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Comparative Assessment of Workability, Compressive Strength and Flexural Strength of Concrete Made with River Gravel and Crushed Granite Aggregates

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ABSTRACT
The selection of suitable coarse aggregates significantly influences the mechanical performance of concrete. Although river gravel and crushed granite have been compared in earlier studies, locally generated data on their combined effects on workability, compressive strength and flexural behaviour under the same mix proportions and curing conditions remain limited. This study compared concrete made with river gravel from the River Benue and with crushed granite from Makurdi, Nigeria, as coarse aggregate. The grading, specific gravity and bulk density of the aggregates were determined. Both concretes were designed by the DoE method and batched at the same mass proportion (1:1.73:3.55, cement:sand:coarse aggregate), with effective water–cement ratios of 0.52 for the cubes and 0.49 for the beams. Workability was measured by the slump test, compressive strength on ten 150 mm cubes per aggregate type, and flexural behaviour on five 100 mm × 100 mm × 450 mm beams per aggregate type tested at 28 days. Crushed granite had a slightly higher specific gravity (2.62) than river gravel (2.61). Both concretes had low workability, with slumps of 15 mm (river gravel) and 14 mm (crushed granite). The mean compressive strength of the crushed granite cubes was 33.32 MPa, 11.41% higher than the 29.90 MPa of the river gravel cubes ($p = 0.047$). The crushed granite beams failed at a mean load of 11.0 kN, compared with 7.0 kN for the river gravel beams, indicating a 57.14% higher flexural strength ($p = 0.004$). The higher strength of crushed granite concrete was attributed to its angular particle shape and better aggregate–paste interlocking. Because the number of specimens was small, the test age of the cubes was not recorded, and durability and cost were not assessed, these findings should be confirmed by larger test programmes before being applied to structural design.

Keywords: River Gravel; Crushed Granite; Coarse Aggregate; Compressive Strength; Flexural Strength; Workability.

INTRODUCTION

Concrete is the most widely utilized construction material in civil engineering due to its versatility, durability, and ability to be molded into various structural forms. The performance of concrete depends largely on the properties of its constituent materials, namely cement, water, fine aggregates, and coarse aggregates. Among these constituents, coarse aggregates occupy approximately 60–75% of the concrete volume and significantly influence its fresh and hardened properties, including workability, density, compressive strength, and flexural strength (Kabir et al.,2019)

The rapid growth of infrastructure development has led to an increased demand for conventional aggregates, particularly crushed granite. Because crushed granite must be quarried, processed and often transported over long distances, interest has grown in locally available alternatives. River gravel is one such material: it occurs naturally in many regions and requires minimal processing before use (Přikryl, 2021).

The engineering performance of concrete is strongly affected by the physical characteristics of aggregates, including particle shape, surface texture, grading, and mineral composition. Crushed granite is characterized by angular and rough-textured particles that enhance mechanical interlocking and bond development within the cement matrix. In contrast, river gravel particles are generally rounded and smooth due to natural weathering and abrasion processes. These differences influence the workability and strength characteristics of concrete. Previous studies have reported that concrete produced with natural gravel generally exhibits higher workability, whereas crushed granite concrete often develops superior compressive strength due to improved aggregate-paste interaction (Sufian et al., 2025).

Several researchers have investigated the suitability of gravel and granite aggregates in concrete production. Aginam et al. (2013) reported 28-day compressive strengths of 25.1, 20.0 and 16.9 MPa for concretes made with crushed granite, washed gravel and unwashed gravel, respectively. Nwafor and Aho (2018) found that partially replacing river gravel with crushed granite improved compressive strength, with an optimum at 50% replacement, and Salman et al. (2021) observed that compressive strength and modulus of rupture both increased as the proportion of crushed granite in a gravel–granite blend increased. Onwasigwe and Onodagu (2024) likewise reported a 28-day strength of 35.02 MPa for granite concrete, compared with 31.01 and 27.93 MPa for concretes made with two local gravels in Anambra State, Nigeria. The trend is not universal, however: Chat et al. (2015) reported that, at equal workability, natural gravel concrete can attain strengths comparable to those of crushed-rock concrete. Granite has also been used in other forms; for example, Mareguddi et al. (2025) showed that granite powder used as a partial replacement for fine aggregate can improve compressive strength.

The influence of aggregate type on concrete strength has also been examined across different geological materials. Kabir et al., (2022) compared concrete produced using igneous, sedimentary, and metamorphic aggregates and found that crushed granite yielded the highest compressive strength among the aggregates investigated. Likewise, Choi et al. (2022) reported superior mechanical properties in concrete produced with crushed basalt compared to alluvial sand-based concrete. These findings demonstrate that aggregate mineralogy and geological origin play significant roles in determining concrete performance.

Recent studies have increasingly focused on sustainable alternatives to conventional aggregates due to concerns regarding resource depletion and environmental degradation. Rifa et al. (2023) conducted a comprehensive review of alternative fine aggregates and emphasized the importance of sustainable aggregate selection in modern concrete technology. Similarly, Anh et al. (2023) demonstrated through life cycle assessment that alternative aggregate materials can reduce environmental impacts while maintaining acceptable engineering performance. Studies by Singh et al. (2016), Manasseh (2010) and Anandaraj et al. (2026) further highlighted the potential of granite-derived materials as sustainable substitutes for natural aggregates in concrete and mortar production.

