International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 8, Issue 3, March 2019)

The Evaluation of the Physical & Mechanical Properties of Recycled Aggregates (Ra) and its Concrete (Rac)

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Abstract*-- This study compared the physical and mechanical properties of virgin aggregates (VA) with recycled aggregates (RA) and the corresponding concretes. The recycled aggregate was gotten from a demolished structure at Area H, Owerri and the virgin aggregate was obtained from Lokpa-Ukwu in Abia State Nigeria. Basic properties of both aggregates, such as specific gravity, water absorption, and the aggregate impact values (AIV) were investigated. The sand was well graded with the coefficient of uniformity, Cu of 2.0; coefficient of gradation, Cc of 1.02; average bulk density of 1564kg/m^3 and average specific gravity of 2.65. The virgin aggregate has AIV of 25%; water absorption of the virgin aggregate was 5.36%, 7.37% and 6.16%. AIV of the recycled aggregate, RA, were 25.97%, 28.17% and 22.78%; and the water absorption readings were 6.64 %, 6.83% and 6.47%. Concrete was prepared with both aggregates at the concrete mix ratio of 1.2:4 and similar workability was ensured. Mechanical properties of the concretes such as compressive strength and slump were examined. Eighteen concrete cubes were cast and tested for compressive strength on 7, 14 and 28 days age of curing. The average compressive strength obtained for recycled aggregate concrete (RAC) were 19.08N/mm^2, 22.53N/mm^2 and 26.50N/mm^2 and that of virgin aggregates concrete were 19.65N/mm^2, 23.20N/mm^2 and 27.29N/mm^2. The slump test value of the RAC was 85mm and that of virgin concrete was 83mm.The 28 days average dry density of both recycled aggregate concrete and virgin aggregate concrete were 2400kg/m^3. From the tests conducted, it was realized that the recycled aggregate concrete differed a little from the virgin aggregate concrete and can also be used in-place of virgin aggregate concretes.

***Keywords* — recycled aggregate, bulk density, concrete mix, compressive strength, dry density**

I. INTRODUCTION

Concrete is the most used man-made material in the world since its invention. The widespread use of this material has led to continuous developments such as ultra-high strength concrete and self-compacting concrete [1]. The civil engineering sector accounts for a significant percentage of global material and energy consumption and is a major contributor of waste materials. The ability to recycle and reuse concrete and demolition waste is critical to reducing environmental impacts in meeting national, regional and global environmental targets [2].

From a purely economical point of view, recycling of building waste is only attractive when the recycled product is competitive with natural resources in relation to cost and quality. Recycled materials will normally be competitive where there is a shortage of both raw materials and suitable deposit sites. With the use of recycled materials, economic savings in transportation of building waste and raw materials can be obtained [3] [4] [5]. Recycling of waste concrete has become an important issue worldwide due to the continued increase of construction wastes. Also, the growing global construction activities urge to find sustainable resources to replace natural materials for the production of concrete. In the past few decades, many researchers have been carried out on the use of recycled aggregate concrete (RAC) derived from construction and demolition wastes to produce concrete products [6] [7]. Utilizing recycled aggregate is certainly an important step towards sustainable development in the concrete industry and management of construction waste. Recycled aggregate is a viable alternative to natural aggregate, which helps in the preservation of the environment. The recycled aggregate can be generated from demolished construction structure which comprises of broken members or components like the slabs, beams, brick walls and others. Recycled aggregate (RA) derived from construction and demolition waste is suitable for partial or entire replacement for virgin aggregate when making new concrete. Using waste concrete as RA could save about 60% of limestone resources and reduce CO2 emissions by about 15% - 20% [8].

Recycling of concrete is a relatively simple process. It involves breaking, removing, and crushing existing concrete into a material with a specified size and quality [9]. The quality of RAC is very dependent on the quality of the recycled material used. Reinforcing steel and other embedded items, if any, must be removed, and care must be taken to prevent contamination by other materials that can be troublesome, such as asphalt, soil and clay balls, chlorides, glass, gypsum board, sealants, paper, plaster, wood, and roofing materials [10] [11] [12].

II. Literature Review

A. Applications of RAC

In general, applications without any processing include: -many types of general bulk fills, bank protection, base or fill for drainage structures, road construction, noise barriers and embankments. After removal of contaminants through selective demolition, screening, and /or air separation and size reduction in a crusher to aggregate sizes, crushed concrete can be used as: new concrete for pavements, shoulders, median barriers, sidewalks, curbs and gutters, and bridge foundations structural grade concrete soil-cement pavement bases lean-concrete or econo-crete bases and bituminous concrete[10].

