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Viability of Recycled Concrete Waste as Construction Material for a Sustainable Environment

Theme: Sustainable Buildings and Cities

Olaoye R. A.[1], Oluremi J.R.[1], Ajamu S.O.[1] & Abiodun Y.O.[2]

[1]Department of Civil Engineering,
Ladoke Akintola University of Technology, Ogbomoso,
Oyo State, Nigeria
[2]Department of Civil and Environmental Engineering,
University of Lagos, Akoka
jroluremi@lautech.edu.ng

Abstract: A major source of environmental burden in construction industries is concrete waste because its generation and accumulation start from the time fresh concrete are produced on-site or off-site till its hardens. This made concrete the largest portion of solid waste stream by weight in the construction industries. Recycling of these waste materials into new form as well as appropriate reuse could therefore conserve natural resources, reduce the space required for land filling and the cost of transportation. This paper assesses the viability of reusing aggregates obtained from concrete waste collected from four different construction sites by comparing compressive strength of concrete made with the recycled concrete waste aggregate with concrete made with natural fresh aggregate as control specimens using an aggregate size not greater than 25mm. A total of 60 cubes of size 150mm x 150mm were cast and cured for different maturity age of 7, 14, 21 and 28 days before crushing. Laboratory results revealed that there was little variation in strength as the cubes matures. Average compressive strength of concrete made with recycled concrete waste aggregates obtained from two of the site were 22.8 N/mm2 and 24.3 N/mm2 and these were almost the same with the control test cubes with average compressive strength of 24.4 N/mm2. However, test cubes obtained from the other two sites had concrete strength lower than 20 N/mm2. Hence, concrete produced with recycled concrete waste aggregate though exhibiting lower compressive strength could be used for walkways and kerbs production in road construction, backfilling, and in concrete production for light load bearing structural components so as to achieve a sustainable environment and conserve natural resources.

Keywords: Environmental sustainability, Construction waste, Waste management, Waste reuse, Recycling

1. **Introduction**

Concrete is the leading construction material across the world and the most widely used material in civil engineering works, therefore concrete waste arising from construction and demolition works constitutes one of the largest waste streams within developing and developed countries (Kumutha and Vijai, 2010; Singh and Sharma, 2010; PWTB, 2004). Environmental and economic implications of this waste demand urgent attention and sustainable solution as the construction industry now experience more pressure now than ever before on how to manage these waste (Snehal et al., 2013; Donalson et al., 2010; Hemalatha et al., 2008). Various measures has been aimed at reducing the use of primary aggregate and increasing the recycling and reuse of concrete waste from construction industries as aggregates for technically, economically, or environmentally acceptable construction work (Otoko, 2014; Agrela et al., 2013). Assurance on the effective reuse of concrete waste requires three basic concepts: (a) safety and quality of the finished material (b) improved and sustainable environment, and (c) increased cost effectiveness of construction (Dosho, 2007). According to Bairagi, 1993, up to 50% of natural aggregate could be replaced by recycled aggregate without seriously affecting the properties of the concrete, both in the fresh and hardened states. A study conducted in South Western Nigeria by Akinkurolere and Franklin (2005) revealed that construction wastes incur additional cost to the construction project as well as reduction in the profit margin of the contractor, taking into account the cost of storing and evacuating the waste along with the loss of revenue from not reclaiming it. Concrete waste can be used for several purposes, apart from land filling, to generate lost revenue for economic reason. Demolished sandcrete blocks waste has been recycled and utilized into fine aggregate in concrete by Akaninyene (2012). Kaosol (2010) reused concrete waste as crushed stone for hollow concrete masonry units. Kenai and Debieb (2007) examined the possibility of using crushed clay bricks as coarse and fine aggregate for a new concrete material while Umoh and Kamang (2005) investigated the use of sandcrete blocks waste collected from block moulding yards as partial replacement of fine aggregate in medium grade concrete of 20N/mm2, 25N/mm2, and 30N/mm2.

