EFFECT OF PARTIAL SUBSTITUTE OF COARSE AGGREGATE WITH RECYCLED AGGREGATE ON CONCRETE STRENGTH

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ABSTRACT

An investigation into the use of recycled aggregate from crushed graded inorganic particles processed from used construction materials and demolition debris is reported. Six batches of concrete mixes with varying content of recycled aggregate from 0% to 100% in steps of 20% were used. Physical property tests including specific gravity, moisture content, sieve analysis, shape index, fineness modulus, fines content, flakiness index, uniformity coefficient, Los Angeles Abrasion, water absorption capacity were carried out on the constituent materials of the concrete. The slump test to determine the workability of the mixes was also carried out. The compressive strength property and characteristics for the different mixes was studied. The test was carried out on both cylinder and cube specimens.

Results showed that workability and compressive strength of concrete mixes decrease with increase in percentage content of recycled aggregate in the concrete. However, the concrete produced with recycled aggregate recorded density values over 2400 kg/m^3 while non of the cube strength is less than 20 N/mm^2. As the value of slump decreased from 35mm at 0% level of recycled aggregate in concrete mix to 17mm at 100% level of recycled aggregate content, the average compressive strength also decreased by about 12%, 10% and 6% respectively for 7-, 14- and 28-day curing ages. However, for the cylinder specimens, the percentage reduction in strength was between 38.14% and 34.85% at 7- and 28-day curing ages respectively.

KEYWORDS: Recycle aggregate, concrete, demolition debris, slump test, density, compressive strength.

1.0 INTRODUCTION

The increasing cost of concrete as construction material has become a major challenge to experts in the construction industry. Many attempts have been made to replace one of the components of normal concrete due to economic and/or design consideration. This development has led to the consideration of recycled aggregate as a possible replacement for normal coarse aggregate in concrete. Recycled aggregate which principally consists of crushed, graded inorganic particles, processed from materials that are waste products from construction or demolition sites are readily available and could be sourced from building, roads and bridge construction sites, as well as from places of catastrophic events like war situations, earthquakes zones and collapsed buildings and structure sites. Traditionally, recycled aggregate is used as landfill material. Today, the applications of recycled aggregate in construction have broadened. Jacob Mehus et al. [1] reported in their report on 'The Norwegian research and development project RESIBA – Recycled Aggregate for Construction and Building', that the materials are used as granular base course in road construction. They also opined that recycled material helps stabilize the base and provide an improved working surface for pavement structure construction.

Also, according to market development study carried out by Thurber Engineering Ltd. [2], recycled aggregate could be readily used as granular base course in road construction. Also the material could be applied to wetlands or sub-base area to help stabilize weak and heavy moisture laden sub-base materials. The study further revealed that recycle aggregate can be used in embankment fill.

Investigations have also been carried out and trial projects commissioned in Hong Kong [3], on the use of recycled aggregate in manufacture of paving blocks as well as building blocks. According to the Department for Environment, Food and Rural Affairs [4], recycled aggregate may also be used in the construction of byways. Mehus et al. [5], report on many advantages associated with the used of recycled aggregate as construction material; the major advantage being the environmental gains derived.

Kajima Technical Research Institute [6] opined that recycling process can be done on site to save energy. Their procedure saves energy on transportation of recycled material to and from site. Also by sustaining the tempo of production and usage of recycled aggregate, there will be considerable reduction in the quantity of materials for dump sites.

Peter Grubl et al [7], reported the experiences encountered in the second building project made from concrete with recycled aggregate, and concluded that concrete made with recycled aggregate can be used in many structural applications requiring strength up to 35 N/mm^2. It was also noted that recycled aggregate concrete can be pumped on sites like normal aggregate concrete. Limbachiya, Leelawat and Dhir [8], reported on results of tests study on the use of recycled concrete aggregate (RCA) in high-strength of 50N/mm^2 or greater. The results show that up to 30% coarse RCA had no effect on concrete strength, but there after, there was a gradual reduction in strength as the RCA content increased. They recommended a method for accommodating the effects of high RCA content involving simple adjustment to water/cement ratio of the mix. They stated that high-strength RCA concrete will have equivalent engineering and durability performance to concrete made with natural aggregates, for corresponding 28-day design strengths. They also observed that recycled aggregate concrete had 7.0 to 9.0 percent higher relative density and two times higher water absorption capacity than normal aggregate.

