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Investigative Study of Recycled Aggregate Concrete as a Sustainable Waste Management Strategy in Nigeria

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Abstract
Derogation of waste is extremely significant in curtailing environmental menace evoked by human activities. Solid waste recycling and reuse are innate tenets in waste management with the aim of salvaging waste materials to wealth products. Concrete cubes of 150mm x 150mm x 150mm were cast with both fresh and recycled coarse aggregates for mix ratios of 1:2:4 and 1:1½:3 by weight. All mixtures were maintained at water/cement ratio of 0.55. The main property investigated was the compressive strength (f_{cu}), after curing for 7, 14, 21 and 28days, respectively. With mix ratio of 1:2:4, the f_{cu} values for fresh aggregate concrete were 25.33, 29.63, 31.83 and 34.82N/mm², respectively, while those for recycled aggregate concrete were 20.09, 25.33, 28.13 and 34.22N/mm², respectively. With mix ratio of 1:1½:3, the f_{cu} values for fresh aggregate concrete were 31.11, 34.08, 35.98 and 37.33N/mm², respectively, while those for recycled aggregate concrete were 29.18, 31.52, 33.33 and 36.89N/mm², respectively. Generally, the values obtained show that the average f_{cu} cast with fresh coarse aggregate is slightly greater than that cast with recycled coarse aggregate. Hence, despite the small discord in strength, fresh coarse aggregate is still the best in concrete construction work. Nevertheless, where the distance is prohibitive, reference can be made to recycled aggregates.

Keywords: *Civil Engineering; Concrete; Recycling; Sustainability; Waste Minimization*

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I. Introduction

Derogation of waste is extremely significant in curtailing environmental menace evoked by human vivacity. Solid waste recycling and reuse are innate tenets in waste management with the aim of salvaging waste materials to wealth products. indisputably, the practical application of these principles severs traversely all environmental related endeavors especially in civil engineering. Recycling is the deed of processing a used material for reuse in creating novel product[1]. Field statistics unwrap that, the exploration and use of fresh aggregate is procuring more and more intense with the advanced development in infrastructure[2]. In last tenner, lofty demand has been settled on building material[1]. This is an indication of heighten in population and thus evoking inveterate deficit in terms of building materials[3]. According to Masood *et al*, civil engineers have been dared to transmute industrial wastes to useful building and construction materials[4]. Chen *et al* suggested that to attenuate the use of probable aggregate, recycled aggregate can be used as substitute materials[5]. Poon *et al* unwrap that fresh aggregate is inseparable material for the construction and maintenance of buildings and other parts of infrastructures[6]. Concrete inclosing about 80% of aggregates by mass, construction projects utilized vast number of aggregates[4]. Nevertheless, by using recycled aggregate concrete from existing infrastructure as a partial or complete substitution for fresh aggregates in novel construction, there would be substantial reduction in the demand for new aggregates[7]. Recycled aggregates comprise of crushed graded inorganic particles processed from the demolished debris that had been used in constructions. These materials are developed generally from broken components like slab, beam, brick wall etc[8]. Masood *et al* has tested and instituted that recycled aggregate has the potential to be applied in concrete roads, drainage work, culverts, etc[4]. Concrete accrues the trunk construction material used in construction industries. Its eligibility and adaptability with respect to the changes in environment is such that it can conserve resources, protect the environment, economize, and lead to proper utilization of energy[9]. Elias-Ozkin suggested major emphasis must be laid on the use of waste and by-products of cement and concrete used for new constructions[9]. They further stated that utilization of recycled aggregates from construction and demolition waste was showing prospective application in construction as alternative to fresh aggregates[10]. The reasons that many investigations and analyses had been made on recycled aggregate are because recycled aggregate is easy to obtain in order to salvage the environmental menace[11]. Works on recycling of waste has emphasized that if old concrete has to be used in second generation concrete, the product should adhere to the requirement of compressive strength which primarily depends upon adhered mortar, water absorption, size of aggregate, age of curing and ratio of replacement, moisture condition[12]. The aim of this study is to salvage waste materials to wealth products with a view of establishing this strategy as a sustainable waste management strategy in the construction and demolition industries.