Most of the comparative studies cited above evaluated compressive strength only, and few reported workability, compressive strength and flexural behaviour together for river gravel and crushed granite concrete batched at the same proportions and cured under the same conditions. In addition, aggregate characteristics are highly dependent on local geological conditions; therefore, findings obtained in one location may not be directly applicable to another. Makurdi lies within the Cretaceous Middle Benue Trough (Obaje, 2009) on the River Benue, which supplies the river sand and gravel used locally, while crushed granite in the area is obtained by blasting rock for construction. Comparative data for these two locally used aggregates are therefore of practical value; the present study adds such data rather than introducing a new test method.

This study aims to comparatively evaluate the engineering properties of concrete produced using river gravel and crushed granite as coarse aggregates. The investigation includes aggregate characterization through sieve analysis, specific gravity determination, and bulk density evaluation, as well as the assessment of concrete workability, compressive strength, and flexural strength. The findings are intended to support aggregate selection for concrete production in the study area.

MATERIALS AND METHODS

Study Area and Materials

The experimental investigation was conducted in the Civil Engineering Laboratory of the Federal University of Agriculture, Makurdi, Benue State, Nigeria. The materials used for concrete production consisted of Ordinary Portland Cement (Dangote, Grade 42.5), river sand, river gravel, crushed granite, and potable water. The river sand and river gravel were obtained from the River Benue, and the crushed granite was obtained from rock blasted for construction purposes by PW Construction Company in Makurdi. The location of the laboratory is shown in Figure 1.

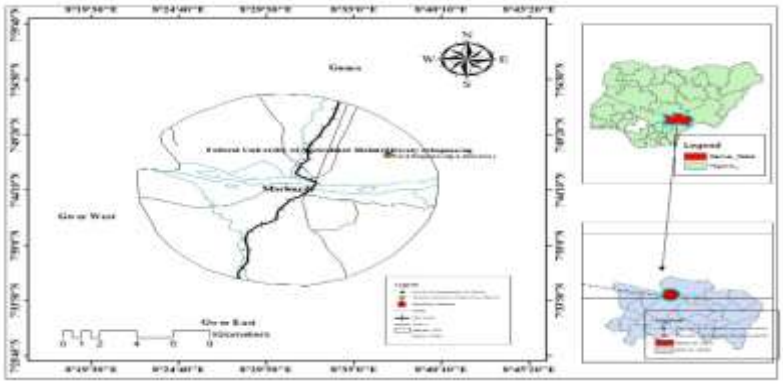


Figure 1: Location of the Civil Engineering Laboratory, Federal University of Agriculture, Makurdi, Makurdi Local Government Area, Benue State, Nigeria (insets: Benue State within Nigeria and Makurdi LGA within Benue State)

Potable water free from harmful impurities was used for mixing and curing operations. Prior to concrete production, the physical properties of the constituent aggregates were determined to assess their suitability for concrete manufacture. The measured specific gravity values of river sand, river gravel, and crushed granite were 2.58, 2.61, and 2.62, respectively, indicating their suitability for normal-weight concrete production.

Table 1: Physical Properties of Aggregates

Property	River Sand	River Gravel	Crushed Granite
Specific Gravity	2.58	2.61	2.62
Bulk Density (kg/m³)	-	1645	1559
Maximum Aggregate Size (mm)	5	20	20

Experimental Framework

The experiment followed the flowchart sequence in Figure 2:

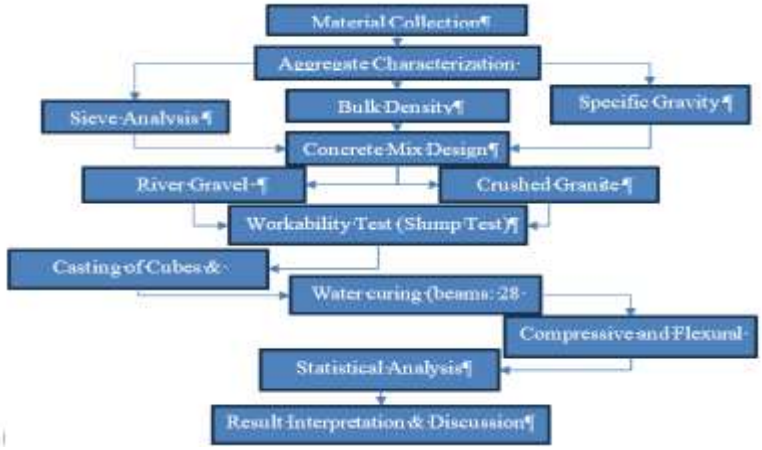


Figure 2: Experimental Framework Flow Chart

Aggregate Characterization

The particle size distribution of river sand, river gravel, and crushed granite was determined through sieve analysis in accordance with BS 882:1992 (British Standards Institution [BSI], 1992). Oven-dried samples of 1 kg were shaken through a nest of standard sieves (20 mm to 75 µm) and the mass retained on each sieve was recorded. The results were used to develop grading curves and evaluate the gradation characteristics of the aggregates. Specific gravity and bulk density tests were conducted in accordance with BS 812-2:1995 (BSI, 1995), with two tests per material. These tests were performed to evaluate the physical characteristics of the aggregates and determine their suitability for concrete production. The suitability of the aggregates was assessed by comparing the measured properties with the requirements of BS 882:1992. The specific gravity of the aggregates was determined by the pycnometer method using Equation (1):$Gs = \frac{W2-W1}{(W4-W1)-(W3-W2)}$ (1)