B.Recycled Aggregate Characteristics

The crushing characteristics of hardened concrete are similar to those of natural rock and are not significantly affected by the grade or quality of the original concrete. Recycled concrete aggregates produced from all but the poorest quality original concrete can be expected to pass the same tests required of conventional aggregates. Recycled concrete aggregates contain not only the original aggregates, but also hydrated cement paste. This paste reduces the specific gravity and increases the porosity compared to similar virgin aggregates. Higher porosity of RA leads to a higher absorption [10] [12].

C. Mix Design OF RAC

It is generally accepted that when natural sand is used, up to 30 percent of natural crushed coarse aggregate can be replaced with coarse recycled aggregate without significantly affecting any of the mechanical properties of the concrete. As replacement amounts increase drying shrinkage and creep will increase and tensile strength and modulus of elasticity will decrease, however compressive strength and freeze-thaw resistance are not significantly affected. It is recommended that RA be batched in a prewetted and close to a saturated surface dry condition, like lightweight aggregates. To achieve the same workability, slump, and water-cement ratio as in conventional concrete, the paste content or amount of water reducer generally have to be increased. Concrete with RA can be transported, placed, and compacted in the same manner as conventional concrete. Special care is necessary when using fine RA. Only up to 10 to 20 percent fine RA is beneficial. The aggregate should be tested at several substitution rates to determine the optimal rate. Often recycled aggregate is combined with virgin aggregate when used in new concrete [10].

D. Sustainability of RAC

Recycling concrete provides sustainability several different ways.

The simple act of recycling the concrete reduces the amount of material that must be landfilled. The concrete itself becomes aggregate and any embedded metals can be removed and recycled as well. As space for landfills becomes premium, this not only helps reduce the need for landfills, but also reduces the economic impact of the project. Moreover, using recycled concrete aggregates reduces the need for virgin aggregates. This in turn reduces the environmental impact of the aggregate extraction process. By removing both the waste disposal and new material production needs, transportation requirements for the project are significantly reduced. In addition to the resource management aspect; recycled concrete aggregates absorb a large amount of carbon dioxide from the surrounding environment [13] [14] [15]. The natural process of carbonation occurs in all concrete from the surface inward. In the process of crushing concrete to create recycled concrete aggregates, areas of the concrete that have not carbonated are exposed to atmospheric carbon dioxide [9][10].

III. Methodology

A. Materials

The materials used for this work were (i) ordinary Portland cement (ii) recycled aggregates (A) (iii)) sharp river sand (iv) water (v) virgin aggregates (vi) recycled aggregate concrete.

A.1 Cement

Dangote brand of ordinary Portland cement which conforms to the requirements of BS EN 197-1:2000 [16] was obtained from dealer in Owerri and for all the work.

A. 2 Aggregate

The aggregates used in this research work were recycled aggregate, RA and virgin aggregate (as control) with maximum size of 19.5mm. Also fine aggregate/sharp sand was as well used. The recycled aggregates were obtained from a demolished structure at Area H, Owerri, Imo state; the virgin aggregates were obtained from Lokpa Ukwu in Abia State, Nigeria while the fine aggregates used were obtained from Otamiri River, also in Owerri, Imo State, Nigeria. These aggregates were sun-dried for seven days inside the laboratory before usage. The aggregates used were free from deleterious matters. The maximum diameter of sand used was 5mm while that of aggregates used were 19.5mm.

A.3 Water

Water used for this research work was obtained from a borehole within the premises of Federal University of Technology, Owerri, Imo State.

The water is potable and conformed to the standard of BS EN 1008: 2002 [17] and BS 3148:1980 [18]. Since it meets the standard for drinking, it is also good for making and curing concrete.

B. Methods

The sand and coarse aggregates (recycled and virgin aggregates) were tested to determine their specific gravities, bulk densities and gradation (sieve analysis), aggregate impact values and water absorption. Collections of samples were in accordance to BS EN 932-1:1997 [19] and BS 812: Part 1:1975 [20]. The sieve analysis of the fine aggregate was performed to determine the particle size distribution. The particle size distribution satisfied BS 882:1992 [21] and BS 410:1986 [22]. Slump test was performed on the mix ratio used to produce concrete made with recycled aggregates and virgin aggregates. The test was conducted in accordance with the specifications of BS EN12350- 2: 2000 [23]. Water absorption test was carried out on coarse aggregate to determine its ability to absorb water. The mixing method used for the production of concrete was machine mix and the batching was by weight. The mix ratio for batching was 0.5:1:2:4, the mix ratios stand for water-cement ratio, cement, coarse aggregation sand and aggregates respectively. The virgin aggregate was used as a control with the same mix ratio.

