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Review Article

Evaluation of the Structural Response of Reinforced Concrete Beams Produced with River Gravel as Coarse Aggregate in Building Construction

John TrustGod A[1], Ebieride Ebiowei[1*], Osoru Gordin T[1]

[1]School of Engineering, Department of Civil Engineering, Niger Delta University, Amassoma, Bayelsa State, Nigeria

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***Corresponding author:** Ebieride Ebiowei
School of Engineering, Department of Civil Engineering, Niger Delta University, Amassoma, Bayelsa State, Nigeria

Abstract

An increase in demand for concrete to meet global needs has been accompanied by an increase in global concerns due to an increase in demand for the non-renewable resources that are and comprise the constituents of concrete. To address these concerns and mitigate the impact of their depletion, researchers have investigated the intrinsic properties of a wide range of available materials and assessed their contribution when mixed with concrete. This paper presents the findings of an experimental study that was carried out to assess the structural response of concrete beams made with river gravel as coarse aggregate. Six reinforced beams (100 x 150 x 1100 mm) and six cubes were cast to investigate the specimens' flexural and compressive behavior. The failure modes, bending, and shear capacity were investigated in this study. According to the findings of the study, river gravel used as coarse aggregate in concrete has a roughly equivalent or slightly lower structural performance than conventional coarse aggregate, indicating the feasibility of river gravel as coarse aggregate for building construction.

Keywords: Stiffness, Ductility Index, Flexural Strength, Crushed Granite and River Gravel.

1.0 INTRODUCTION

The earth's population, characterized with a slow rate of increase, is projected to grow by a significant 26% increment by 2050 from 2019 [1] which would directly influence the demand for the construction of concrete structures to meet housing needs. Concrete, a chemically inert composite material composed of fine and coarse aggregates bonded with cement paste, is the most consumed construction material, second only to water [2]. However, this high demand (of concrete) cannot be correlated by a greater or equal supply of its constituents without incurring a detriment to the environment. The constituents of concrete are and are produced from non-renewable resources. The production process of cement requires the availability of limestone, a non-renewable resource, among other raw materials and is an energy intensive process requiring 40% - 60% of production cost whilst also raising global concerns of greenhouse gas emission with this process contributing up to 8% of all man-made CO_2 emissions [3]. These environmental implications have resulted in the research of the suitability of a vast amount of natural and or industrial materials in supplementing or replacing cement in concrete [4, 5]. This intensive research has not been limited only to cement alternatives but also aggregate alternatives. Aggregates contribute up to 75% of the volume of ordinary portland cement concrete hence their properties are majorly responsible for the overall performance of concrete in its fresh and hardened state [6].

Coarse aggregates measure a minimum 4.75mm and are retained in a #4 sieve [18]. Coarse aggregates, when properly graded, act as a filler, reducing the amount of cement paste required to fill a volume whilst also contributing to the mechanical properties of the concrete when hardened [19]. Gravel and crushed stone, non-renewable materials, are the most sought-after materials in terms of volume due to their suitability as coarse aggregate in concrete [7]. However, the use of gravel and crushed stone as coarse aggregate is considered unsustainable as the demand for these materials rapidly approach the point of exceeding the rate of natural renewal [7].

On this note, researchers have investigated the suitability of several natural and industrial materials as coarse aggregate in other to mitigate the demand of the aforenamed established coarse aggregates. [8] investigated the structural behavior of reinforced concrete beams subjected to flexure using recycled coarse aggregates (RCA). Bending tests employing a universal testing machine were carried out on concrete cylinders measuring 100mm x 200mm casted with graded coarse aggregates of varying sizes measuring a maximum 25mm and the compressive strength was multiplied by 0.97 in order to compute the compressive strength of a standard test cylinder [8, 9]. Conclusively [8], stated that a greater amount of cracking would occur in RCA beams compared to natural coarse aggregate (NCA) beams due to the effect of high shrinkage while also noting that for low rebar ratios, the flexural strength capacity of the RCA beams decreased with increasing RCA content.