II. Material And Methods

Description of Study

The study is to investigate the viability of recycled aggregate in concrete which will serve as a sustainable strategy in construction waste management[12]. The Portland limestone cement of grade 42.5 was bought at Dums marbles and building materials complex located at No 12 Poly-Ihiagwa road. Fine aggregate that passed through 4.75mm sieve size was obtained from Otamiri River. Fresh coarse aggregate passing through 20mm sieve and retained in 4.75mm sieve was used. This aggregate was obtained from AbohUmuloloOkigwe-Owerri road Okigwe. Recycled coarse aggregate material was obtained from a demolished structure located at zone 6 AbohUmuloloOkigwe-Owerri road Okigwe. These samples were conveyed to the Civil Engineering Laboratory Services, Federal Polytechnic Nekede, Owerri, where the experiments were carried out. Care was exercised to ensure that both the fresh and recycled aggregates were products of the same geological formation.

Recycled coarse aggregate was prepared and impervious materials were removed. Aggregates were recovered from broken structural components such as slabs, beams, and columns. These components were crushed using steel hammer. After hammering the components, the aggregates were separated from hardened cement paste and mortar. It was sieved. The aggregate passing through 20mm sieve and retained on 4.75mm sieve were used as recycled aggregates[11].

The water used was collected from Civil Engineering Concrete laboratory.

Experimental Procedure

Batching

The method of batching adopted was batching by weight, whereby the weighing balance was used to ascertain the proportional quantity of each material with respect to the output of the design[12]. The mix ratios used were 1:2:4 and 1:1½:3. These mix ratios were used for concrete cubes that were prepared with both fresh coarse aggregate and recycled aggregates.

Sieve Analysis

This involved a rested column of sieves with wire mesh cloth. The column was typically placed on a mechanical shaker. The shaker shakes the column usually for about 30 minutes. The material on each sieve was weighed to give the percentage retained. The size of average particle on each sieve was analyzed to obtain the result of the test which was used to describe the properties of the aggregate.

Slump Test

The cone was placed on a hard non- absorbent surface, filled with concrete in three layers. The concrete was tamped 25 times with tampering rod in each layer. At the end of the third layer, concrete was struck off to flush with top of the cone. The cone was carefully lifted vertically upwards so as not to disturb the concrete cone. The concrete cone subsidence is termed as slump and was measured in millimeters.

Mix Proportions

This was carried out on cube size of 150mm x 150mm x 150mm. The mixing of concrete was by hand/shovel. Cement and fine aggregate were mixed on a water-tight non-absorbent platform until the mixture was thoroughly blended and of uniform color. Coarse aggregate was added and mixed uniformly. Water was added and mixed thoroughly until the concrete appeared to be homogeneous and of the desired consistency. Moulds were applied with oil and concrete was filled in them in layers approximately 50mm thick. It was compacted with tampering rod for 35strokes per layer. The top surface was levelled and smoothened. A total of four series of concrete mixtures were prepared in the laboratory with two different mix ratios of 1:2:4 and 1:1½:3. The concrete mixtures in series one and two were prepared with fresh coarse aggregate to produce twenty-four concrete cubes with each mix ratio having twelve cubes. The mixtures in the third and fourth series were prepared with recycled aggregate to produce equivalent concrete cubes in the mix ratios of 1:2:4 and 1:1½:3.

Curing and Testing Work

After casting, the test specimens were stored in moist air for 24hours. After this period, the specimens were marked and removed from the moulds and kept submerged in water until taken out prior to test.

Compressive Test

After each age of curing (7, 14, 21, and 28 days), the cubes were crushed with compression machine to determine their load bearing values. Load was applied gradually on the cube until the cube fails. Load, (kN) at the failure divided by the area, (m^2) of the cube gives the compressive strength of concrete.

$$\text{Compressive strength, } (kN/m^2) = \frac{P}{A} \quad 1$$

Where A= area of the cube in m^2, P= load in the cube in kN

III. Results

Sieve Analysis

The results of sieve analysis for fine and coarse aggregate summarized the angularity of aggregates. The particle size distribution curves (figure 1-3) of fine and coarse for fresh and recycled aggregates showed that aggregates used for this study complied with the standard, were well graded and are therefore suitable for making good concrete.

