2, 37.50N/mm^2, 34.07N/mm^2 and 27.11N/mm^2 respectively. The decreases when compared to the control test (0% RCA) showed a lower compressive strength at all ages of the concrete from 1.19% reduction at 3day-strength to 32.29% reduction at 28 day- strength as shown in figure 2. The reduction in strength reached the peak value at 100% RCA replacement of virgin coarse aggregate as the 28-day compressive strength reduced to about 77% of the normal virgin aggregate concrete. The reduction in strength also confirmed the earlier view by some researchers that compressive strength of RCA concrete is about two-third of the virgin aggregate concrete, Frandistous-Yannas (1977). The decrement can be attributed to weaker interface between the recycled concrete aggregates (RCA) which is surrounded by residual cementatious matrix of cement and sand before the new concrete mix. Other possible reasons for reduction in compressive strength include the flakiness and angularity of the RCA which makes compaction limited and hence reduced bulk density.

It is also noticeable that at 75% or less RCA replacement that the concrete compressive strength is well above the designed characteristic strength of grade 30 concrete hence it can be implored for structural grade concrete work.

CONCLUSION:

1. The use of recycled concrete aggregates (RCA) as alternative to natural or virgin aggregate in structural concrete reduces the strength development of the concrete.

2. A combination of RCA with natural virgin coarse aggregates in cases where high compressive strength and durability is not a priority with percentage replacement of 50% or less RCA is suitable for structural work.

3. More water is needed to maintain suitable workability of fresh concrete when RCA is used in concrete work.

Further research work is recommended in areas of flexural strength, drying shrinkage, creep and age effect of the RCA in concrete work

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Received for Publication: 21/02/08
Accepted for Publication: 18/04/08