To investigate the structural behavior of concrete beams using ceramic waste as a coarse aggregate alternative [10], subjected a number of unreinforced and reinforced concrete beams to two points loading. Ehikhuenmen, S *et al*., [10] concluded that the flexural strength of the beams would increase with increasing ceramic waste (CW) content, peaking at 75% replacement and then decline with further increasing CW content. [10] noted that at 25% replacement level, maximum allowable deflection would occur.

Priya, V [11] used pumice stone as a coarse aggregate supplement at varying replacement levels in lightweight unreinforced concrete beam in other to investigate its ability to resist flexure. Specimens were designed to measure a dimension of 150 x 150 x 700 mm with pumice stone replacing coarse aggregate at 0%, 25%, 50%, 75% and 100% replacement levels. Priya, V [11] concluded that an increase in pumice stone content resulted in a reduction of concrete weight (20%). However [11], observed the flexural capacity reduced with increasing pumice stone content.

Steel slag, a by-product from the production process of steel, has been reported to be economical due to a 50% difference in cost to conventional aggregates [17]. On this note, several researchers have investigated its effect on the intrinsic characteristics of concrete. Based off extensive research on the suitability of steel slag as coarse aggregate in concrete when subjected to rapid chloride penetration [12], concluded that at a 100% replacement, only a low amount of chloride penetration is recorded compared to a very low amount recorded for 80% replacement. Also [13], investigated the effect on the mechanical properties of concrete when steel slag was used as coarse aggregate. Steel slag in concrete was designed to meet the requirement of a M40 mix. Saravanan J *et al*., [13] concluded that compared to conventional coarse aggregate concrete, steel slag incorporation effected an increment in the compressive strength (6%), split tensile strength (28%) and flexural strength (34%).

Chandrashekar A *et al*., [14] assessed the effect of river stone as coarse aggregate in concrete. River stone was used to substitute conventional (crushed stone) coarse aggregate at five replacement levels; 0%, 25%, 50%, 75% and 100%. The mix proportion was done as per [15]. Concrete specimens were measured for their compressive strength, flexural strength and split tensile strength. The following conclusions were drawn by [14]; the shape of crushed stone resulted in an increase in workability with increasing river stone replacement level, and an increase in river stone replacement level would result in a reduction in flexural strength.

In this research the failure modes, shear and bending capacity of reinforced concrete beam produced with river gravel as coarse aggregate would be evaluated.

2.1 EXPERIMENTAL PROGRAM

2.1.1 Specimen Design

A total number of six beams and six cubes were constructed. Constructed beams included deformed high grade steel bars measuring 2Ø8mm provided at both the tension zone and compression zone along the longitudinal axis. Steel reinforcement measuring Ø4mm and spaced at 200mm($^C/_C$) was provided along the shear span. RCC beams tested throughout the course of this program had a rectangular cross section of (100 x 150 x 1100) mm and were designed to meet the requirement of [23] as per minimum and maximum longitudinal reinforcement while concrete cubes of (150 x 150 x 150) mm were cast. Specimen configuration included a combination of numbers and letters: T3A represented the sample group type and T3B represented the reference group type.

2.1.2 Specimen Mix Design

Concrete batches for both sample group types employed a mix ratio of 1:2:4. Concrete mix consisted of sand, river gravel (for batch T3A) and crushed granite (for batch T3B). In accordance with [16], the maximum aggregate size used in this experiment was 25mm and a w/b ratio of 0.50 was applied. Sample concrete structures were cured for 28days. The curing method adopted for this experiment was continuous sprinkling. The water was maintained at an average temperature of 27^{O}C.

2.1.3 Specimen Test

Physical and mechanical tests were conducted in the laboratory at Niger Delta University, Bayelsa state, Nigeria. Physical tests were carried out on the aggregates (crushed granite, river gravel and sand) to ascertain the following properties; specific gravity, bulk density, water absorption, void ratio, workability and particle size distribution. Physical test results are shown in Table 1. Mechanical tests carried out on both sample sets include; compressive strength test and flexural strength test. The compressive strength of cube specimens was obtained using a compressive strength testing machine while the beam specimens were subjected to two points load application using a loading frame.