Xiao and Zhang [9], presented a statistical analysis of the compressive strength of recycle aggregate concrete (RAC) with recycled coarse aggregate from the same source. They concluded that the statistical characteristics of the compressive strength of recycled aggregate concrete do not differ very much from those of normal concrete with similar strength, irrespective of the content of the recycled aggregate. Belen Gonzales-Fonteboa and Fernando Martinez-Abella [10], reported on the shear behaviour of concrete made with recycled concrete aggregates. The tests results showed that the deflections and the ultimate loads were not significantly affected by the different types of concrete aggregates, but in recycles aggregate beams, cracking was premature. Major Rakshvir and Sudhirkumar Barai [11], carried out investigation on recycled aggregates-based concretes and noted that reduced extraction of raw materials, reduced transportation cost, improved profits, reduced environmental impact as well as fast depleting reserves of conventional naturally occurring aggregates has necessitated the use of recycled aggregate in order to conserve existing reserves of normal aggregates. The results of study showed that properties such as compressive strength showed a decrease up to 10% as the percentage of recycled concrete aggregate. Also, water absorption of recycle concrete was found to be greater than natural aggregate, and this requires to be considered during mix design.

Matsushita et al [12], carried out experimental study on compressive strength and drying shrinkage of concrete with varying replacement level of recycle aggregate with normal aggregate and water/cement ratio. The results show that with increase in the percentage content of recycled aggregate in the mix, water requirement to achieve good workability also increased. They also reported that as the replacement ratio of the recycled aggregate increased, the drying shrinkage also increased. Similarly, Mandal S and Gupta A [13], observed that adjusting water/cement ratio when using recycled aggregate during the concrete mixing process can help improve the strength of recycled aggregate based concrete. Results of his investigation showed that recycled aggregate concrete specimens exhibited the same engineering and durability performance values when compared with concrete specimens made of normal, natural occurring aggregates within 28-day testing period.

Sawamoto Takehiro and Tsuji Maanori [14], reported that the strength of recycled aggregate concrete can be increased by using pozzolanic material that can absorb water.

Chen, Yen and Kuan [15], reported that the strength of concrete made of recycled aggregate is affected by unwashed recycled aggregate in the concrete. They further stated that the strength characteristics of recycled aggregate concrete can be improved upon by inclusion of fly ash in the concrete mix. Poon et al. [16], also reported in their investigations that the use of fly ash helps to improve the strength of concrete made from recycled aggregate. They reported specifically that with the use of fly ash in paving blocks, compressive strength of 49.0MP (49N/mm^2) at 28-day curing/testing age was achieved.

Many countries have done a lot of research on the use of different recycled materials in concrete. In Nigeria, due to high cost of concrete materials, developers and contractors arbitrarily use recycled aggregates from demolished structures and collapsed buildings in concrete without any technical information. The utilization of readily available recycled aggregates has great practical values and potentials in the construction industry as shown from various researches on the subject, however, properties of recycled aggregates will depend on the quality of the initial concrete which varies from one source to another and even the construction practice in each country. Considering the need to improve on cost effectiveness of structural components of building and in order to contribute meaningfully to achieving the millennium goal of "housing for all" by 2020", there is the need, therefore, to carry out studies on the structural characteristics of recycled aggregate in Nigeria as major component of concrete for structural elements. In this work, attention is focused on the preliminary properties and strength characteristics of recycled aggregates from demolished structures and collapsed building sites.

2.0 MATERIALS AND EXPERIMENTAL PROCEDURE

The river sand used for this study was collected from Ogun River Basin in Abeokuta, Ogun State. All particles passing BS sieve No.4 (aperture 4.75mm) but retained on sieve No. 220 (aperture 0.06mm) were used as fine aggregate. This ensured that the dust particles are removed from the sand.

