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Comparison of Some Strength Properties of Concrete Made from Reclaimed Aggregates and Crushed Granite Aggregate

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ABSTRACT

Wastes generated through demolition of concrete and asphalt civil engineering structures constitute environmental nuisance. In this study, an attempt has been made to find the suitability of reclaimed concrete aggregate (RCA) and reclaimed asphalt pavement (RAP) aggregate in the production of concrete that is, recycling these wastes to produce concrete. The concrete strengths were then compared to the strength of crushed granite aggregate concrete Laboratory experimental procedures were used to determine the compressive strength of crushed granite aggregate (CGA) concrete, reclaimed concrete aggregate and reclaimed asphalt aggregate concrete. The study was done in three mix ratios, 1:2:4, 1:1.5:3 and 1:1:2. The surface texture of RCA and CGA were rough while that of RAP aggregate was relatively smooth. The maximum size of aggregate used is 20mm. The specific gravity values of RCA, RAP and CGA are 2.49, 2.23, and 2.63 respectively. The average water absorption values of the aggregates are 3.1, 2.8, and 1.3 percent for RCA, RAP and CGA respectively. 1The average values of the compressive strengths of RCA concrete, at 28 day, are 26, 39 and 52N/mm^2 for the three mix ratios respectively. The values for RAP concrete are 25, 37, and 49N/mm^2 respectively, while that of CGA concrete are 27, 41 and 54N/mm^2 respectively. The values of the specific gravity and compressive strength of the three aggregates are close. Therefore, NCA and RAP aggregate are recommended as good substitutes to natural crushed granite aggregate for production of structural concrete. It is also discovered that it could be cheaper to use the reclaimed aggregates than the crushed granite aggregate.

KEY WORDS: *Compressive Strength, Reclaimed Aggregate, Recycling, Waste,*

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I. INTRODUCTION

Concrete plays an important role in the construction industry all over the world. Concrete is basically a mixture of cement, fine aggregate, coarse aggregate and water. The cost of concrete is high, especially in the developing nations. Waste concrete and asphalt materials are often dumped in the open, constituting environmental nuisance, or used as landfill in Nigeria. Recycling industries in many parts of the world, including South Africa, convert low-value waste into secondary construction materials such as a variety of aggregates. Often, these materials are used as road construction materials, backfill for retaining walls, low-grade concrete production, drainage and brick work and block work for low-cost housing [1].To achieve sustainable availability of construction materials coupled with the need for a healthy environment, this research focuses on using waste concrete and asphalt as construction aggregates. Reclaimed concrete aggregate (RCA) has been primarily used as an unbound material in embankments, bases, and sub-bases. Engineers have also used reclaimed concrete as an aggregate in the construction of structures such as concrete pavement but with limited frequency. The use of recycled concrete in load bearing structures has not gained wide acceptance probably because of the lack of accessible information on the subject, such as expected fresh and hardened material properties [2].In future, it may be useful to find new sources of aggregates for the production of concrete due to increase in demand but decreasing supply of natural aggregates. Increasing number of concrete buildings are being demolished and the difficulty of disposing of the rubble has prompted an interest in the possibility of using crushed concrete as aggregate in new concrete. In Australia, RCA has been the most common construction and demolition waste used in concrete production. About five million tons of recycled concrete and masonry are available in Melbourne and Sydney of which 500,000 tons is RCA [3].

Aggregates vary in size from grain of sand to a stone several inches in diameter [4]. The aggregates in RAP are coated with asphalt cement that reduces the water absorption qualities of the material while the aggregate in RCA are coated with a cementitious paste that increases the water absorption qualities of the material [3].