2.2 Test Procedures

2.2.1 Flexural Strength

The two-point loading test is carried out in accordance with British Standard BS 1881-118 (1983), method for determining flexural strength. This method explains how to use two-point loading to determine the flexural strength of hardened concrete test specimens by moment in the center zone (BSI, 1983). The specimen was positioned in the center of the flexural machine, with two supports and two loadings as shown in the schematic diagram in Figure 1. The two supports are regarded as a single supported condition. Loading was applied to the specimen's center and transmitted through two points until failure. The lateral deflection and load reading were displayed on the machine's screen as the load was measured directly by the unit test machine.

Table 1: Summary of Physical Test Results

S/N	TEST TYPE	TEST STANDARD	AGGREGATES		
			Crushed granite	**River gravel**	**Sand**
1	Specific gravity (kg/m^3)	[21]	2.70	2.61	1.71
2	Bulk density (kg/m^3)	[21]	1851.85	1740.75	1666.70
3	Water absorption (mm)	[22]	60	5	-
4	Void ratio	[24]	0.314	0.334	0.025
5	Fineness modulus	[25]	4.28	1.82	3.12

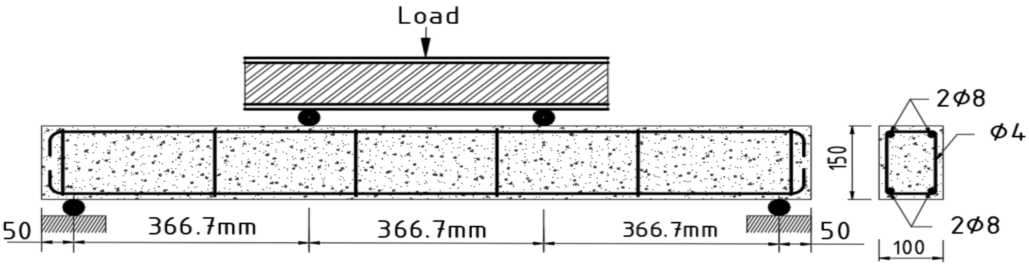

Figure 1: Test Setup

3.1 EXPERIMENTAL DISCUSSION

3.1.1 Workability

Figure 1 depicts the slump values for each sample type, with a significant difference. The river gravel concrete mix has a workability rating of 75, which is considered high. The round shape of river gravel contributes to its high workability. According to [20], a reduction in angularity of coarse aggregates would result in an increase in workability.

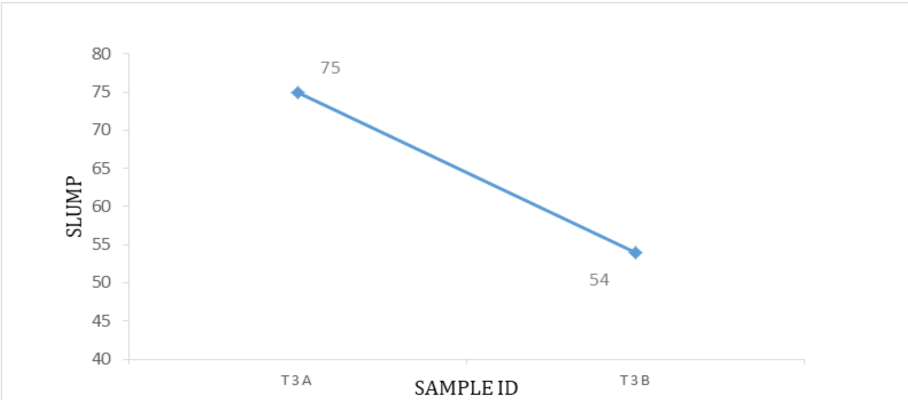

Figure 1: Workability of Sample Types

3.2 Ductility Index

Figure 2 shows the deformation at ultimate failure load of the beam samples. Beam group T3A contains the beams in which river gravel was incorporated as coarse aggregate. The results of Beams T3A1, T3A2 and T3A3 were very close to those of beam group T3B (beams in which crushed conventional aggregates were used as coarse aggregate). The average deformation at ultimate failure load of group T3A was 6.61mm. at ultimate failure load, Beam group T3B deformed at an average 6.42mm. From table 2, it can be seen that beams T3A failed at an average cracking load (30.09kN) lower than that of T3B (31.89kN) but at a higher cracking deflection (6.61mm) than T3B (6.42mm) indicating that beams T3A has a greater ductility during elastic range compared to beams T3B.