The concrete cubes were produced in moulds measuring 150 x 150x 150 mm in size. The moulds were first oiled for easy removal of the samples after setting. The concrete samples were introduced into the mould in three layers with proper vibration. A total of 18 cubes were produced from the mix ratio used and the mix ratio is 1:2:4, for control the mix ratio is 1:2:4, three cubes from each mix. The first set of six (6) cubes were used to obtained the seventh (7^{th}) day compressive strength, while the second set of six (6) cubes, were used to obtained the 14-day compressive strength. The last sets were used to obtain the 28-day strength. The moulding, curing and crushing of the concrete specimens were in accordance with BS 1881: 108:1983 [24], BS 1881: Part 111: 1983 [25] and BS 1881: Part 116:1983 [26] respectively. The testing of the cubes was done using in Okhard Machine Tool's WA-1000B digital display Universal Testing Machine (UTM). The machine has a testing range of 0-1000kN.

IV. Results And Discussion

A. Material Test Results

Figure I shows the grading curve of the river sand used in the concrete mixes. From the grading curve, uniformity coefficient, C_u and curvature coefficients, C_c were calculated as $C_u = 2.0$ and $C_c = 1.02$.

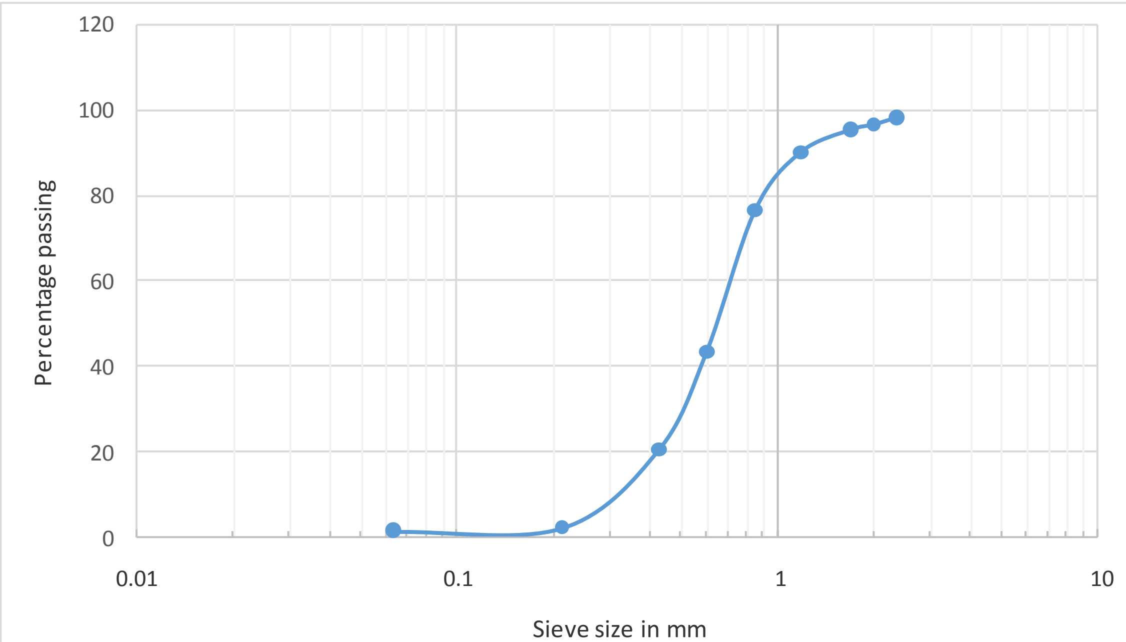

Figure I: Grading Curve of River Sand

International Journal of Recent Development in Engineering and Technology
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Table I
Bulk density Result/ Calculations of the sand

Sample number	**1**	**2**	**3**
Mass of container W_1	2.60	2.55	2.60
Mass of soil +container,W_2	2.605	2.6625	2.6732
Mass of soil (M)	0.025	0.0625	0.0732
Volume occupied, $V(m^3)$	0.000035	0.00004	0.000047
Bulk Density =M/V(kg/m^3)	1571	1563	1557
Average Bulk density(kg/m^3)		1564	

This showed that the sand was well graded and was suitable for making concrete [20] [21]. Table I shows the bulk density result and calculation table.

The bulk density of the River sand was found to be 1564 kg/m^3. Table II shows the specific gravity result for the river sand. From the table, the specific gravity of the sand was 2.65.