Where:

Gs = specific gravity of the aggregate (dimensionless)

W1 = mass of the empty pycnometer (g)

W2 = mass of the pycnometer and oven-dry sample (g)

W3 = mass of the pycnometer, sample and water filled to the mark (g)

W4 = mass of the pycnometer filled with water only to the mark (g)

The bulk density was calculated using Equation (2): $\rho b = \frac{M}{V}$ (2)

Where:

ρb = Bulk density (kg/m³)

M = Mass of aggregate (kg)

V = Volume of measuring container (m³)

Concrete Mix Design

Two concrete mixtures were produced: river gravel concrete (RGC), in which river gravel served as the coarse aggregate, and crushed granite concrete (CGC), in which crushed granite served as the coarse aggregate; apart from the coarse aggregate, the two mixtures were identical. The mix was designed by the British Department of the Environment (DoE) method (Teychenné et al., 1988) for a maximum aggregate size of 20 mm and medium workability (target slump 50 mm). A free-water content of 180 kg/m³ and a water–cement ratio of 0.50 gave a cement content of 360 kg/m³. The total aggregate content of 1,922 kg/m³ was divided into 615.04 kg/m³ of fine and 1,306.96 kg/m³ of coarse aggregate. An absorption allowance of 2% (factor 1.02) was applied to bring the aggregates from the oven-dry to the saturated-surface-dry condition, giving 621.20 kg/m³ of fine and 1,320.00 kg/m³ of coarse aggregate, and the mixing water was correspondingly reduced to 163.60 kg/m³ (water–cement ratio 163.6/360 = 0.45). The design per cubic metre was therefore 360 kg of cement, 621.2 kg of sand, 1,320.0 kg of coarse aggregate and 163.6 kg of water (1:1.73:3.67 by mass). The field moisture content of the aggregates was not measured, so no further moisture correction was made.

For cube production, each batch contained 7.5 kg of cement, 13.0 kg of river sand, 26.62 kg of coarse aggregate, and 3.9 kg of water. For beam production, each batch contained 3.9 kg of cement, 6.8 kg of river sand, 13.7 kg of coarse aggregate, and 1.9 kg of water (Table 2). The as-batched mass proportion was 1:1.73:3.55 for the cubes and 1:1.74:3.51 for the beams, close to the design proportion. The water actually added was higher than the adjusted design water, giving effective water–cement ratios of 3.9/7.5 = 0.52 for the cube batches and 1.9/3.9 = 0.49 for the beam batches; these effective ratios are used in interpreting the results. Because both aggregate types were batched with identical quantities, the comparison between them is not affected.

Table 2: Concrete Mix Proportions (as Batched)

Material	Cube Mix (kg)	Beam Mix (kg)
Cement	7.5	3.9
River Sand	13.0	6.8
Coarse Aggregate	26.62	13.7
Water	3.9	1.9
Effective water–cement ratio	0.52	0.49
Mass proportion (C:S:CA)	1:1.73:3.55	1:1.74:3.51

All materials were batched by weight to ensure consistency and reduce experimental variability.

Preparation and Curing of Specimens

The dry constituent materials were thoroughly mixed until a uniform colour and consistency were achieved. Water was subsequently added gradually while mixing continued until a homogeneous concrete mixture was obtained. A total of twenty cube specimens measuring 150 mm × 150 mm × 150 mm were prepared for compressive strength determination, comprising ten cubes produced with river gravel and ten cubes produced with crushed granite. Additionally, a total of ten beam specimens measuring 100 mm × 100 mm × 450 mm were prepared for flexural strength evaluation, consisting of five beams produced with river gravel and five beams produced with crushed granite. The concrete was placed into the moulds, compacted on a vibrating table to remove entrapped air, filled to the brim and levelled. After casting, the specimens were left undisturbed for 24 hours before demoulding. The demoulded specimens were immersed in the laboratory curing tank containing potable water until testing. All beams were tested at 28 days. The age at test of the individual cubes was not recorded in the laboratory record; the ten cubes of each aggregate type are therefore treated as a single set. For each aggregate type, two cubes were tested at each of 7, 14 and 21 days and four cubes at 28 days. Because the laboratory record does not identify the test age of each individual cube, the ten cubes of each aggregate type are reported as a single set, and their mean values combine results from all four test ages.

Table 3: Summary of Experimental Programme

Concrete Type	Number of Cubes	Number of Beams	Test Age
River Gravel Concrete (RGC)	10	5	Cubes: not recorded; beams: 28 days
Crushed Granite Concrete (CGC)	10	5	Cubes: not recorded; beams: 28 days

Results for individual specimens are reported in Tables 6–8.

Workability Test

The workability of each fresh mixture was measured by the slump test in accordance with BS 1881-102:1983 (BSI, 1983a). A standard slump cone (300 mm high, with a 200 mm base diameter and a 100 mm top diameter) was placed on a smooth, flat, non-absorbent surface, held firmly in place and filled in three layers of approximately equal height, each layer being tamped with 25 strokes of a 16 mm diameter steel rod. After the top had been struck off level, the cone was lifted slowly and vertically, and the slump was measured as the difference between the height of the cone (300 mm) and the highest point of the slumped concrete. One slump test was performed on each batch, that is, on one cube batch and one beam batch for each aggregate type.