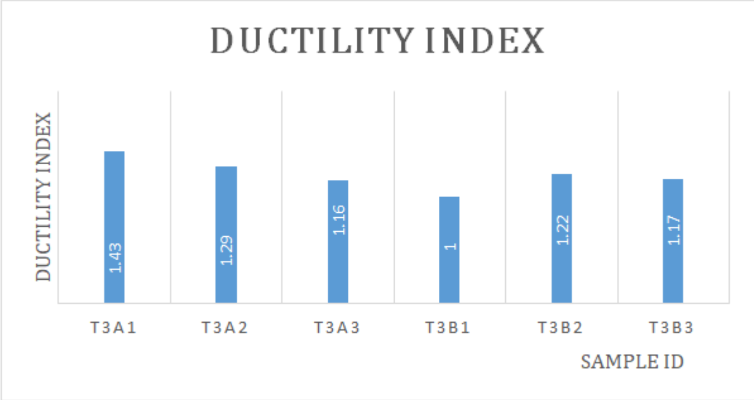

Figure 2: Ductility Index

3.3 Stiffness

Figure 3 represents the load-deflection behavior of the beam specimens as a relationship curve when subjected to flexure. At initial loading, all beam specimens are stiff and un-cracked after which cracking occurs at the center of the span due to flexure. During loading, the first crack for sample beams T3A cracked at an average yield load of 30.09kN causing an average deflection of 5.19mm. Further loading on sample beams T3A caused them to fail at an average ultimate failure load of 34.34kN and average deflection of 6.61mm. Sample beams T3A generally failed due to flexural shear occurring at mid-span.

On subjection to loading, sample beams T3B yielded (cracked) at an average yield load of 31.07kN at a deflection of 5.69mm. An increase in loading resulted in failure at an ultimate failure load of 33.35kN and deflection of 6.42mm. While beam T3B failed due to its brittle nature, the other beams in this sample group generally failed due to web shear.

On comparison of their (sample beams) ultimate failure load to yield load, beams T3A exhibited a more ductile behavior than beams T3B. The ductility index of both beams T3A and T3B were computed at 1.27 and 1.13 respectively.

Table 2: Test Results for River gravel and Conventional aggregate

SAMPLE ID	*Yield Load (KN)*	*Deflection at Yield Load(mm)*	*Ultimate Failure Load (KN)*	*Deflection at Failure Load (mm)*	*Failure Mode*
T3A1	*27.47*	*4.6*	*35.32*	*6.6*	*Flexural shear*
T3A2	*28.45*	*4.07*	*29.43*	*5.24*	*Flexural shear*
T3A3	*34.34*	*6.9*	*38.26*	*8*	*Flexural shear*
T3B1	*29.43*	*5.78*	*29.43*	*5.78*	*Brittle failure*
T3B2	*34.34*	*6.14*	*39.24*	*7.48*	*Web shear*
T3B3	*29.43*	*5.15*	*31.39*	*6*	*Web shear*