Testing the suitability of both the natural and the recycled concrete waste aggregate using experimental approach is vital before opting for reuse. Research by Chan and Fong (2006) revealed that recycled aggregate and natural aggregate should have physical properties satisfying the requirement listed in Table 1. However, the major characteristic of concrete includes the strength, durability, deformation under load and shrinkage among other properties, but the aggregate for concrete production must meet the requirements set in relevant specification for its particular use. For lower grade applications, concrete with 100% recycled coarse aggregate is allowed. Recycled fines are not allowed to be used in concrete. The target strength is specified at 20 N/mm2 and the concrete can be used in benches, stools, planter walls, concrete mass walls and other minor concrete structures. For higher grade applications (up to C35 concrete, 35 N/mm2), the current specifications allows a maximum of 20% replacement of virgin coarse aggregates by recycled aggregates and the concrete can be used for general concrete applications except in water retaining structures (Chan and Fong, 2002). Most research work had focused on demolished concrete waste from old structures or demolished blocks and bricks from old building rather than the hardened concrete waste generated on-site from on-going construction work. This paper assesses the characteristics of concrete produced with aggregates from concrete waste obtained from four construction sites in Southwestern Nigeria.

Table 1: Properties of natural and recycled aggregate

Property	Coarse Aggregate	
	Natural Aggregate	Recycled Aggregate
Density kg/m^3	2500	2300
Slump (mm)	50-75	Tolerance of ± 25
Compacting factor	0.82- 0.92	0.80-0.90
Water absorption	0.5 % -1.0 %	5 % - 6 %

Source: Poon and Chan, 2007

2. Methodology

2.1 Sample Collection and Preparation

Concrete wastes were collected from four different construction sites where concrete mixed in the right proportions are used for various concrete works: Ogbomoso (OG), Oyo (OY), Saki (S), and Ibadan (I) all within Oyo state, Nigeria. This includes left over waste from casting of column and column bases, slab and flooring processes. The collected hardened concrete wastes were crushed to a specific size to obtain the recycled aggregates free from soil, clay, wood and others debris as contaminants. Samples obtained from each site were labeled for proper identification. The natural fresh crushed stone aggregate samples were collected directly from a quarry.

2.2 Experimental Tests

2.2.1 Sieving

BS sieves ranging from size 0.125mm to 8mm (for fine aggregate) and 4.75mm to 25mm (for coarse aggregate) were used for sieve analysis. The samples retained on each sieve were collected, weighed and recorded. Both natural and recycled concrete waste aggregates of size not greater than 25mm were used for concrete production.

2.2.2 Water Absorption Test

This test was performed to determine the amount of water (in percent) absorbed by aggregates and hence the porosity and soundness of the aggregates. The effective water absorption (EA) was calculated as the amount of water required to bring an aggregate in a concrete from the air-dry state (AD) to the saturated–surface dry (SSD) weight. A certain mass of aggregate was wrapped in the net and immersed in the water for 24 hours, allowed to be dried and reweighed again. Water absorption capacity of the aggregate is determined from the equation 1.

$$\text{Water Absorption capacity} = \frac{\text{Final mass} - \text{Initial mass}}{\text{Initial mass}} \times 100\% \qquad 1$$

2.2.3 Casting of Concrete Cube

Concrete mix was prepared by mixing ordinary Portland cement with fine aggregates and recycle concrete waste and the natural aggregate as coarse aggregates using mix ratio of 1:2:4. Concrete cubes test specimens were cast using 150x150x150 mm mould. Mixing, casting, compacting and curing processes were carried out using standard methods in accordance with BS 1881, Part 108 of 1997 in the Structural Laboratory of the Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso.

2.2.4 Workability Tests

Slump and Compacting factor tests were carried out in accordance to procedures described in BS 1881, Part 102, 1997 and BS 1881, Part 103, 1997 respectively to determine the workability and amount of useful work necessary to produce full Compaction. The compacting factor was evaluated using equation 2.

$$\text{Compacting factor} = \frac{\text{mass of sample}}{\text{mass of fully self compacted sample}} \qquad 2$$

2.2.5 Compressive Strength Test

Concrete cubes were cast in triplicate and cured for 7, 14, 21 and 28 days, 24 hours after casting as shown in Plate 3 and thereafter each cube was crushed under incremental compressive load until failure occurred to obtain the maximum compressive load for 7, 14, 21 and 28 days and average compressive strength was determined for each maturing age. The development of failure was monitored on the compression machine for each of the cubes cured and the compressive strength was determined from equation 3.

$$\text{Compacting factor} = \frac{\text{mass of sample}}{\text{mass of fully self compacted sample}} \qquad 2$$

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strength was determined from equation 3.

$$\text{Compressive strength } (N/mm^2) = {}^{P}/_{A} \qquad 3$$

Where:

P: Ultimate compressive crushing load of concrete (N)