Compressive Strength Test

Compressive strength tests were conducted in accordance with BS 1881-116:1983 (BSI, 1983b). Each cube was removed from the curing tank, surface dried and weighed to determine its density, then placed between the platens of a 1560 kN electric hydraulic compression testing machine. The load was applied gradually without shock until failure, and the failure load was recorded. The loading rate and the date of the most recent calibration of the compression testing machine were not available in the laboratory records. The compressive strength was calculated using Equation (3):

$$fc = \frac{P}{A} \quad (3)$$

where:

fc = compressive strength of concrete (MPa or N/mm²)

P = maximum load at failure (N)

A = loaded cross-sectional area of the specimen (22,500 mm² for a 150 mm cube).

Flexural Strength Test

Flexural strength tests were conducted at 28 days on five 100 mm × 100 mm × 450 mm beams per aggregate type using a universal testing machine fitted with a bend fixture. Each beam was placed on two roller supports and loaded gradually until failure, and the failure load was recorded (Table 8). The flexural loading arrangement (centre-point or third-point) and the support span were not recorded in the laboratory records and therefore could not be verified. For centre-point loading, the flexural strength is calculated using Equation (4); for third-point loading, the corresponding expression fr = PL/(bd²) applies:

$$Fr = \frac{3PL}{2bd^2} \quad (4)$$

Where:

Fr = flexural strength (MPa)

P = maximum applied load (N)

L = support span (mm)

b = width of beam specimen (100 mm)

d = depth of beam specimen (100 mm).

Because all beams had the same dimensions and were tested with the same arrangement and span, flexural strength is directly proportional to failure load, so the two concretes were compared using the beam failure loads.

Quality Assurance and Reliability Measures

To ensure consistency and reliability of the experimental results, all specimens were produced using identical material sources, batching procedures, curing conditions, and testing equipment. Materials were weighed accurately prior to mixing, and all tests were conducted in accordance with the standards cited above (BSI, 1983a, 1983b, 1992, 1995). Specific gravity and bulk density were each determined twice per material, and ten cubes and five beams were tested per aggregate type. Mean values are reported together with their standard deviations and confidence intervals.

Data Analysis

The experimental data obtained from aggregate characterization, workability, compressive strength, and flexural strength tests were analyzed using descriptive statistical techniques. The statistical parameters evaluated were the mean, standard deviation (SD), coefficient of variation (CV), 95% confidence interval (CI = mean ± t0.975, n−1 × SD/√n) and percentage difference. Differences between the two concretes in compressive strength (n = 10 per group) and beam failure load (n = 5 per group) were tested using Welch's two-sample t-test at the 5% significance level. The results were also compared qualitatively with findings from previous studies.

The percentage difference in each property (slump, compressive strength and flexural failure load) between crushed granite concrete and river gravel concrete was

calculated relative to river gravel concrete using Equation (5):

$$\Delta fc(\%) = \frac{fCG - fRG}{fRG} x\ 100 \quad (5)$$

Where:

Δfc (%) = percentage difference relative to river gravel concrete (positive values indicate a higher value for crushed granite concrete);

f_{CG} = value of the property (slump, compressive strength or flexural failure load) of crushed granite concrete

f_{RG} = value of the same property of river gravel concrete.

RESULTS AND DISCUSSION

Physical Properties of Aggregates

The physical properties of the aggregates used in this study are presented in Table 1. The specific gravity values obtained for crushed granite and river gravel were within the acceptable range for normal-weight concrete production. The crushed granite exhibited a specific gravity of 2.62 (mean of 2.67 and 2.57), while river gravel recorded 2.61 (mean of 2.52 and 2.71) and river sand 2.58 (mean of 2.54 and 2.61), indicating negligible differences in aggregate density.

River gravel, however, recorded a higher compacted bulk density (1645 kg/m³) than crushed granite (1559 kg/m³). This observation suggests a more compact packing arrangement resulting from the rounded shape of gravel particles. Despite this apparent advantage, the higher bulk density did not translate into superior mechanical performance, indicating that aggregate morphology exerts a stronger influence on concrete behaviour than density alone.

The satisfactory physical characteristics observed for both aggregates indicate compliance with standard requirements for concrete production. Similar observations have been reported by Přikryl (2021) and Smarzewski and Stolarski (2022), who noted that aggregates possessing acceptable density and specific gravity characteristics generally produce structurally adequate concrete.

Particle Size Distribution and Aggregate Gradation

The sieve analysis results (masses retained and percentages passing) are given in Table 4, and the grading curves plotted from them are shown in Figures 3–5. The river sand falls within the overall BS 882:1992 limits for fine aggregate and within the medium (M) additional grading, with 39.5% passing the 600 µm sieve and a fineness modulus of 2.81. Both coarse aggregates are essentially single-sized, with no material passing the 5 mm sieve: 76.5% of the crushed granite and 84.2% of the river gravel was retained between the 20 mm and 10 mm sieves. The river gravel complies with the BS 882:1992 limits for 20 mm single-sized aggregate, whereas the crushed granite is slightly coarser, with 22.2% retained on the 20 mm sieve (77.8% passing, against a minimum of 85%). Neither coarse aggregate meets the limits for 20–5 mm graded aggregate.

