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EFFECT OF PARTIAL REPLACEMENT OF GRANITE WITH WASHED GRAVEL ON THE CHARACTERISTIC STRENGTH AND WORKABILITY OF CONCRETE

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ABSTRACT

In this paper, the effects of partial replacement of crushed granite as coarse aggregate with washed gravel on the strength and workability of concrete are reported. 1:2:4 concrete mix (Cement: Fine Aggregate: Coarse Aggregate) was used, with a water/cement ratio of 0.65. Six batches of concrete were produced in which the granite was progressively replaced with washed gravel at intervals of 20 percent, from 0% to 100% replacement level. (0% replacement was the control). Twelve (12) nos. 150x150x150 mm concrete cubes were cast from each batch and cured in a water tank at room temperature. The cubes were crushed for strength in sets of three at curing ages of 7, 14, 21, and 28 days, respectively. A slump test was carried out on each batch. It was observed that the workability of the concrete decreased with increase in gravel content. Also, it was observed that for all curing ages, as the percentage replacement level increased, the compressive strength of the concrete increased to a maximum at 20 percent replacement level. Thereafter, it decreased as the replacement level increased to 100%. The maximum 28-day compressive strength at 20% replacement level was 37.2 N/mm^2; indicating a 54% increase when compared to the 28-day strength of the control mix (24.2 N/mm^2). The results also showed that the 28-day strengths of 100% granite concrete and 100% gravel concrete were comparable.

Keywords: granite, gravel, concrete, compressive strength, slump.

INTRODUCTION

In an attempt to reduce the high cost of providing housing in Nigeria, researchers are searching for less expensive alternatives to the traditional materials employed in the construction industry. Thus local gravel is being increasingly used as coarse aggregate in place of the more expensive crushed granite in the production of concrete in parts of the country where it is found. Research is on-going on the properties of such concrete, but this work reports the results of an investigation into the properties of concrete in which crushed granite is partially replaced as coarse aggregate with washed gravel. Akpokodje and Hudec [1] carried out studies on the compressive strength and expansion of concrete made with concretionary laterite gravels found in the Port-Harcourt (south eastern) area of Nigeria. They reported compressive strengths which ranged from 19 to 42 N/mm^2.

Falade [2] investigated the use of periwinkle shells as coarse aggregate in concrete, and found that the compressive and flexural strengths decreased with increase in proportion of periwinkle shells to granite. He concluded from density measurements that periwinkle shells could be considered as lightweight aggregate. Adewuyi and Adegoke [3] also investigated the suitability of periwinkle shells as partial or full replacement for granite in concrete. They opined that 35.4% and 42.5% of the periwinkle shells in replacement for granite was quite satisfactory without compromising the compressive strength requirements for concrete mix ratios 1:2:4 and 1:3:6. Udoh [4] studied the effects of using periwinkle and palm kernel shells as coarse aggregate on the properties of concrete and concluded that the resulting concrete would be suitable for road work where power vibration machines were more common. Agbede and Manasseh [5] reported studies on the use of periwinkle shells as partial replacement for river gravel in concrete. They observed that the workability and the compressive strength of periwinkle shell concrete increased with increasing inclusion of river gravel, and concluded that periwinkle shells could be used as partial replacement for river gravel in normal construction works especially in places where river gravel is in short supply and periwinkle shells are readily available.

Ata *et al*., [6] investigated the strength characteristics of concrete produced with coconut shells and palm kernel shells as coarse aggregate. They found that resulting concrete strengths were comparable to those obtained with natural coarse aggregates. Mahmud *et al*., [7] studied the mechanical properties of palm kernel shell concrete as sand/cement ratio was varied. Concrete densities measured at 28 days ranged between 1850 and 1960 kg/m^3 and the 28-day strengths between 28 and 38 N/mm^2. The results of their studies also showed that when the sand to cement ratio was increased from 1.0 to 1.6, the 28 day compressive strength increased by about 24%, and the density by about 4%.

Zeghichi [8] investigated the effect of replacement of natural aggregates with slag aggregate, and found that partial replacement resulted in increased concrete strength while total replacement reduced the strength.

Rifath *et al*., [9] compared the strengths of concretes made with crushed and uncrushed coarse aggregate. They showed that for the same workability, the strength of uncrushed aggregate concrete exceeded that of crushed aggregate by 22% at the age of 28 days.