The particle sizes for normal aggregate (granite chippings) which was obtained from a quarry in Ibadan was from 2.36mm to 19mm. The recycled aggregates were obtained from real demolition debris collected from sites of collapsed buildings in Lagos. Demolished concrete structural members were selected from the mass of rubbles and manually crushed with sledged hammers to sizes varying from 5.5mm to 25.0mm. The crushed recycled aggregate chippings were later sieved to ensure the removal of smaller particles that may otherwise be classified as fines. The cement is Ordinary Portland Cement (OPC) whose properties conform to the requirement of BS 12 [17]. Figure 1 shows the particle size distribution of both the fine and coarse aggregates. The results of the preliminary tests, carried out on the recycled aggregate and normal aggregate (granite chippings) as well as the fines, are shown in Table 1.

The mix proportion of 1:2:4 (cement: sand: granite chippings/recycled aggregate) by weight with water cement ratio of 0.6 was considered for this investigation. The proportion of recycled aggregate of the total coarse aggregate was varied from 0% to 100% in steps of 20% in the mixes. The water cement ratio was kept constant for each mix at all proportions of recycled aggregate to the coarse aggregate.

Fifty-four cubes of 150 x 150 x 150mm as well as fifty-four cylinders 100mm diameter were cast and tested. Batching was by weight. Mixing was done mechanically in a mobile rotating drum type mixer. After the final mixing, the workability of the fresh concrete was determined using slump test. The specimens were made in accordance with BS 1881 [18]. The specimens were de-moulded after 24 hrs for adequate setting of the mixes. They were then transferred into a large curing tank filled with clean water until the age of tests. The specimens were tested in accordance with BS 1881. The strength characteristics of each test specimen (cubes and cylinder) were determined at loading rate of 120kN/min on a 600 kN Avery Denison Universal Testing machine. Three specimens for each curing age (7,14 and 28 days) were brought out of the curing tank and allowed to dry for 2 hrs and then crushed. The average values of the maximum loads at which each group of three specimens failed were observed and then used to determine the compressive strength of each mix group.

3.0 RESULTS AND DISCUSSION

3.1 Physical Properties and Sieve Analysis.

The coefficient of curvature of the sand, granite and recycled concrete aggregates as shown in Table 1 are 1.5, 1.071 and 0.90 respectively. It showed that the sand and granite particles were better graded than the recycled aggregate materials in this experiment. More physical work has to be done on the material during hand crushing process in order to obtain a well graded recycled aggregate. A mechanical crushing system should be used, just as done in quarries, to obtain well graded recycled aggregate.

The recycled aggregates with shape index value of 0.22 were more roughly textured than the granite aggregate with shape index value of 0.19. The moisture content, determined in accordance to BS 1377 – part 2 [19], and water absorption capacity values for the recycled aggregate were 2.69 and 2.84 respectively. These are higher than the corresponding values for the granite and sand which recorded 1.92, 2.80 and 1.38, 2.69 respectively. This shows that the concrete materials from which the recycled aggregate were obtained were well compacted in the first instance. This probably also explains the relatively low difference in values obtained for the Los Angeles Abrasion and void ratio for the recycled aggregate when compared with the corresponding values for the granite and sand.