Table 4: Sieve Analysis Results and BS 882:1992 Grading Limits (1 kg samples)

Sieve size (mm)	River sand retained (g)	River sand passing (%)	Crushed granite retained (g)	Crushed granite passing (%)	River gravel retained (g)	River gravel passing (%)	BS 882 fine aggregate, overall (%)	BS 882 20 mm single-sized (%)
20.0	0	100.0	222	77.8	110	89.0	100	85–100
14.0	0	100.0	588	19.0	535	35.5	–	0–70
10.0	0	100.0	177	1.3	307	4.8	100	0–25
6.3	10	99.0	13	0.0	48	0.0	–	–
5.0	15	97.5	0	0.0	0	0.0	89–100	0–5
3.35	24	95.1	0	0.0	0	0.0	–	–
2.36	36	91.5	–	–	–	–	60–100	–
1.70	52	86.3	–	–	–	–	–	–
1.18	115	74.8	–	–	–	–	30–100	–
0.850	143	60.5	–	–	–	–	–	–
0.600	210	39.5	–	–	–	–	15–100	–
0.425	148	24.7	–	–	–	–	–	–
0.300	113	13.4	–	–	–	–	5–70	–
0.150	108	2.6	–	–	–	–	0–15	–
0.075	22	0.4	–	–	–	–	–	–
Pan	4	–	0	–	0	–	–	–
Total / FM	1000	FM 2.81	1000	–	1000	–	–	–

Note: FM = fineness modulus of the river sand, calculated from the cumulative percentages retained on the 5.0, 2.36, 1.18, 0.600, 0.300 and 0.150 mm sieves.

Proper aggregate gradation is critical for achieving optimum packing density, minimizing internal voids, reducing cement paste demand, and enhancing concrete performance. The single-sized grading of both coarse aggregates increases the void content that must be filled by mortar, which may have contributed to the low slumps measured (Section 3.3).

Because the two coarse aggregates had similar single-sized gradings, grading is unlikely to explain the differences between the two concretes, which are attributed mainly to particle shape and surface texture (Subash et al., 2025).

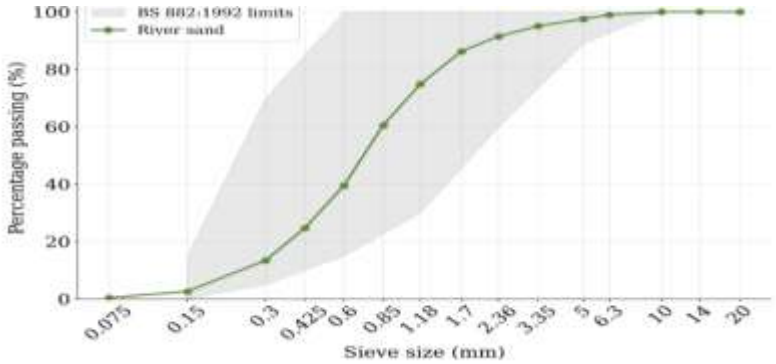


Figure 3: Particle Size Distribution Curve for River Sand (Data from Table 4)

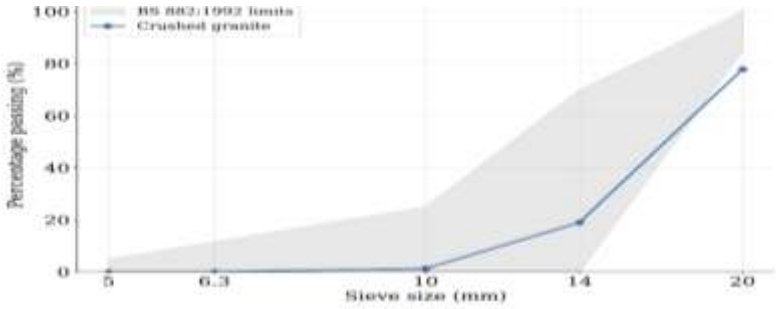


Figure 4: Particle Size Distribution Curve for Crushed Granite (Data from Table 4)

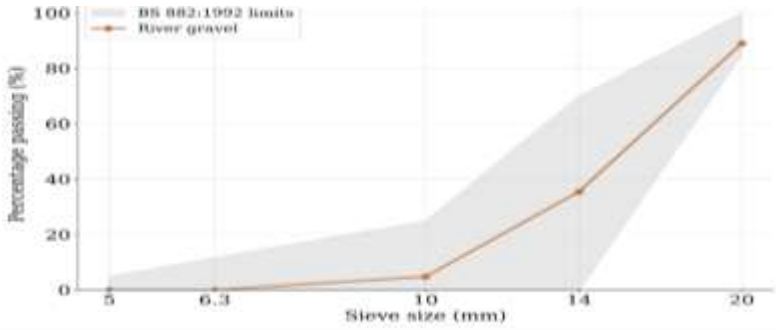


Figure 5: Particle Size Distribution Curve for River Gravel (Data from Table 4)

Workability Characteristics

The workability results presented in Table 5 and Figure 6 showed that concrete produced with river gravel achieved a slump value of 15 mm, compared with 14 mm obtained for crushed granite concrete. The same values were obtained for the cube batch and the beam batch of each mixture.