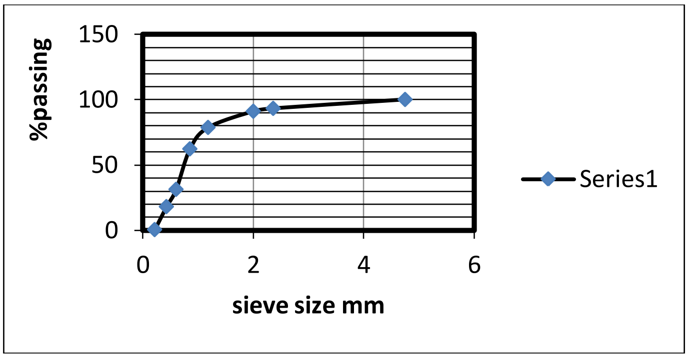

Figure 1: Graph of sieve analysis of fine aggregate

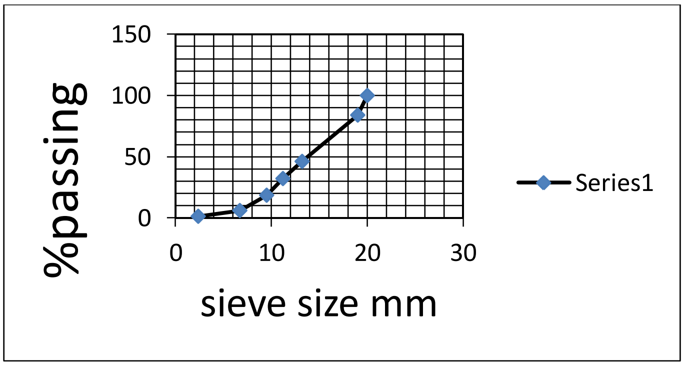

Figure 2: Graph of sieve analysis of fresh coarse aggregate

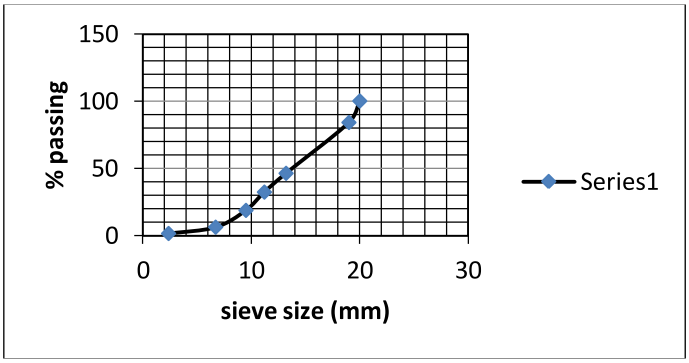

Figure 3: Graph of recycled coarse aggregate

Slump Test

The workability of concrete obtained from the slump test (table 1) shows that the value of concrete with fresh aggregate is greater than that of recycled aggregate.

Table 1: Result of slump test

Aggregates	**Values of slump(mm)**
Fresh coarse	18
Recycled coarse	15

Compressive Strength Tests

The compressive strength tests and average compressive results for Fresh and recycled aggregates are presented in table 2-5. From the tables, it was observed that the strength attainment at various days was gradual and then became very rapid at 21 and 28 days for the 1:2:4 and 1:1.5:3 mix ratios of the compressive strength.

Table 2: Compressive strength of concrete cast with fresh coarse aggregate (FA).
Mix ratio= 1:2:4