The self cementing capabilities of RCA are an interesting secondary property. The crushed material exposes un-hydrated concrete that can react with water, potentially increasing the material strength and durability when used as unbound base course for new road way construction. It was discovered that the RCA required relatively lower water cement ratio as compared to parent concrete to achieve a particular compressive strength [5]. RAP aggregate is normally produced through milling operations, which involves breaking the boulder materials into small pieces. The inclusion of sub-grade materials in the recycled material also contributes to a higher instance of fines. Finer gradations of RAP aggregate are produced through milling operations compared to crushing operations [6]. Asphalt pavement is excavated using full-size Re-claimers or portable asphalt recycling machines. RAP can be stockpiled, but is most frequently reused immediately after processing at site [7]. RCA production involves crushing the material to a gradation comparable to that of typical roadway base aggregate. Fresh RCA typically contains a high amount of debris and reinforcing steel, and the RCA must be processed to remove this debris prior to placement. The material is first crushed in a jaw crusher that breaks the steel from the material and provides an initial crushing of the concrete [3].
It was shown that recycled aggregates could be used for high performance concrete [4].

Compressive and Flexural Strength of Concrete

The compressive strength of concrete is calculated from:

$$\text{Compressive strength } (N/mm^2) = \frac{\text{Maximum load at failure (N)}}{\text{Cross-sectional area of cubes (mm2)}} \qquad 1$$

The flexural strength is given by:

$$\text{Flexural Strength } (\sigma) = \frac{3FL}{2bd^2} \qquad 2$$

F is the maximum load (force) causing fracture. L is the span of the beam (mm), b is the width and d is the depth of beam cross-section.

II. MATERIALS AND METHODS

2.1 **Materials**

The fine aggregate used in all the tests is sand obtained from River Bakin Kogi in Nasarawa State, Nigeria. The crushed rock was obtained from Nasarawa Eggon, Nigeria. The RAP RCA coarse aggregate were obtained from Lafia, Nigeria. Ordinary Portland cement was used as purchased. The water used for mixing was from public water supply, Lafia- Nigeria.

III. METHODOLOGY

Sieve Analysis Test

Sieve analysis test was carried out on sand, crushed rock, RCA and RAP aggregate. The test was done in accordance with BS 812: Part 103: 1985 [8].

Specific Gravity Test

The specific gravity of the materials was carried out according to BS 812: Part 2: 1975 [9]

Specific gravity is calculated using:

$$Gs = \frac{w_2 - w_1}{(w_4 - w_1) - (w_3 - w_3)} \qquad 3$$

Aggregate Crushing Value Test

The aggregate crushing value test was carried out according to BS 812: Part 110: 1990 [10].

Aggregate crushing value (ACV) is given by:

$$ACV = \frac{\text{Weight passing}}{\text{Total weight}} \times 100\% \qquad 4$$

Aggregate Water Absorption Test

The water absorption tests of the three aggregates were carried out according to BS 1881: Part 109: 1990 [11].

Natural Aggregate water absorption (WA) is given by:

$$WA = \frac{\text{Mass of water absorbed by aggregate}}{\text{Mass of dry aggregate}} \; x \; \frac{100}{1} \qquad 5$$

Concrete production

Crushed granite concrete was produced manually with the aid of a shovel. Concrete mix ratio of 1:2:4 with water-cement ratio of 0.50 was used. The batch quantities were measured by weight. The same procedure was used for concrete mix ratios of1:1.5:3 with water-cement ratio of 0.49, and1:1:2 with water-cement ratio of 0.48. The above method was repeated for reclaimed concrete aggregate (RCA) and reclaimed asphalt (RAP) aggregate.

Concrete Slump Test
The sump test was done according to BS 1881: part 102: 1983 [12] for all the mixes.

Compressive Strength Test
Compressive Strength Test was carried out with a 156kg capacity ELE electronic hydraulic jump-power testing machine, according to BS 1881: part 116: 1983 [13]. The compressive strength is calculated from (1).

Cost Analysis : The cost of getting the three types of the aggregates to the site of the production of the concrete was estimated.

IV. RESULTS AND DISCUSSION

Physical and Mechanical Properties of the Aggregates
TABLE 1 shows the results of average specific gravity, impact value and crushing values of the aggregates.

Sieve Analysis of the Aggregates
TABLE 2 shows results of the sieve analysis of the sand while TABLE 3 shows results RCA, RAP and Crushed Granite aggregate

Slump Test
The RAP aggregate-concrete has an average slump between 33-58mm; NCA and RCA slump ranges from 70 to 95mm, for all the mixes. RAP aggregate concrete appears to be more cohesive. The reason could be that RAP aggregate contains fine soil from road base or sub-grade earth [6].