Both slumps are low and well below the 50 mm targeted in the mix design, despite effective water–cement ratios of 0.49–0.52. The difference between the two mixtures (1 mm) is within the precision of the slump test, so the two concretes should be regarded as having similar workability; by Equation (5), the slump of crushed granite concrete was 6.67% lower than that of river gravel concrete. The slightly lower value for crushed granite is consistent with the rounded geometry and smoother surface texture of gravel particles, which reduce internal friction and facilitate easier movement of particles within the fresh concrete matrix.

Conversely, the angular and rough-textured nature of crushed granite particles increases interparticle friction and reduces mobility, leading to slightly lower workability. Similar observations were reported by Přikryl (2021) and Sufian et al. (2025), who found that naturally occurring gravel aggregates generally produce more workable concrete than crushed stone aggregates.

From a practical standpoint, both mixtures were of low workability and required compaction on a vibrating table; the small difference between them is of little practical significance.

Table 5: Workability Characteristics of Concrete

Concrete Type	Cement (kg)	Sand (kg)	Aggregate (kg)	Water (kg)	Slump (mm)
Crushed Granite Concrete	7.5	13.0	26.62	3.9	14
River Gravel Concrete	7.5	13.0	26.62	3.9	15

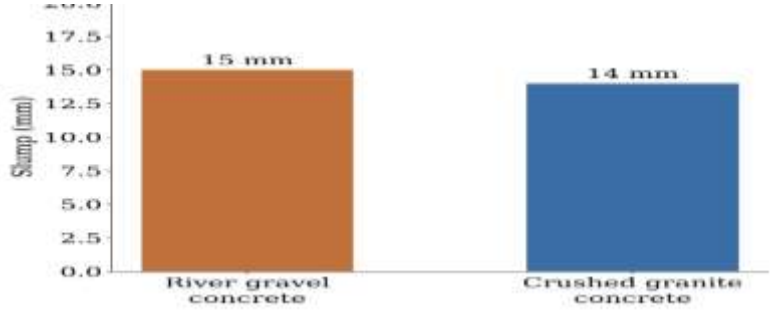


Figure 6: Slump of River Gravel Concrete and Crushed Granite Concrete

Compressive Strength Performance

The compressive strength results for individual cubes are presented in Tables 6 and 7 and illustrated in Figure 7, and are summarised in Table 10.

The crushed granite cubes had a mean compressive strength of 33.32 MPa (SD 3.51 MPa, 95% CI 30.81–35.82 MPa, n = 10), compared with 29.90 MPa (SD 3.64 MPa, 95% CI 27.30–32.51 MPa, n = 10) for the river gravel cubes, a difference of 11.41% (Equation 5). The difference was statistically significant at the 5% level (Welch's t = 2.14, df ≈ 18.0, p = 0.047), although the confidence intervals overlap and the margin is small. Each set contained two markedly lower results (26.67 and 27.56 MPa for crushed granite; 23.11 and 23.56 MPa for river gravel), which were retained because the laboratory record gives no reason to exclude them; because the test age of individual cubes was not recorded, it cannot be established whether these values reflect an earlier test age or specimen defects. The superior strength performance of crushed granite concrete may be attributed to two factors: the angular geometry of crushed granite particles, which promotes stronger interparticle interlocking within the concrete matrix, thereby increasing resistance to compressive loading, and the rough surface texture of granite particles, which provides a larger contact area for cement hydration products, resulting in stronger adhesion between aggregate and cement paste.

This trend agrees with Aginam et al. (2013), Nwafor and Aho (2018), Salman et al. (2021) and Onwasigwe and Onodagu (2024), all of whom reported higher compressive strength for concrete containing crushed granite than for gravel concrete.

The mean strengths of both concretes were close to or above 30 MPa. However, compressive strength alone does not establish structural suitability: use in structural members also requires compliance with the relevant design code (for example, a characteristic strength established from an adequate number of tests at a known age, and durability and exposure requirements), which was outside the scope of this study.

Table 6: Compressive Strength Results for Crushed Granite Concrete Cubes (150 mm)

Cube	Mass (kg)	Density (kg/m³)	Failure load (kN)	Compressive strength (MPa)
1	8.445	2502.2	760	33.78
2	8.425	2496.3	808	35.91
3	8.277	2452.4	600	26.67
4	8.255	2445.9	780	34.67
5	8.850	2622.2	800	35.56
6	8.455	2505.2	740	32.89
7	8.435	2499.3	828	36.80
8	8.287	2455.4	620	27.56
9	8.235	2440.0	750	33.33
10	8.840	2619.3	810	36.00
Mean	–	2503.8	749.6	33.32

Table 7: Compressive Strength Results for River Gravel Concrete Cubes (150 mm)

Cube	Mass (kg)	Density (kg/m³)	Failure load (kN)	Compressive strength (MPa)
1	8.069	2390.8	520	23.11
2	8.495	2517.0	680	30.22
3	8.337	2470.2	720	32.00
4	8.455	2505.2	744	33.07
5	8.437	2499.9	700	31.11
6	8.079	2393.8	530	23.56
7	8.475	2511.1	660	29.33
8	8.347	2473.2	730	32.44
9	8.445	2502.2	734	32.62
10	8.447	2502.8	710	31.56
Mean	–	2476.6	672.8	29.90