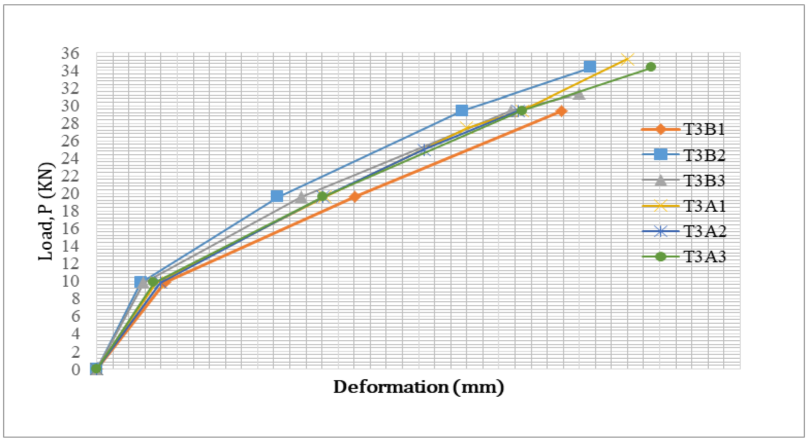

Figure 3: Failure Load vs Deformation for Sample Type

3.4 Bending Capacity

The bending capacity of the sample beams is shown in Table 2. The average bending capacity of beams T3B was 6.11, while beams T3A had a bending capacity of 6.30. Beams T3A shows an increased bending capacity by 3.11% compared to sample beams. This demonstrates that using river gravel instead of crushed granite can improve the bending resistance of reinforced concrete beams.

3.5 Tensile Stress

The tensile stresses for sample beams T3A and T3B are presented in table 3. The average tensile stress of beams T3A was 2.54 while the average tensile stress of beams T3B was 1.84. The incorporation of river gravel in reinforced concrete beams evidently improved the tensile stress by a significant 38% increment. As a result, it can be concluded that using river gravel as coarse aggregate in reinforced concrete beams will improve their elongation resistance.

3.6 Shear Strength

Table 4 presents the shear strength capacity of sample beams T3A and T3B. The average shear strength of beams T3B was 16.67kN while the average shear strength of beams T3A was 17.17kN. The shear strength of the beam samples was improved by a percentile increase of 3%. Hence, the incorporation of river gravel as coarse aggregate in reinforced concrete beams would result in an increase in shear stress resistance.

3.7 Compressive Strength

Table 5 shows the average compressive strength of concrete cubes of sample batches. concrete cubes integrated with conventional coarse aggregate (T3B) achieved an average 29.48KN/mm^2 while concrete cubes integrated with river gravel as coarse aggregate (T3A) achieved an average 18.51KN/mm^2, 37.2% less compressive strength compared to T3B.

Table 2: Bending Capacity of Sample Beams (PL/6)

SAMPLE ID	ULTIMATE FAILURE LOAD (KN)	BENDING CAPACITY (KNm)
T3A1	35.32	6.48
T3A2	29.43	5.4
T3A3	38.26	7.01
T3B1	29.43	5.4
T3B2	39.24	7.19
T3B3	31.39	5.75

Table 3: Tensile Stress of the Sample Beams (P/2)

SAMPLE ID	FIRST YIELD LOAD (KN)	TENSILE STRESS (MPa)
T3A1	4.6	2.25
T3A2	4.07	1.99
T3A3	6.9	3.37
T3B1	0	0
T3B2	6.14	3
T3B3	5.15	2.52

Table 4: Shear Strength of the Sample Beams (PL/bh^2)

SAMPLE ID	ULTIMATE FAILURE LOAD (KN)	SHEAR STRENGTH (KN)
T3A1	35.32	17.7
T3A2	29.43	14.7
T3A3	38.26	19.1
T3B1	29.43	14.7
T3B2	39.24	19.6
T3B3	31.39	15.7

Table 5: Average 28-Days Compressive Strength of Sample Cubes

BATCH ID	SPECIMEN WEIGHT (KG)	APPLIED COMPRESSION LOAD (KN)	COMPRESSIVE STRENGTH (MPa)
T3A	9	416.67	18.51
T3B	10	663.33	29.48

4.0 CONCLUSION

This paper investigates the structural response of reinforced concrete structures when river gravel is incorporated as coarse aggregate. Throughout the course of this research, the workability, ductility index, deformation response and compressive strength were closely studied. Based on the discussion, the following conclusions were drawn:

i. The compressive strength of concrete cubes incorporated with conventional coarse aggregate was greater than that of concrete cubes incorporated with river gravel as coarse aggregate by 37%.
ii. If available, river gravel can be employed as coarse aggregate in concrete due to it being characterized as ductile.

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