Table II
Specific Gravity Test Result of Sand

Trial Sample	**1**	**2**	**3**
Mass of empty pyncnometer bottle (M_1)g	443	443	443
Mass of bottle + dry sample (M_2)g	900	959	932
Mass of bottle + dry sample + water (M_3)g	1757	1791	1774
Mass of bottle filled with water only (M_4)g	1471	1471	1471
Mass of dry sample $(M_5)=(M_2)-(M_1)$g	457	514	489
Mass of water occupying same volume as the sample $(M_6) = (M_4)-(M_3-M_5)$g	171	194	186
Specific Gravity = M_5/M_6	2.673	2.649	2.629
Average Specific Gravity	2.65		

Table III
Impact Test Result on virgin aggregates

Trials	Mass of Steel cylindrical cup (kg)	Mass of Steel cylindrical cup + aggregates in kg	Mass of aggregate in kg(W_1)	Mass passing 2.36 sieve. W_3	AIV (W_3/W_1 ×100)
1	3.2kg	4.00	0.8	0.2	25
2	3.2kg	4.00	0.8	0.2	25
3	3.2kg	4.00	0.8	0.2	25

Table III shows the impact test results of the virgin aggregate. The aggregate impact value (AIV) of the virgin aggregate was 25%. The impact test results of the recycled aggregate (RA) is shown in Table IV. The AIV of the RA ranged from 25.97% to 28.17%.

Aggregate that have impact values less than 10% are considered to be exceptionally strong; from 10% to 20% are considered to be strong; from 20% - 30% are considered to be satisfactory. Both the virgin aggregate and RA were considered satisfactory.

Table IV
Impact Test Result on Recycled Aggregates

Trials	Mass of Steel cylindrical cup	Mass of Steel cylindrical cup + aggregate in kg	Mass of aggregate in kg, W_1	Mass passing 2.36 sieve, W_3	AIV W_3/W_1 ×100
1	3.2kg	3.97	0.77	0.2	25.97
2	3.2kg	3.91	0.71	0.2	28.17
3	3.2kg	3.92	0.72	0.2	27.78

The results of the water absorption test of the virgin aggregate are shown in Table V. For a 500g sample, the values ranged from 5.356% to 6.77%. Also, the results of the water absorption test of the RA are shown in Table VI. The values ranged from 6.47% to 6.83% for a 500g sample.

This is consistent with the findings that recycled aggregates contain not only the original aggregates, but also hydrated cement paste **[10]**. This paste reduced the specific gravity and increased the porosity compared to similar virgin aggregates. The higher porosity of RA led to a higher absorption.

Table V
Water absorption test on virgin aggregates

Sample number	A (g)	B (g)	C (g)	$\left(\frac{B-A}{A}\right)\times 100$
1	500	526.78	529.45	5.356
2	500	533.85	538.78	6.77
3	500	530.81	532.95	6.162

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435(Online) Volume 8, Issue 3, March 2019)

Table VI
Water absorption test on recycled aggregates

Sample number	A (g)	B (g)	C (g)	$\left(\frac{B-A}{A}\right)\times 100$
1	500	533.21	531.22	6.64
2	500	534.16	536.21	6.83
3	500	532.33	535.01	6.47

Table VII
Slump test results

Mix ratios	Slump Value (mm)	Type of slump
Slump test on recycled aggregates concrete		
1:2:4	85	True
Slump test on virgin aggregates concrete		
1:2:4	83	True

Table VIII
Density of the concretes

Mix ratio	Sample No	Volume of Sample in (m^3)	Weight of Sample in (kg)	Density of the concrete in kg/m^3
Recycled aggregates				
1:2:4	A	0.003375	8.12	2405.9
1:2:4	B	0.003375	8.10	2400.0
1:2:4	C	0.003375	8.10	2400.0
Virgin aggregates				
1:2:4	A	0.003375	8.12	2405.9
1:2:4	B	0.003375	8.00	2370.4
1:2:4	C	0.003375	8.14	2411.9

The slump value of the RAC was 85 while that of the virgin aggregate concrete was 83. The slump value for the RAC shows that it is true slump, just like that of normal weight concrete which ranges between 50-90mm. The results of density tests were obtained from the 28-day weight of compressive strength test sample before they were crushed and the results are as presented in Table VIII.

B. Compressive Strength Test Results

A comparison of the compressive strengths at 7th, 14th and 28th day between the RAC and the virgin concrete is shown in Figure II. The 7th day compressive strength results for the RAC and virgin aggregates concrete were 19.08 and 19.65N/m^2. The 14th day compressive strength results for the RAC and virgin aggregates concrete were 22.53 and 23.20 N/m^2 respectively.