Katz and Baum [10] investigated the effect of using high quantities of fine aggregate - material passing the 0.075 mm sieve - in the production of concrete with constant workability. They found that increasing the fines content to up to 227 kg/m^3 increased the concrete strength by as much as 30%. Waziri and Mua'zu [11] investigated the strength properties of concrete when quarry sand is used as fine aggregate. They noted that quarry sand could be used with satisfactory results as fine aggregate in the production of concrete. Neptune and Putman [12] reported on their investigation on the effects of aggregate size and gradation on the unit weight, strength, porosity, and permeability of pervious concrete mixtures. With a constant water-cement ratio of 0.29, a constant cement-aggregate ratio of 0.22, and a design unit weight of 2002 kg/m^3, they found that as the porosity increased, the strength decreased and permeability increased. They also found that there was an optimum gradation at which the strength of the pervious concrete reached a maximum and the permeability reached a minimum.

MATERIALS AND METHODS

The cement used in this investigation was Ordinary Portland Cement whose properties conformed to BS 12 [13]. Ogun River sand, with particles passing through 5mm sieve but retained on 75 micron sieve was used as fine aggregate. The coarse aggregates were crushed granite passing through 20 mm sieve and retained on 6.3 mm sieve, and gravel (supplied as unwashed) passing through 20 mm sieve and retained on 600 micron sieve. The gravel was washed free of all mud silt and dust, and air- dried. The particle size distribution of the sand, the gravel and the granite was determined. The Coefficient of Uniformity (C_u) and Coefficient of Curvature (C_c) which are used to standardize gradation criteria for the sand, gravel and granite are obtained from the relationships $C_u = (D_{60}/D_{10})$ and $C_c = ((D_{30})^2/(D_{60} * D_{10}))$; where D_{60} = diameter in millimeters of the 60% passing size, D_{30} = diameter in millimeters of the 30% passing size and D_{10} = diameter in millimeters of the 10% passing size [14]. Moisture content measurements were carried out on all the aggregates. The water used was obtained from the taps at the Concrete Laboratory, Department of Civil and Environmental Engineering, University of Lagos.

The control test samples of 1:2:4 concrete mix (Cement: Fine Aggregate: Course Aggregate) were produced with granite as coarse aggregate. Subsequent test samples were produced with gravel progressively replacing the granite at 20% intervals by weight. The water/cement ratio was kept constant at 0.65 throughout the investigation. Twelve (12) nos. 150 x 150 x 150 mm cubes were cast from each mix and cured in water in accordance with BS 1881 [15]. The test samples (cubes) were crushed at 7, 14, 21, and 28-day curing ages to determine their compressive strengths.

The slump test was carried out on the fresh concrete test specimens to determine the consistency. The mould for the slump test measures 305 mm in height. The base diameter is 203 mm while the smaller opening at the top is 102 mm. the slump cone was filled in three layers, tamping between each 25 times with a 16 mm diameter rod to remove voids. The concrete was levelled off with the top of the cone. With the cone removed, the height of the slump was then measured.

RESULTS AND DISCUSSIONS

Sieve analyses and physical properties

Figure-1 shows the grading curves obtained for the sand, gravel and granite respectively.

The results of preliminary tests on the concrete constituent materials showed that the granite coarse aggregate ranged in particle sizes from 6.3 to 19.0 mm with specific gravity of 2.63, uniformity coefficient of 1.50, coefficient of curvature of 0.78 and fineness modulus of 6.97.

The gravel coarse aggregate ranged in particle size from 0.60 to 19.0 mm with specific gravity of 2.40, uniformity coefficient of 2.32, coefficient of curvature of 1.00 and fineness modulus of 5.54. The particle sizes of the sand were those passing the 4.75 mm sieve and retained on the 75 µm sieve; it had a specific gravity of 2.3, a uniformity coefficient of 2.84, a coefficient of curvature of 1.20, and a fineness modulus of 2.89. The moisture contents of the granite, gravel and sand were 0.02, 0.10 and 0.03%, respectively.

Slump test

The results of the slump test showed that all the mixes indicated true slump, irrespective of the percentage replacement of granite with gravel. At 0% replacement level, the concrete mix gave a slump value of 40 mm. The slump decreased as percentage replacement level increased from 0% to 100% at 20% interval. The slump values are 40, 32, 15, 6, 4 and 3 mm for 0, 20, 40, 60, 80 and 100% replacement levels, respectively.