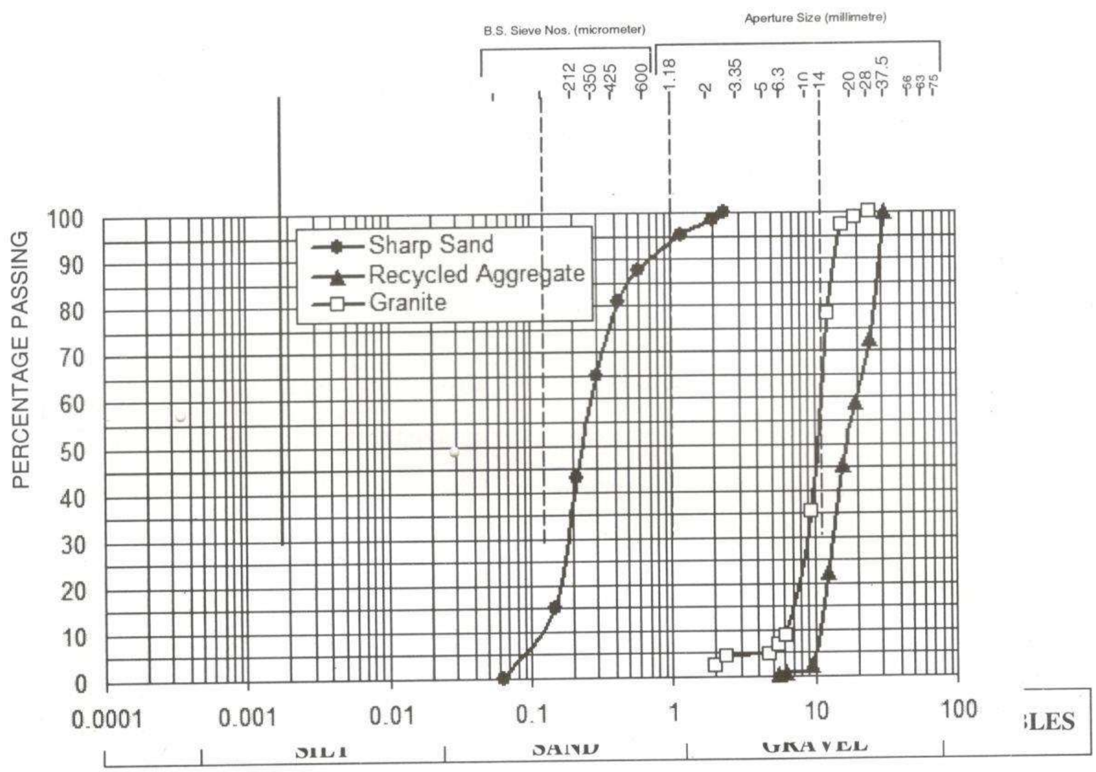

Figure 1. Particle Size Distribution Curves of Aggregates

Table 1: Physical Properties of Aggregates Used

	Sand	Granite	Recycled Aggregate
Shape Index	-	0.19	0.22
Fineness Modulus	3.15	5.63	5.04
Fines content (% passing through 0.063 sieve)	0.0	0.0	0.0
Flakiness Index (%)	-	10	7
Dry Density (kg/m^3)	2770.0	2667.37	2540.25
Water Saturated Surface Dry Density (kg/m^3)	2844.5	2742.06	2612.40
Moisture Content (%)	1.38	1.92	2.69
Water Absorption Capacity (%)	2.69	2.80	2.84
Los Angeles Abrasion (%)	-	25	28
Uniformity coefficient	-	1.3	1.92
Void Ratio	0.4	0.37	0.42

The sieve analysis results, as indicated in Figure 1, show that for fine, 98.4% of the aggregate passed through 2.0mm sieve with none passing through the 600 micron sieve. For the recycled aggregate, 95% of the aggregate passed through 38.1mm sieve while only 0.34% passed through 5.5mm sieve. The normal aggregate recorded 100% passing through 25mm sieve while 4.26% passed through the 2.36mm sieve. The results largely, indicate that the fine, normal and recycled aggregate were uniformly graded but there are more coarse particles in the recycled aggregate than in the granite.

3.2 Workability

Workability is the measure of the amount of useful internal work necessary to be done on concrete mix to produce full compaction. A standard measure of workability of wet concrete mix is the slump test. The workability of the fresh concrete, as determined by the slump test, for all the mix proportions with different percentages of recycled aggregate in coarse aggregate with constant water/cement ratio is presented in Table 2.

Table 2: Physical Characteristics of Concrete mixes with Different Percentages of Recycled Aggregate at Constant w/c Ratio.

% Recycled Aggregate in Coarse Aggregate	Slump (mm)	Average Density (kg/m^3) of Cube Specimens at Different Ages (Days)			Average Density (kg/m^3) of Cylinder Specimens at Different Ages (Days)		
		7	14	28	7	14	28
0	35	2488	2496	2560	2492	2498	2514
20	31	2471	2476	2524	2483	2485	2494
40	29	2455	2459	2502	2475	2479	2483
60	21	2446	2451	2497	2462	2472	2476
80	20	2440	2446	2488	2454	2459	2465
100	17	2440	2442	2478	2446	2452	2460

The slump test revealed a decreasing trend in workability with corresponding percentage increase of recycled aggregate. The test results showed that for less than 40% of recycled aggregate, the value of slump was greater than 25mm; an indication of a well blended and workable mix that could be easily placed. With water/cement ratio of 0.60, a replacement of normal aggregate with up to 80% recycled aggregate could be worked and placed as the height of the true slump is between 20 -29mm. however, adequate compaction is needed. A 100% replacement of normal aggregate with recycled aggregate at 0.6 w/c ratio results in a relatively very hard mix with honey combs. Although it showed no shear slump tendency, this mix could be difficult to work with.