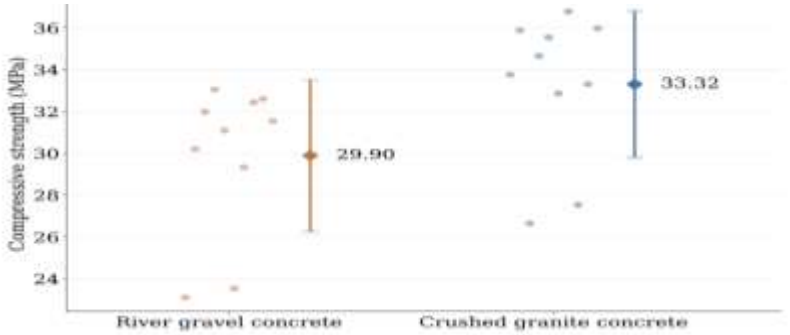


Figure 7: Compressive Strength of Individual Cubes (Light Markers) And Mean ± SD for Each Aggregate Type (N = 10)

Flexural Strength Performance

The flexural test results are presented in Table 8 and Figure 8. Similar to the compressive strength results, crushed granite concrete exhibited higher flexural resistance than river gravel concrete.

At 28 days, the crushed granite beams failed at a mean load of 11.0 kN (SD 1.58 kN, 95% CI 9.04–12.96 kN, n = 5), compared with 7.0 kN (SD 1.58 kN, 95% CI 5.04–8.96 kN, n = 5) for the river gravel beams. Because all beams had the same dimensions and were tested with the same arrangement, flexural strength is directly proportional to failure load, so the flexural strength of crushed granite concrete was 57.14% higher than that of river gravel concrete (Equation 5). This difference was statistically significant (Welch's $t = 4.00$, $df = 8$, $p = 0.004$).

Absolute flexural strengths are obtained from the failure loads in Table 8 using Equation (4) and the support span; for centre-point loading of these 100 mm × 100 mm beams, f_r (MPa) = 0.0015 × P (kN) × L (mm). Absolute flexural strengths could not be calculated because the support span and loading arrangement were not recorded. The comparison is therefore limited to the failure loads of beams with identical dimensions.

Table 8: Flexural Test Results for 100 Mm × 100 Mm × 450 Mm Beams at 28 Days (CG = Crushed Granite Concrete; RG = River Gravel Concrete)

Beam	CG mass (kg)	CG density (kg/m³)	CG failure load (kN)	RG mass (kg)	RG density (kg/m³)	RG failure load (kN)
1	11.865	2636.7	12	10.865	2414.4	6
2	11.855	2634.4	10	10.854	2412.0	8
3	11.860	2635.6	13	10.860	2413.3	7
4	11.850	2633.3	9	10.850	2411.1	9
5	11.870	2637.8	11	10.870	2415.6	5
Mean	–	2635.6	11.0	–	2413.3	7.0

Note: density = mass ÷ beam volume (0.0045 m³).

Flexural strength is strongly influenced by crack initiation and propagation mechanisms within the concrete matrix. The enhanced aggregate interlock and stronger aggregate–paste bond associated with crushed granite contributed to improved resistance against tensile stresses generated during bending.

The higher flexural strength observed suggests improved crack resistance. These findings are consistent with the observations of Smarzewski and Stolarski (2022) and Jahami et al. (2024), who reported that aggregate morphology significantly influences tensile and flexural behaviour.

For structural members subjected to bending stresses, such as beams, slabs, pavements and bridge decks, the results indicate a potential advantage for crushed granite aggregates (Traore et al., 2026), which should be confirmed by tests on a larger number of beams.

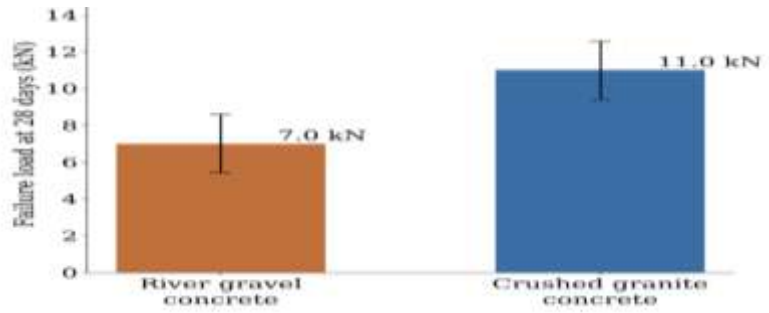


Figure 8: Flexural Failure Load Of River Gravel and Crushed Granite Concrete Beams at 28 Days (Mean ± SD, N = 5)

Performance Comparison

To provide a clearer comparison of the influence of aggregate type on concrete properties, the percentage differences between crushed granite and river gravel concrete (Equation 5) are summarized in Table 9. River gravel concrete had a marginally higher slump, whereas crushed granite concrete had a higher compressive strength and flexural failure load. The largest relative difference was in flexural failure load (57.14%), followed by compressive strength (11.41%). These results indicate that aggregate type has a substantial effect on the mechanical performance of concrete.