Compressive Strength Results
The compressive strength results are shown in Fig. 1-3. It can be observed that the 28 day average compressive strength of the concrete, for each aggregate type, is very close. Therefore, Reclaimed Concrete Aggregate (RCA) and Reclaimed Asphalt Pavement (RAP) Aggregate are good substitutes to Natural Crushed Rock Aggregate (NCA).

Cost analysis
The average estimated cost of production, processing and transportation of the three types of aggregate is shown in TABLE 4. It can be observed that it is about 40 and 60 percent cheaper to use reclaimed concrete and reclaimed asphalt aggregates respectively than crushed granite aggregate. The wide deference in the cost is due to the fact that granite rock needed explosives to have it in small bits.

V. CONCLUSIONS AND RECOMMENDATIONS

Conclusion : Wastes generated from concrete and pavement structures do constitute environmental nuisance. This research examined the possibility of recycling these materials as aggregate in concrete production. The use of these materials could also reduce the pressure on the conventional natural aggregate. The physical and some engineering properties of reclaimed concrete aggregate (RCA) and reclaimed asphalt pavement (RAP) aggregate were compared with crushed granite aggregate (CGA). The particle grade values of reclaimed aggregate wastes were close to the crushed granite aggregate. The specific gravities of RCA, RAP and CGA are 2.49, 2.23 and 2.63 respectively. It is observed that the reclaimed aggregates absorbed more water than the natural crushed granite rock. The percentage water absorption values are 3.1, 2.8, and 1.3 for RCA, RAP and CGA respectively. At the concrete characteristic strength of M30, the mean compressive strengths at 28 day for the aggregates' concrete are 39.0, 36.8, and 40.5 N/mm^2 respectively. Hence, there is little difference in the compressive strength of the aggregates. The cost analysis showed that it is relatively cheaper, within the limits of the experimental procedure and analysis, to produce concrete with the reclaimed aggregates than with crushed granite rock.

Recommendations : Based on the findings from this work, it is recommended that

- Reclaimed concrete aggregate and reclaimed asphalt pavement aggregate could be used to produce structural concrete

- Further investigations into effective ways of removing steel fibers and other constituents of the wastes from the desired aggregate materials.

Table 1: Summary of Physical Properties of NCA, RCA and RAP

Physical/Mechanical Property	Type of Aggregate		
	NCA	RCA	RAP
Specific Gravity	2.63	2.49	2.23
Aggregate impact value (%)	8.2	8.0	4.5
Aggregate crushing value (%)	20	18	0
Aggregate water absorption (%)	12.5	3.1	2.8

Key:
NCA-crushed granite aggregate
RCA-reclaimed concrete aggregate
RAP-reclaimed asphalt pavement aggregate

Table 2: Particle Size Distribution of the River Sand

Sieve size	Weight retained (g)	Percentage retained (g)	Percentage passing (g)
2.36mm	60	6.01	93.99
1.70mm	49	4.91	89.08
1.18mm	88	8.82	80.26
850µm	192	19.24	61.02
600µm	318	31.86	29.16
425µm	132	13.23	15.93
300µm	111	11.12	4.81
180µm	32	3.21	1.60
75µm	8	0.802	0.80
Pan	8	-	-

Table 3: Particle Size Distribution of CGA, RCA and RAP

Sieve size (mm)	Type of Aggregate		
	NCA	RCA	RAP
28	100	100	100
20	98	96.5	98
14	88	80	85
10	57	65	58
5	1	0	1
Pan	-	-	-