A comparison of the grading curves for gravel and granite (Figure-1) shows that the gravel particles are generally finer than those of granite. For the same weight therefore, the gravel possesses a greater surface area than the granite. Hence more water is required to saturate the aggregate, and the result is that the workability of the concrete is reduced. The greater the percentage replacement of the granite with gravel in the concrete, the less the workability of the concrete as indicated by the slump.

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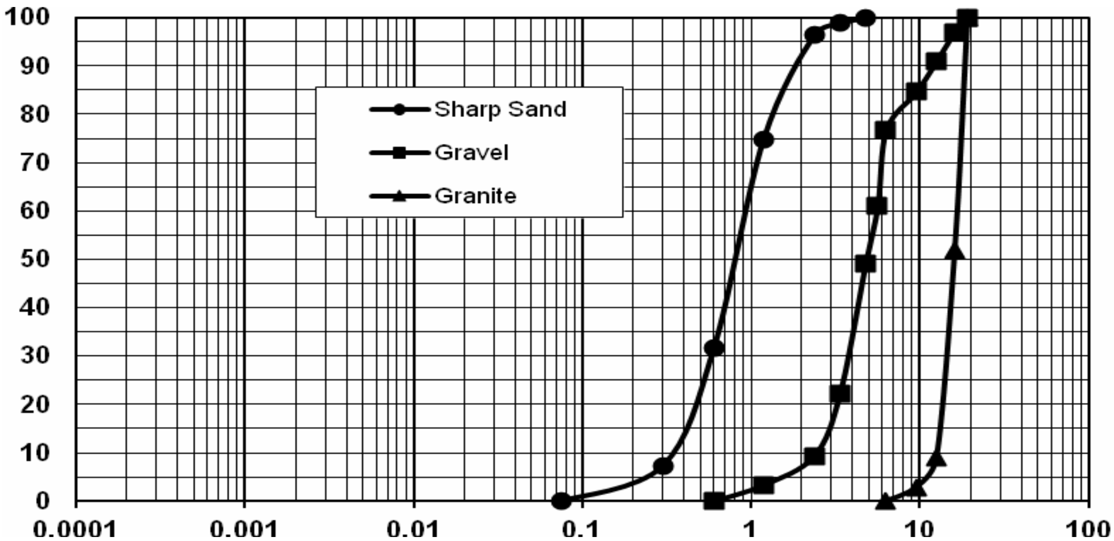

Clay	Particle size (D), mm									Cobbles
	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	
	Silt			Sand			Gravel			

Figure-1. Grading curves for sand, granite and gravel.

Effect of gravel inclusion in mixes on weight and density of test specimens

It was observed that the weight of test specimens decreased with increase in gravel content. At 7 days of curing, the weight generally decreased with higher gravel content. At 0% gravel replacement level, the weight of the concrete was 8.67 kg while for concrete with 100% gravel content as aggregate, the weight was 8.33 kg; indicating a weight reduction of about 3.92%. This same trend was observed for all other curing ages. Likewise, the density of test specimens at 7-day curing age reduced as gravel content increased. For 0% and 100% gravel contents, the densities were 2548 and 2469 kg/m^3, respectively; indicating 3.10% reduction in density? This trend was observed for other curing ages.

Compressive strength at varying gravel content

Table-1 and Figure-2 show the variation of compressive strength with percentage replacement of granite with gravel at various curing ages. It can be seen that for each curing age, the compressive strength increased as the gravel content in the concrete mix increased, attaining a maximum value at 20% gravel replacement level. However, beyond 20% replacement level, the compressive strength reduced continually to a value (at 100% replacement level) approximately equal to the value at 0% replacement level. Generally, for all replacement levels, it was observed that as curing age increased, compressive strength of test specimens also increased.

Table-1. Average compressive strength (N/mm^2) of concrete specimens with different percentages of gravel.