Cubes	Age of curing (days)	Weight of cube (kg)	Dimension (mm)	Density of concrete (kg/m³)	Area of cube (mm²)	Load (KN)	Compressive strength (N/mm²)	Average compressive strength (N/mm²)
FA7	7	8.4	150x150x150	2488.89	22500	452	20.09	
FA7	7	8.4	150x150x150	2488.89	22500	454	20.18	20.09
FA7	7	8.4	150x150x150	2488.89	22500	450	20	
FA14	14	8.6	150x150x150	2548.115	22500	570	25.33	
FA14	14	8.3	150x150x150	2429.63	22500	580	25.78	25.33
FA14	14	8.2	150150x150	2459.26	22500	560	24.89	
FA21	21	8.4	150x150x150	2488.89	22500	630	28	
FA21	21	8.2	150x150x150	2429.63	22500	630	28	28.13
FA21	21	8.3	150x150x150	2429.63	22500	640	28.4	
FA28	28	8.5	150x150x150	2518.52	22500	780	34.67	
FA28	28	8.5	150x150x150	2518.5	22500	760	33.78	34.22
FA28	28	8.6	150x150x150	2548.15	22500	770	34.22	

Table 3: compressive strength of concrete cast with recycled coarse aggregate (RA). Mix ratio 1:2:4

Cubes	Age of concrete (days)	Weight (kg)	dimension (mm)	Density (kg/m³)	Area mm²	Load KN	Compressive strength N/mm²	Average strength N/mm²
RA7	7	7.9	150x150x150	2326.36	22500	570	25.33	
RA7	7	7.6	150X150X150	2207.41	22500	560	24.89	25.33
RA7	7	8.2	150x150x150	2429.63	22500	580	25.78	
RA14	14	8.2	150x150x150	2429.63	22500	660	29.33	
RA14	14	8.05	150x150x150	2385.19	22500	660	29.33	29.63
RA14	14	8	150x150150	2370.37	22500	680	30.22	
RA21	21	8	150x150x150	2370.37	22500	700	31.11	
RA21	21	8	150x150x150	2370.37	22500	705	31.33	31.33
RA21	21	7.8	150x150x150	2311.11	22500	710	31.56	
RA28	28	8.2	150x150x150	2429.63	22500	780	34.67	
RA28	28	8.4	150x150x150	2488.89	22500	780	34.67	34.82
RA28	28	8	150x150x150	2370.37	22500	790	35.11	

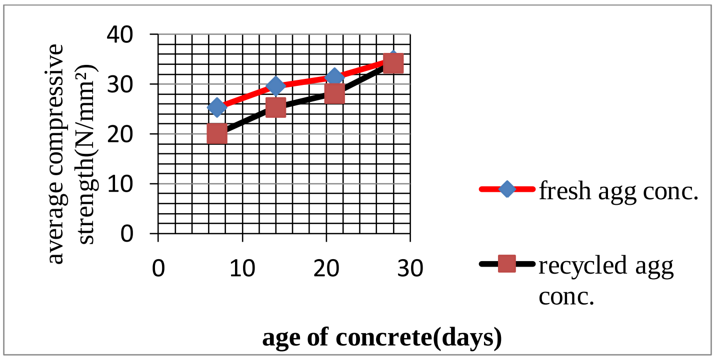

Figure 4: Graph of concrete strength with mix ratio of 1:2:4

Table 4: Compressive strength of concrete cast with fresh coarse aggregate (FA) Mix ratio 1:1½:3

Cubes	Age of concrete (days)	Weight kg	Dimension mm	Density Kg/m³	Area mm²	Load KN	Strength KN/mm²	
FA7	7	8.4	150x150x150	2488.79	22500	700	31.11	
FA7	7	8.6	150x150x150	2548.15	22500	710	31.56	31.11
FA7	7	8.4	150x150x150	2488.69	22500	690	30.67	
FA14	14	8.6	150x150x150	2548.15	22500	780	34.67	
FA14	14	8.4	150x150x150	2488.89	22500	780	34.67	34.08
FA14	14	8.4	150x150x150	2488.89	22500	740	32.89	
FA21	21	8.6	150x150x150	2548.15	22500	809	36	
FA21	21	8.6	150x150x150	2548.15	22500	811	36.04	35.98
FA21	21	8.4	150x150x150	2488.89	22500	808	35.9	
FA28	28	8.4	150x150x150	2488.89	22500	840	37.33	
FA28	28	8.5	150x150x150	2518.52	22500	820	36.44	37.33
FA28	28	8.6	150x150x150	2548.15	22500	860	38.22	

Table 5: Compressive strength of concrete cast with recycled coarse aggregate (RA).
Mix ratio 1:1½:3