Table 4: Cost of Aggregate

Aggregate Type	S/No.	Type of Operation	Cost per 3.4 m^3 (US Dollar)
Crushed granite rock (CGA)	1	of Cost machine production per 3.4m^3	256
	2	Cost of explosives (dynamite) per 3.4m^3	94
	3	Cost of labor per 3.4m^3	131
	4	Transportation to site (Lab)	32
	5	Miscellaneous per 3.4m^3	113
Total			**626**
Reclaimed concrete (RCA)	1	Cost of bulldozer for breaking boulders per 3.4m^3	74
	2	Cost of pay loader for loading materials per 3.4m^3	50
	3	Transportation of materials per 3.4m^3	32
	4	Cost of removing reinforce steel (bars) and other debris per 3.4m^3	50
	5	Breaking of aggregate to sizes per 3.4m^3	100
	6	Miscellaneous per 3.4m^3	69
Total			**374**
Reclaimed asphalt (RAP)	1	Cost of scarification of Asphalt per 3.4m^3	77
	2	Cost of pay loader for loading material per 3.4m^3	50
	3	Transportation per 3.4m^3	32
	4	Cost of breaking of boulders to aggregate sizes 3.4m^3	100
	5	Miscellaneous per 3.4m^3	56
Total			**245**

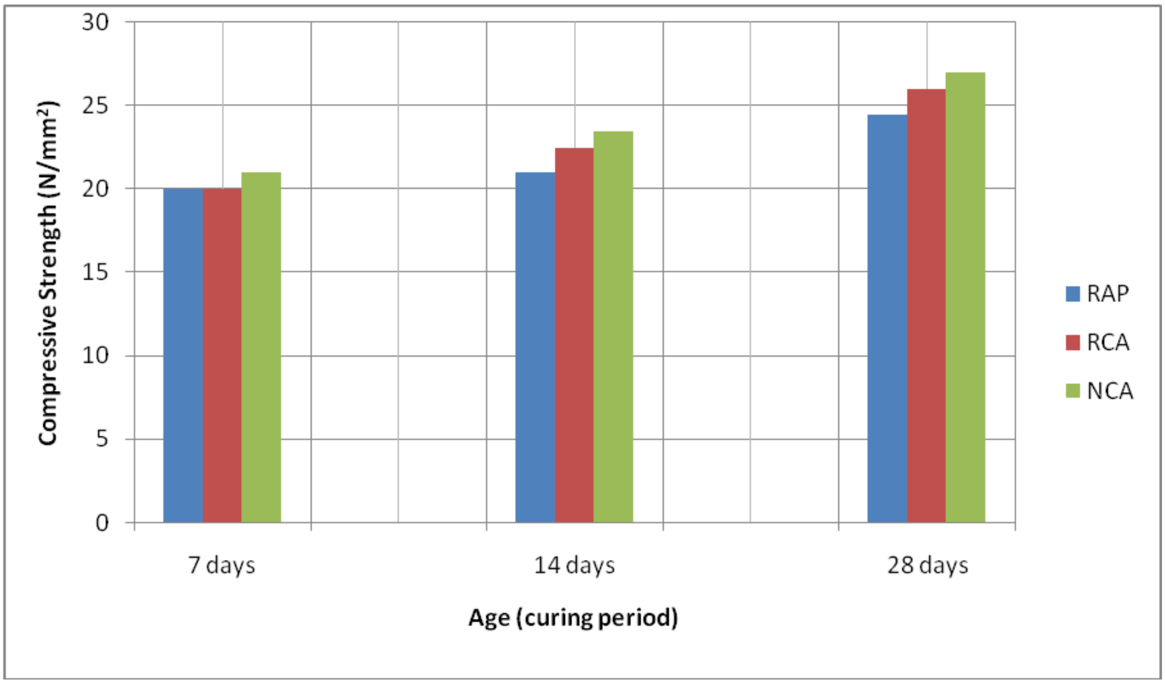

Figure1: Graph of compressive strength results (1:2:4)