A: Surface area of cube under loading (mm^2)

The density of the cubes was also determined according to the relation in equation 4

$$\text{Density of concrete} = \frac{\text{Weight of the cube } (kg)}{\text{Volume of the cube } (m^3)} \qquad 4$$

Plate 1: Stack of Sieves Plate 2: Compression machine Plate 3: Cubes after casting

3.0 Results and Discussion

3.1 Aggregate gradation

The result of the sieve analysis for the fine aggregate is presented in Figure 1. The fine aggregate was found to be well graded sand which provide strong affinity for gripping with lesser binding materials. The gradation curve gave an S-Shape with effective size of 0.36 mm, coefficient of uniformity of 2.08 and coefficient of gradation of 1.12. Data from sieve analysis for the coarse natural aggregates, N and recycled concrete wastes OG, OY, S and I are presented in Table 1-5 of Appendix respectively. The gradation curve for both natural and recycled concrete waste aggregate were relatively the same as shown in Figure 2. The natural crushed stone coarse aggregate has effective size of 7.50 mm, coefficient of uniformity of 2.4 and coefficient of gradation of 1.25. The recycled concrete waste aggregate from Ogbomoso (OG) has effective size of 11 mm, coefficient of uniformity of 1.91 and coefficient of gradation of 1.25 while effective size, coefficient of uniformity and coefficient of gradation for concrete waste aggregate from Oyo (OY), Saki (S) and Ibadan (I) approach infinity respectively. Similar results were obtained from by Singh and Sharma (2010) on the use of recycled aggregates in concretes.

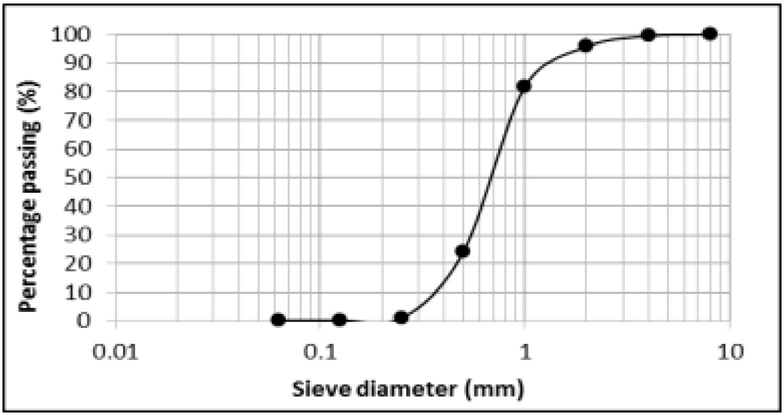

Figure 1: Gradation curve for fine aggregate

3.2 Workability and Consistency of Concrete

The average slump and compacting factor test result for the concrete mixes using natural and recycled concrete waste aggregate is shown in Table 2. True slump of 52 mm was obtained for concrete made from natural crushed stone aggregate which satisfies the specification for workability of such aggregate sizes. For the concretes produced with recycled concrete waste aggregates, result showed a reduction in slump value, but which remained essentially within the specified tolerances of +25mm according to BS 5328 (1990). The slump values for the four samples ranged from 25 to 35 mm hence the concrete waste aggregates still maintained the appropriate slump. The compacting factor for the concrete produced from natural crushed stone aggregate was 0.92 which is an indication of good workability and consistency properties. The compacting factor for fresh concrete produced from recycled concrete waste aggregates is low compared with natural aggregates with values ranging from 0.80 to 0.90 however, the concrete made with the four recycled concrete waste aggregates still have good workability property with consistency moving between hard to plastic.

Table 2: Average slump and compacting factor of the natural and recycled aggregates using 1:2:4 mix ratio

Aggregate type ≤ 25mm	Slump (mm)	Compacting factor	Consistency
Natural aggregate	52	0.92	Plastic
OG	26	0.83	Hard
OY	35	0.82	Hard
S	25	0.80	Hard
I	25	0.90	Plastic

3.3 Water Absorption of the Concrete Cubes

The average values of water absorption for the concrete cube produced from each of the aggregates types used are shown in Table 3. The rate of water absorption increased as the cubes matured from the 7^{th} day to the 28^{th} day. Water absorption of the concrete made from natural aggregate fell within the standard of 0.5 - 1%. For the concrete produced from recycled concrete waste aggregates, sample OG gave the highest absorption at the end of the 28days (5%), though it does not exceed the maximum value of 10% water absorption specified by Winston et al., (2002) for recycled aggregates. Results obtained indicated that recycled concrete waste aggregate absorb more water than the ordinary fresh granite due to the present of porous cement paste on the aggregates.