3.3 Densities of Concrete with Recycled Aggregate

Table 2 showed the values of densities for cubes and cylinder specimens with different contents of recycled aggregates.

For the 100mm cylinder specimens and 150mm cubes, the obtained range of densities is between 2400 and 2600 kg/m^3. This is an indication that recycled aggregate could be used for production of dense concrete, just as normal aggregate. It was observed that as the percentage content of the recycled aggregate in the mix increased, the mean relative density of a set of test specimens decreased for all test ages; although the decrease is not appreciable as it was less than 5%. At 7-day curing age, the mean density of test specimens reduced from 2840 kg/m^3 at 0% of recycled aggregate in coarse aggregate to 2440 kg/m^3 at 100% of recycled aggregate, amounting to 1.93% reduction. However,

rate of decrease in mean density increased with curing age. At 14-day curing age, a reduction of 2.16% in value was noted between the values for 0% recycled aggregate and 100% recycled aggregate where for 28-day curing age, a reduction of 3.20% in value of mean density was observed. These results showed that the moisture content and moisture absorption tendency of the specimens increased with curing age, thus resulting into increase in weight and density of test specimens with age. It should be noted that as the values of workability of the mixes reduced, the specimens will record reduced weight as a result of increase in the volume of pores in the concrete matrix.

3.4 Effect of Content of Recycled Aggregate on Compressive Strength

Table 3 shows the strength with variation in content of recycled aggregate. For the tested cylinder specimens, for all test ages, the compressive strength of the concrete decreased with increase in the percentage content of the recycled aggregate for both cube and cylinder specimens. At 7-day curing age, with 0% recycled aggregate content, the cube compressive strength was 23.11 N/mm^2. With 20%, 40% and 60% recycled aggregate content, the compressive strength was 22.31, 21.78 and 21.48 N/mm^2 respectively; showing a reduction of 3.46%, 5.76% and 7.05% respectively when compared with mix of 0% recycled aggregate.

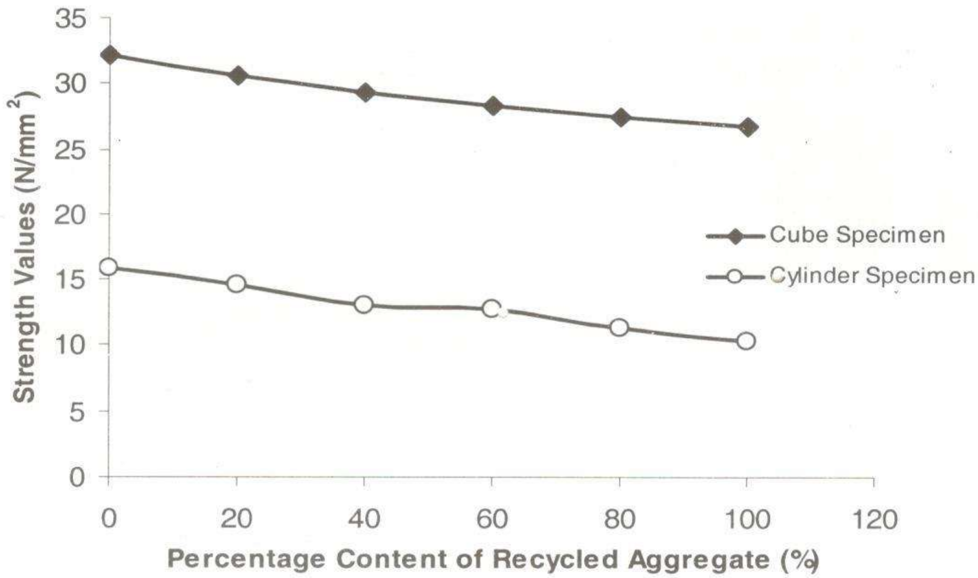

Figure 2. Strength Variation With Percentage Content of Recycled Aggregate

For 80% and 100% recycled aggregate content, the observed reduction in compressive strength was 8.96% and 11.55% respectively. At 28-day test age, the trend in reduction of compressive strength was same. It was observed that the compressive strength reduced from 30.67 N/mm^2 at 0% recycled aggregate content to 28.30 and 26.85 N/mm^2 at 60% and 100% respectively recycled aggregate content, indicating a 7.73% and 12.46% reduction in compressive strength values.