% Gravel content in coarse aggregate	**Curing age** (Days)			
	7 days	**14 days**	**21 days**	**28 days**
	Average compressive strength (N/mm^2)			
0	16.30	18.52	21.78	24.15
20	25.33	31.26	29.78	37.18
40	24.30	25.28	27.85	35.11
60	21.78	22.85	26.96	30.96
80	20.44	21.04	21.92	26.85
100	18.96	19.60	20.80	23.85

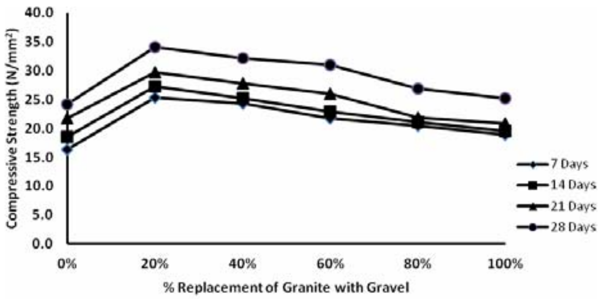

Figure-2. Variation of compressive strength with percentage replacement (at different ages).

From Table-1, it is observed that at 7-day curing age, with 20% replacement of granite with gravel the compressive strength of the test specimens increased by 55.40% when compared with the control having 0% gravel inclusion. From this point, for every additional 20% inclusion of gravel; i.e., 40%, 60%, 80% and 100% the compressive strength reduced by 4.10, 10.18, 6.15 and 7.24%, respectively when compared with the value for the immediate previous level of replacement. This same trend was observed for all the curing ages. The maximum compressive strength of the test specimens at all curing ages was achieved at 20% level of granite replacement with gravel.

Generally, the observed trend in compressive strength development of test specimens could be attributed to the fact that at 0% granite replacement level, the relatively large granite particles, surrounded by the products of hydration, possess voids/gaps between them, and these would lead to low crushing strengths. With the replacement of small amounts (say 20%) of the granite with the finer-graded gravel, the finer particles pack themselves into these voids, and when they (with the granite particles) are surrounded by the products of hydration, a more compact mass with a higher compressive strength value results. As the percentage replacement increases beyond 20%, other factors which tend to lower the strength of the concrete play a more significant role in concrete strength development. Such factors include the texture (smoothness) and the fineness of the gravel. The smoothness of the gravel reduces the bond between the coarse aggregate and the mortar, leading to lower strengths. Furthermore, the fineness of the gravel reduces the workability of the concrete, making it difficult to achieve a high degree of consolidation of the concrete; again, this leads to lower concrete strengths.

7-day and 28-day strengths at different replacement levels

The 7-day and 28-day strengths of the concrete are shown in Table-2 for all replacement levels. Also shown are the ratios of the 7-day strength to the 28-day strength for each percentage replacement. It is observed that the average value of the ratio of the 7-day to 28-day strength was 0.74, with a minimum of 0.67.

It is further observed that the 28-day strengths of all specimens were reasonably above 20 N/mm^2, irrespective of the percentage content of the gravel.

Table-2. 7-Day and 28-day strengths at various percentage replacement levels.

% **Replacement**	**0**	**20**	**40**	**60**	**80**	**100**	
7-day strength (N/mm^2)	16.30	25.33	24.30	21.78	20.44	18.96	
28-day strength (N/mm^2)	24.15	34.18	32.11	30.96	26.85	23.37	**Average**
$\frac{7-day\ Strength}{28-day\ Strength}$	0.67	0.74	0.76	0.70	0.76	0.81	0.74

Variation of compressive strength with curing age

Figure-3 shows the variation in strength with age for different percentage replacement levels of granite with gravel in the concrete cube specimens tested. It is observed that, as in normal concrete, the curing age had a significant effect on the strength development characteristics of the concrete.

It is further observed that the strength development pattern was generally similar for all the concrete specimens, irrespective of the replacement level of granite with gravel – a steep rise in the strength curve in the first 7 days followed by a gentle rise between 7 and 28 days. However, concrete with 20% replacement level showed higher compressive strength values than all the other concretes at all curing ages. (See figure 2 and the accompanying discussion).

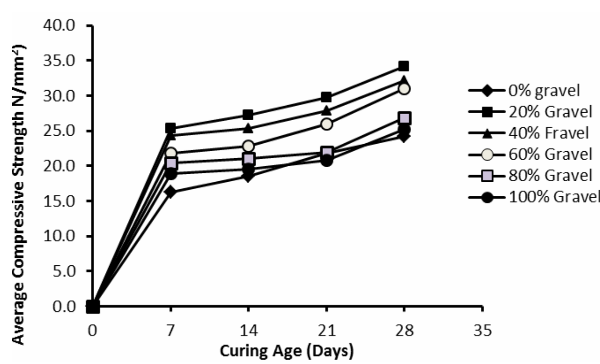

Figure-3. Effect of curing age on the compressive strength.