Table 3: Average water absorption test result for concrete cubes (%)

Aggregate type (Water absorption %)	**Testing days**			
	7	14	21	28
Natural aggregate	0.8	0.91	1.0	1.0
Sample OG	2.6	3.2	3.51	5.0
Sample OY	2.9	3.2	3.6	3.9
Sample S	3.0	3.4	3.6	3.7
Sample I	2.7	3.4	3.6	3.9

3.4 Density and Compressive Strength of Concrete

The average densities of concrete cubes for each curing period are presented in Table 4. According to Jackson and Dhir (1996), the most suitable concrete density usually lies between 2300kg/m^3 and 2500kg/m^{3}with minimum value at 2000kg/m^3 (Winston et al., 2002). Based on this, concrete density made from the natural aggregate, samples OY and S (recycled aggregate) are within the range of suitable concrete density at 28 days,. The other two samples gave a density value little below the specified range.

Table 4: Average Density of the Concrete Cubes

Aggregate type	Testing days	7	14	21	28
Natural aggregate	Mean density of cubes (kg/m^3)	2465	2409	2405	2406
Sample OG	Mean density of cubes (kg/m^3)	2264	2313	2243	2272
Sample OY	Mean density of cubes (kg/m^3)	2273	2254	2277	2315
Sample S	Mean density of cubes (kg/m^3)	2493	2488	2395	2487
Sample I	Mean density of cubes (kg/m^3)	2399	2318	2378	2234

Average compressive strengths of the concrete cubes are presented in Figure 3. Compressive strength for concrete made with natural crushed stone aggregates increased with age and the maximum strength was attained at the 28th day. The compressive strength of concrete with recycled concrete waste aggregates also increased with increase in age. The highest average compressive strength of concrete made with natural crushed stone aggregates is 24.4N/mm^2. The concrete made with recycled concrete waste aggregate sample OG, OY, S and I samples have maximum compressive strength of 18.0, 22.8, 24.3 and 17.5N/mm^2 respectively at 28th day. The compressive strengths of OY and S samples were almost equal that of natural crushed stone aggregates.

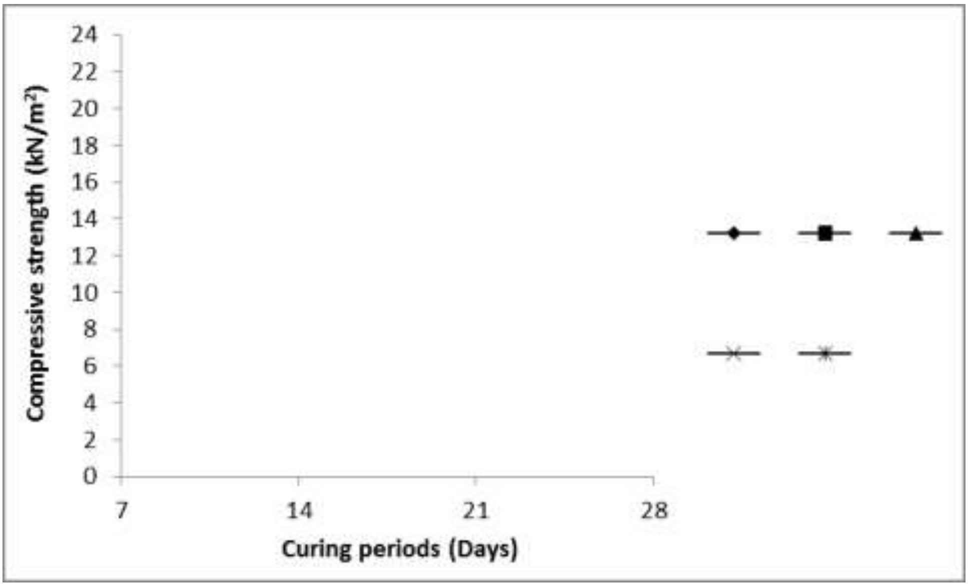

Figure 3 Variation of the compressive strength of concretes with curing days

The results are in agreement with the conclusion of (Okafor, 2010; Katz, 2003) that the strength of concrete with recycled aggregates could be only the same or lower but cannot be higher to that of concrete made from natural crushed stone aggregate. The changes might be attributed to the differences in the qualities of the materials and the concrete itself from which the recycled concrete waste aggregates are produced and which invariably governs the properties of the concrete made from recycled concrete waste aggregate.