The short-term variation in strength values of mixes for cylinder specimens with different percentages of recycled aggregate contents relative to 0% recycled aggregate content mix at different curing ages is shown also in Figure 2. It was also observed that with increase in the percentage replacement of normal aggregate with recycled aggregate, there was a corresponding reduction in the compressive strength of the cylinder specimens, just as for the cube specimens. Also, the compressive strength of the test specimens increased with increase in the curing age. The rate (slope) of increase in compressive strength reduces with age and behaved just like the cube specimens.

3.4 Compressive Strength with Curing Age of Cube and Cylinder Specimens

Table 3 shows the variation in strength with age as the percentage content of recycled aggregate increases in cubes and cylinder specimens. As in normal concrete, it was observed that the curing age had a significant effect on the strength development characteristics of the concrete.

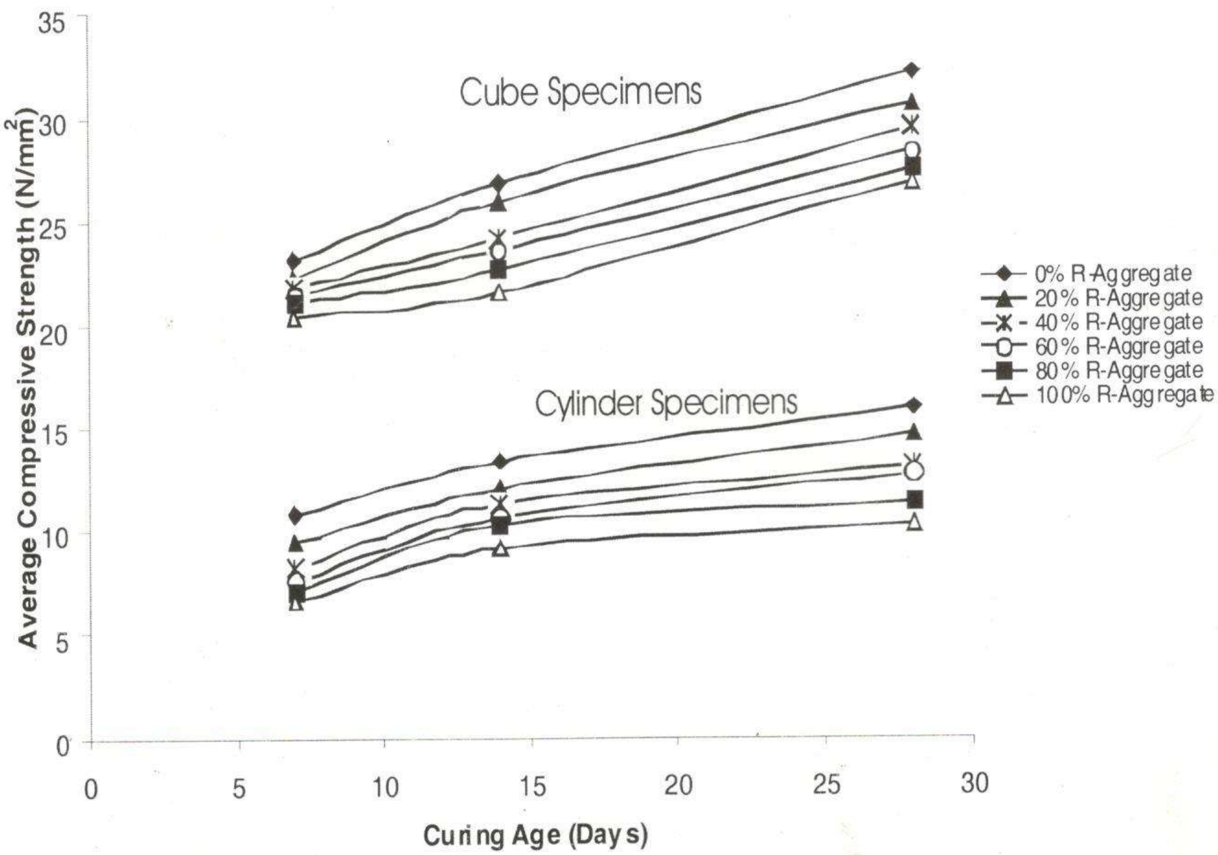

Figure 3. Effect of Curing Age on the Compressive Strength

However, the behaviour with different content of recycled aggregate is similar and show a near linear relationship as shown in Figure 2. In Table 3, for 0% recycled aggregate mix the compressive strength at 7-day and 14-day curing ages for cubes were 23.11 and 26.83 N/mm^2 respectively, indicating a 16.05% increase in strength within 7 days. This trend in increase of compressive strength with increase in curing age was also observed at 28-day curing age which recorded an increase of 39.12% and 19.87% when compared to the strength at 7 and 14-day curing ages respectively.

It was further observed that between the 14th and 28th-day curing ages, variation of compressive strength development in all tests cube specimens showed a near linear relationship as well as further percentage increase. This is an indication that the rate of growth in strength in the test specimens for all mix proportions during the time interval being considered was same; irrespective of the percentage content of the recycled aggregate. Also, none of the test cubes compressive strength observed was less than 20N/mm^2.

Table 3: Summary of Variation of Average Compressive Strength (N/mm^2) with Age

Type of Specimen	Age (Days)	Compressive strength (N/mm2)					
		Percentage Replacement With Recycled Aggregate (%)					
		0	20	40	60	80	100
50mm Cube	7	23.11	22.31	21.78	21.48	21.04	20.44
	14	26.82	25.93	24.15	23.56	22.67	21.50
	28	32.15	30.67	29.40	28.30	27.50	26.85
100mm diameter Cylinder	7	10.82	9.55	8.27	7.64	7.01	6.65