Strengths developed by100% granite concrete and 100 % gravel concrete

Figure-4 shows the strengths developed by the 100% granite concrete and the 100% gravel concrete

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respectively, as the curing age increases. It is observed that the rates are similar. However, in the first 7 days, the rates of strength development and value were higher in the 100% gravel concrete. For 100% granite concrete and 100% gravel concrete, compressive strengths were 16.30 and 18.96 N/mm^2, indicating growth rates of 2.33 N/mm^2 and 2.71 N/mm^2 per day, respectively.

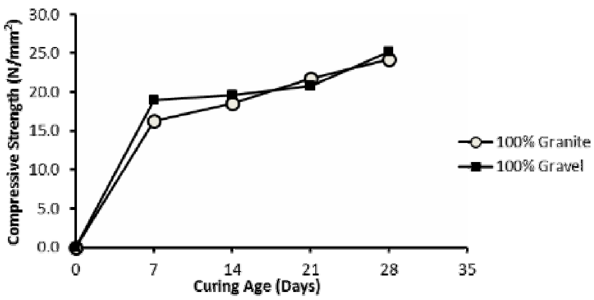

Figure-4. Strength development in 100% granite and 100% gravel concrete.

At 28-day curing age, the 100% gravel concrete developed strength of 25.20 N/mm^2 and the 100% granite concrete developed strength of 24.15 N/mm^2, indicating a 4.35% lower value. The generally high strength developed by the 100% gravel concrete could be attributed to the large amount of 'fine' material (passing the 5 mm sieve) in the gravel, accompanied by a large aggregate surface area which reduces the amount of water in the mix. This in effect reduces the water/cement ratio, resulting in higher concrete strengths than would be developed if the fines were not present in the gravel. This is in line with the result obtained by Katz and Baum [10] in which material finer than 75 micron was included in the fine aggregate. They reported that concrete produced with up to 227 kg of fines per m^3 developed 28-day strengths 30% greater than that of ordinary concrete.

Percentage replacement of granite with gravel for practical use in design

Table-3 shows the 28-day concrete strengths at various percentage replacement levels of granite with gravel, compared with the concrete 28-day strength at 0% replacement.

Table-3. Ratios of 28-day strengths at various percentage replacement levels to the 28-day strength at 0% replacement.

% **Replacement**	**0**	**20**	**40**	**60**	**80**	**100**
28-day Strength (N/mm^2)	24.15	34.18	32.11	30.96	26.85	25.20
$\frac{Strength\ at\ \%\ Replacement}{Strength\ at\ 0\%\ Replacement}$	1.00	1.42	1.33	1.28	1.11	1.04

It is noted that the concrete crushing strengths for concretes with percentage replacements 20 to 100 are all greater than the strength at 0% replacement (100 % granite concrete). With washed gravel of similar grading therefore, a 28-day strength equal to the 28-day strength of 100% granite concrete is achievable, and hence recommended. Higher compressive strengths may be used with replacement levels of 20 to 40%. (However, see below for recommendation for further research).

CONCLUSIONS AND RECOMMENDATION

The effects of the partial replacement of crushed granite as coarse aggregate with washed gravel on the workability and strength of 1:2:4 concrete with a water/cement ratio of 0.65 have been investigated. The following conclusions are drawn:

a) As the percentage replacement of granite increases, the workability of concrete decreases.
b) For every percentage replacement, the compressive strength of the concrete increases from a minimum or near-minimum at a curing age of 7 days to a maximum at 28 days.
c) The rates of strength development of 100% granite concrete and 100% gravel concrete are comparable, the granite concrete developing a 28-day strength of 24.15 N/mm^2 as against 25.20 N/mm^2 (4.45% higher) developed by the gravel concrete.
d) At every curing age, the concrete with 20% replacement of granite with gravel gives the maximum compressive strength.
e) With gravel of similar grading as used in the present work, a concrete strength equal to that of 100% granite concrete is recommended for use in design.

It is recommended that further investigation be carried out on the effects of the grading of the gravel which is used to partially replace granite in concrete. As suggested above, the large proportion of fine particles present in the gravel may have contributed to the high values of the ratio, $\frac{Strength\ at\ \%\ Replacement}{Strength\ at\ 0\%\ Replacement}$ at 28 days.

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