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Also, at 28th day, the compressive strengths of the RAC and virgin aggregate concrete were 26.50 and 27.29N/m2 respectively. The differences between the compressive strengths of the RAC and the virgin aggregate concrete at the various ages were very minimal

C. Comparison with Previous works

In October of 2009, a field test of RCA was initiated in two lanes at Gate F7B of the Chicago O'Hare International Airport [10]. In a side-by-side comparison, a lane of concrete using virgin aggregates was placed next to a lane of concrete using RAC. The RA was produced on-site using concrete removed at the airport. The ready mixed concrete supplier treated the RA like lightweight aggregates and was able to produce concrete in a single-stage mixing process. Contractors placing the RAC said the workability was similar to that of the virgin aggregate concrete and the placement had good finishability. Within four days, the placement was in full service. Sensors were placed in the concrete at the time of placement to measure the internal relative humidity, temperature, and the lift-off of the slab from the cement-treated permeable base. Other properties were regularly monitored, such as surface appearance and joint width.

After five months of monitoring, the data between the two concrete lanes were statistically the same, showing no difference in behaviour between the RAC concrete and virgin aggregate concrete. Laboratory testing using a two-stage mixing method showed that using RAC for the coarse aggregate reduced bleeding and segregation and produced similar workability and compressive strength as virgin aggregates [10]. These concur with the findings of this work.

V. CONCLUSION

This study compared the physical and mechanical properties of virgin aggregates (VA) with recycled aggregates (RA) and also their corresponding concrete. The physical properties of the RA and the virgin aggregate are not much different. The physical and mechanical properties of the RAC are also similar to that of the normal concrete made from the corresponding virgin aggregates. RA reduced bleeding and segregation and produced similar workability and compressive strength as virgin aggregates in concrete mixes. The adherence of mortar to the RA increased the porosity leading to higher water absorption.

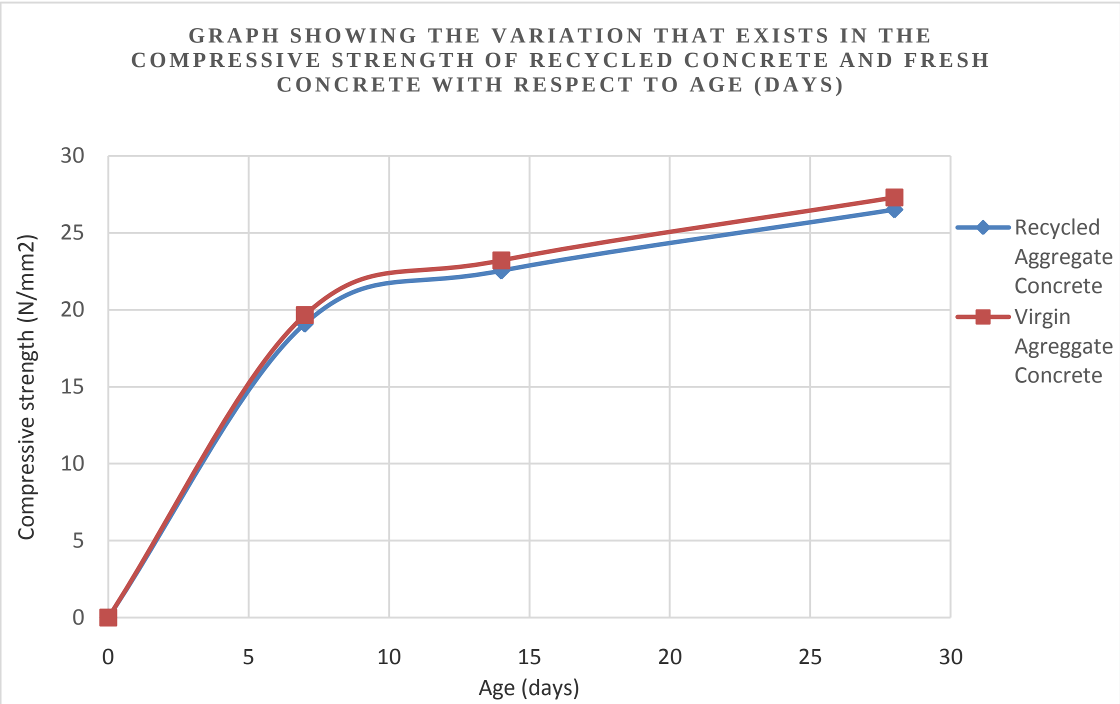

Figure III: The variation in the compressive strength of recycled concrete and fresh concrete with respect to age (days)

International Journal of Recent Development in Engineering and Technology
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