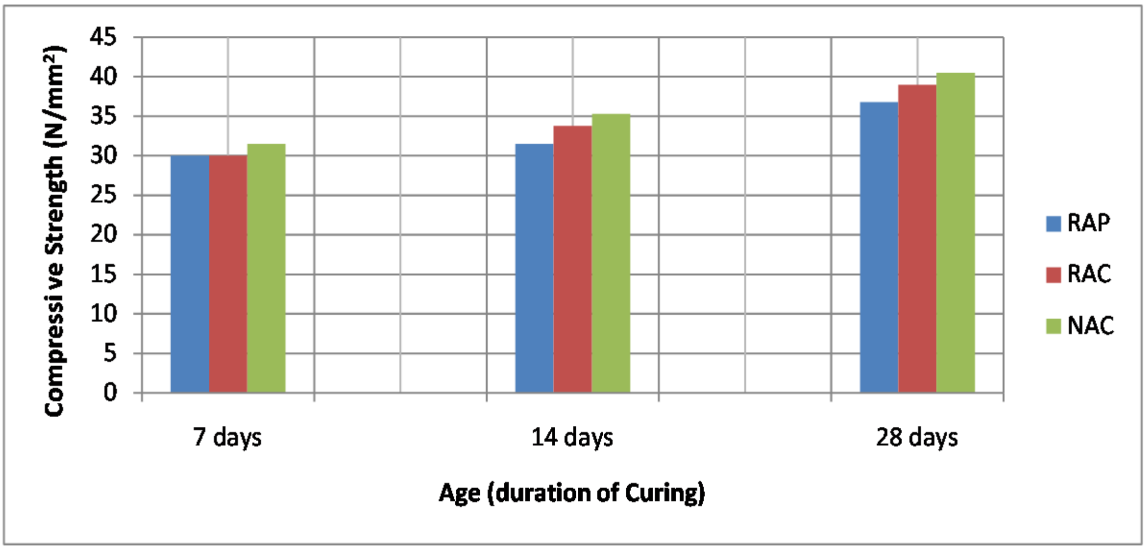

Figure 2: Graph of Compressive Strength Results (1:*1*½:3)

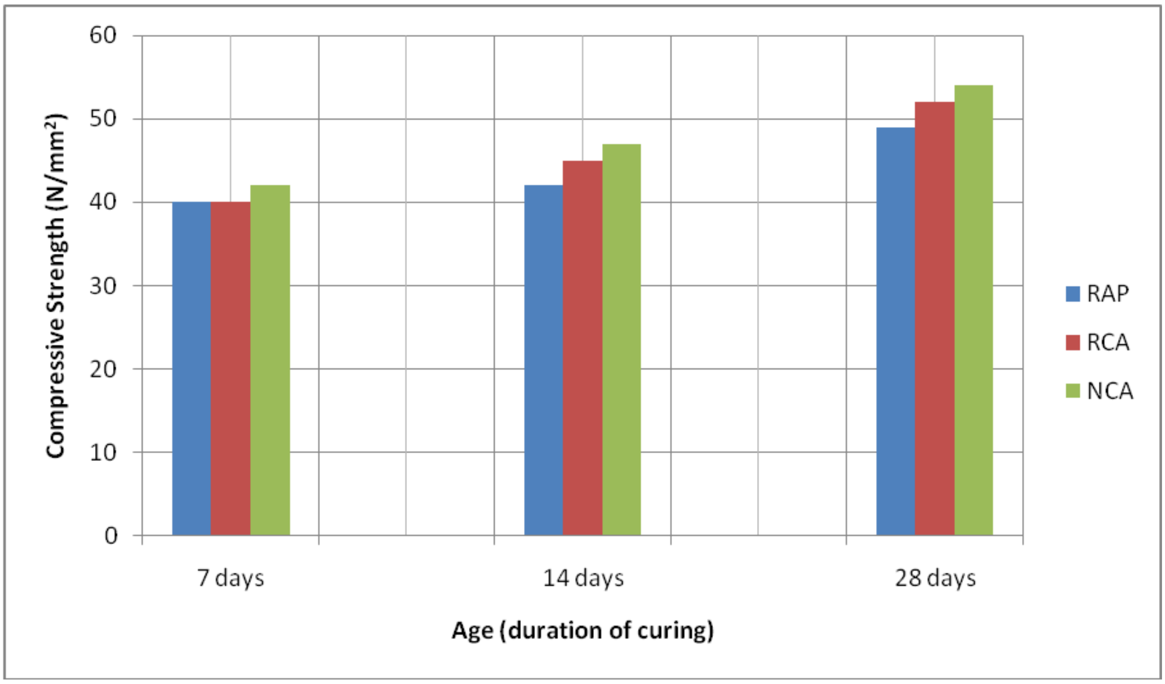

Figure 3: Graph of compressive strengths result (1:1:2)

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