Cubes	Age of concrete (days)	Weight Kg	Dimension mm	Density Kg/mm	Area mm²	Load KN	Strength N/mm²	Average strength
RA7	7	8	150x150x150	2370.37	22500	630	28	
RA7	7	8.2	150x150x150	2429.63	22500	680	30.22	29.18
RA7	7	8.2	150x150x150	2429.63	22500	660	29.33	
RA14	14	8.o5	150x150x150	2385.19	22500	700	31	
RA14	14	8.2	150x150x150	2429.63	22500	720	32	31.52
RA14	14	8	150x150x150	2370.37	22500	710	31.56	
RA21	21	8.4	150x150x150	2488.89	22500	730	32.44	
RA21	21	8	150x150x150	2370.37	22500	740	32.89	33.33
RA21	21	8.2	150x150x150	2429.63	22500	780	34.67	
RA28	28	8.2	150x150x150	2429.63	22500	840	37.33	
RA28	28	8	150x150x150	2370.37	22500	820	36.44	36.89
RA28	28	8.2	150x150x150	2429.63	22500	830	36.89	

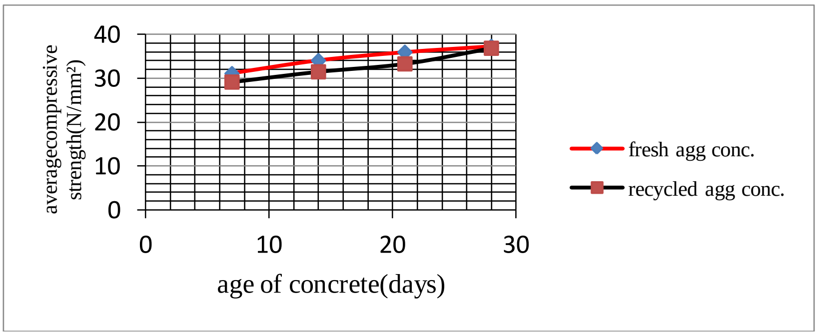

Figure 5: Graph of concrete strength with mix ratio of 1:1½:3

IV. Discussion

The aggregate size used for the study is 20mm and from the values obtained (figure 1-3), it is found that the angularity number of conventional aggregates is higher than that of recycled aggregate (RA). Thus, the higher the angularity number, more angular and less workable is the aggregate mix. In cement concrete mix, rounded aggregates may be preferred because of better workability, lesser specific surface and higher strength for particular cement content. However, the slump value (table 1) is an indication of water absorption by recycled aggregate which shows poor workability. Therefore, fresh coarse aggregate is better than recycled coarse aggregate in concrete works. Nevertheless, the positive of the compressive strength can be attributed to the mechanical properties of the aggregates. The average compressive strength for 1:2:4 mix ratio for fresh aggregates (figure 4) shows the results of cube crushing at 7, 14, 21 and 28 days respectively. Table 4 and 5 shows the compressive strength result for recycled aggregate at 1:1.5:3 mix ratio at the different curing days of 7, 14, 21, and 28 days respectively. However, it was observed that the average strength of recycled aggregate concrete (table 4-5) is slightly less than that of fresh aggregate concrete (table 3-4). This is an indication that the strength of recycled aggregate concrete (figure 5) is encouraging and therefore recycled aggregate can be a substitute to fresh aggregate in construction works.

V. Conclusion

The study unwraps a greater discord in average compressive strength of probable coarse aggregate concrete than recycled coarse aggregate concrete. In line with Tighare et al, the workability of concrete incurred from the slump test (table 1) divulged that the value of concrete with probable (fresh) aggregate is way higher than that of recycled aggregate[7]. Sahan et al describe that the significant upshot in water absorption by recycled aggregate indicates poor workability[12]. Whence, probable coarse aggregate is more suitable than recycled coarse aggregate in concrete works[10]. According to Turkey et al the use of recycled aggregate in concrete has heightened the mechanical properties of concrete[10]. Additionally, its strength increases as the age increases, unlike that in the mix 1:1½:3, which change. By and large, strength of recycled aggregate concrete is inciting and can be a commute to fresh aggregate in construction works.

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