4.0 Conclusions and Recommendations

In this work the potential for reclaiming and recycling hardened concrete waste from construction sites for use in value added application to maximize economic and environmental benefit has been experimented and the following conclusions were made:

i. Fresh concrete made with recycled concrete waste aggregates tends to be plastic and less workable compared to concrete made with fresh aggregate, they exhibit higher water absorption due to previous bonding of cement paste on the aggregate surface.

ii. The compressive strength of concrete produced with recycled concrete waste aggregates increases with curing day irrespective of the aggregate type.

iii. There are variations in the compressive strength of concretes made with recycled concrete waste aggregates depending on the location of collection which ascertains the fact quality of mix and workmanship affect greatly the quality of concrete produced and hence the quality of the concrete to be produce if the concrete waste generated from those productions were to be reused as aggregates.

Based on these facts, while accepting the need to promote its usage in wider application, it must be ascertained that the aggregate for concrete application must meet the requirement set in relevant specification for its particular use because recycled concrete waste aggregate may result in higher absorption, water demand, shrinkage and creep, lower density, durability, permeability and strength. Hence concrete made from such aggregates could be used for a wide range of civil engineering works of high structural integrity if they are confirmed to be of excellent qualities otherwise while they should be used only in low strength required works like walkways and kerbs production in road construction, backfilling, low-grade concrete production, or in low-cost housing.

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Appendices

Table 1: Sieve analysis for natural granite N (not greater than 25mm)

Sieve diameter (mm)	Mass retained (g)	Percentage retained %	Cumulative % passing	Percentage passing %
25.00	0.00	0.00	0.00	100
19.00	562	32.77	32.77	67.23
13.20	5000	30.05	62.82	37. 18
9.50	1544	17.47	80.29	19.71
6.30	1368	15.46	95.75	4.25
4.75	231	3.18	98.93	1.07
Receiver	95	1.07	100.0	0
Total	8850	100		

Table 2: Sieve analysis for sample OG (not greater than 25mm)

Sieve diameter (mm)	Mass retained (g)	Percentage retained%	Cumulative percentage%	Percentage passing%
25.00	0.00	0.00	0.00	100
19.00	3590	56.51	56.51	43.49
13.2	1629	25.64	82.15	17.85
9.5	690	10.86	93.01	6.99
6.3	299	4.71	97.72	2.28
4.75	35	0.55	98.27	1.73
Receiver	110	1.73	100	0.00
Total	6353	100		

Table 3: Sieve analysis for sample OY (not greater than 25mm recycled aggregate)

Sieve diameter (mm)	Mass retained (g)	Percentage retained%	Cumulative percentage%	Percentage passing%
25.00	0.00	0.00	0.00	100
19.00	2161	31.36	31.36	68.64
13.20	1874	27.20	58.56	41.44
9.50	1006	14.60	73.16	26.84

6.30	758	11.00	84.16	15.84
4.75	266	3.86	88.02	11.90
Receiver	825	11.97	100	0.00
Total	6890	100		

Table 4: Sieve analysis for sample S (not greater than 25mm recycled Aggregate)

Sieve diameter (mm)	**Mass retained (g)**	**Percentage retained%**	**Cumulative percentage%**	**Percentage passing%**
25.00	0.00	0.00	0.00	100
19.00	2730	34.07	34.07	65.93
13.20	1752	21.87	55.94	44.06
9.50	959	11.97	67.91	32.09
6.30	764	9.54	77.45	22.55
4.75	452	5.64	83.09	16.91
Receiver	1354	16.90	100	0.00
Total	8011	100		

Table 5: Sieve analysis for sample I (not greater than 25mm recycled Aggregate)

Sieve diameter (mm)	Mass retained (g)	Percentage retained%	Cumulative percentage%	Percentage passing%
25.00	0.00	0.00	0.00	100
19.00	3340	34.46	34.46	65.54
13.20	2434	25.12	59.58	40.42
9.50	1365	14.09	73.67	26.33
6.30	856	8.83	82.50	17.50
4.75	267	2.76	85.26	14.74
Receiver	1429	14.75	100	0.00
Total	9691	100		