	14	13.37	12.10	11.32	10.64	10.32	9.18
	28	15.84	14.65	13.10	12.74	11.35	10.32

These same trends were also observed in the strength development characteristics of the cylinder specimens; though the strength characteristics displayed by the cylinder specimens were considerably lower, as expected, than those of cube specimens for all curing ages. It is observed that in all test cases and for all curing ages, the compressive strength of cube specimens recorded were at least 75% more than the compressive strength of corresponding cylinder specimen of the same age. This could be attributed to 'shear' failure tendency of the cylinder test specimens as a result of the relatively high value of diameter/high ratio of 3. For the cube specimens, the diameter/height ratio was equal to 1. With increase in the ratio, the specimens tend to fail in shear rather than in compression.

4.0 CONCLUSIONS & RECOMMENDATIONS

From the experimental results, the following conclusions can be made.

i. The physical properties of recycled aggregates are well comparable with the normal coarse aggregate (granite)

ii The workability of concrete made from recycled aggregate as coarse aggregate decreases with corresponding percentage increase of recycled aggregate. This can be attributed to the high absorption capacity of the recycled aggregate when compared to normal aggregate, hence, the water/cement ratio should be considered in effective usage of recycled aggregate. For example a 1:2:4 mix proportion, for a moderate workable mix, it is desirable that the percentage replacement of normal aggregate with recycled aggregate be kept within 50%, with water/cement ratio of 0.70.

iii. With increase in the percentage of recycled aggregate, the compressive strength reduced slightly. However, none of the strength, even with 100% recycled aggregate is less than 20 N/mm^2; showing that the concrete with recycled aggregate can be used in low rise structures. The results also show that the recycled aggregate concrete falls within the rage of normal weight concrete as the density is not less than 2400 kg/m^3.

iv. Mechanical crushing and sorting machines should be used to produce the recycled aggregate chippings as this will reduce overall labour inputs as well as guaranteeing the production of well graded aggregate.

The physical properties of recycled

It is recommended that further investigations be conducted on flexural characteristics, bond strength as well as shear strength of structural concrete elements in which granite is replaced wholly or partially with recycled aggregate.

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