Table 9: Percentage Difference between Crushed Granite Concrete and River Gravel Concrete (Equation 5, Relative to River Gravel Concrete)

Property	River Gravel	Crushed Granite	Percentage Difference (%)
Slump (mm)	15	14	−6.67
Mean Compressive Strength (MPa)	29.90	33.32	+11.41
Mean Cube Density (kg/m³)	2476.6	2503.8	+1.10
Mean 28-Day Flexural Failure Load (kN)	7.0	11.0	+57.14

Note: for beams of identical size tested with the same arrangement, flexural strength is proportional to failure load, so the percentage difference in failure load equals the percentage difference in flexural strength.

Statistical Reliability of Experimental Results

The statistical summary is presented in Table 10. The coefficients of variation of compressive strength were 10.53% for crushed granite concrete and 12.18% for river gravel concrete, with ranges of 26.67–36.80 MPa and 23.11–33.07 MPa, respectively. Part of this scatter may reflect differences in test age, which was not recorded for individual cubes, so the variability should be interpreted with caution.

For the beams (n = 5 per group, all tested at 28 days), the coefficient of variation of failure load was 14.37% for crushed granite concrete and 22.59% for river gravel concrete. The 95% confidence intervals of the mean failure loads (9.04–12.96 kN and 5.04–8.96 kN) do not overlap, consistent with the significant difference reported in Section 3.5.

Given the small number of specimens, these statistics describe the present test programme only; larger samples tested at known ages would be needed to establish characteristic strengths.

Table 10: Statistical Summary of Mechanical Properties (Compressive Strength in Mpa; Flexural Failure Load In Kn)

Property	Aggregate Type	n	Mean	Standard Deviation	Coefficient of Variation (%)	Minimum	Maximum
Compressive Strength	Crushed Granite	10	33.32	3.51	10.53	26.67	36.80
Compressive Strength	River Gravel	10	29.90	3.64	12.18	23.11	33.07
Flexural Failure Load	Crushed Granite	5	11.00	1.58	14.37	9.00	13.00
Flexural Failure Load	River Gravel	5	7.00	1.58	22.59	5.00	9.00

Comparative Evaluation with Previous Studies

The comparison of the present findings with previous studies is presented in Table 11.

The mean compressive strengths obtained in this study (33.32 MPa for crushed granite and 29.90 MPa for river gravel concrete) are of the same order as the 28-day values reported by Onwasigwe and Onodagu (2024) and higher than those of Aginam et al. (2013) (Table 11). In all three studies, crushed granite concrete was stronger than gravel concrete; the granite-to-gravel strength ratio was 1.11 in the present study, compared with 1.13–1.25 and 1.26 in the earlier studies.

Because these studies used different mix proportions, water–cement ratios, aggregate sources and curing regimes, and the cube test age was not recorded in the present study, the comparison is qualitative only: agreement in absolute strength values cannot be taken as validation of the present results. Differences between studies may be attributed to variations in aggregate mineralogy, particle shape, grading, water–cement ratio, curing regime and specimen preparation.

Table 11: Comparison of Present Study with Previous Investigations (Different Mixes and Curing Conditions; Qualitative Comparison Only)

Study	Coarse Aggregates Compared	Compressive Strength, Granite / Gravel (MPa)	Granite-to-Gravel Ratio
Aginam et al. (2013)	Crushed granite vs washed gravel (20 mm), 28 days	25.1 / 20.0	1.26
Onwasigwe & Onodagu (2024)	Granite vs Umunya gravel (1:2.2:3.7, w/c 0.60), 28 days	35.02 / 31.01	1.13
Onwasigwe & Onodagu (2024)	Granite vs Nkpor gravel (1:2.2:3.7, w/c 0.60), 28 days	35.02 / 27.93	1.25

Study	Coarse Aggregates Compared	Compressive Strength, Granite / Gravel (MPa)	Granite-to-Gravel Ratio
Present study	Crushed granite vs river gravel (1:1.73:3.55, w/c 0.52); age not recorded	33.32 / 29.90	1.11

Engineering Significance

The results demonstrated that aggregate selection markedly influences both fresh and hardened concrete properties. While river gravel provided marginally better workability, crushed granite delivered higher compressive and flexural strengths.

The improved strength performance observed for crushed granite concrete suggests a higher load-carrying capacity. Crushed granite may therefore be preferred where higher strength is required; however, its use in heavily loaded members such as reinforced concrete beams, columns, foundations, bridge decks and rigid pavements must be justified by design-code compliance and by additional evidence (e.g., characteristic strength from larger samples tested at known ages, modulus of elasticity and durability) that was not obtained in this study. River gravel may remain attractive for applications where ease of placement, reduced compaction effort, and local material availability are primary considerations.

Sustainability and Durability Implications

The use of locally sourced aggregates contributes to sustainable construction by reducing transportation requirements and associated environmental impacts. River gravel may therefore provide economic and environmental benefits where local deposits are readily available, although no cost or life-cycle analysis was carried out in this study.

However, the superior strength performance achieved by crushed granite suggests the development of a denser concrete microstructure, which may contribute to improved durability characteristics, including reduced permeability and enhanced resistance to environmental deterioration. Although durability was not directly investigated in this study, the observed strength enhancement indicates the potential for improved long-term performance. Future investigations should incorporate durability assessment and life-cycle analysis to establish the overall sustainability performance of both aggregate types.

Contribution and Limitations of the Study

Building on earlier comparative studies (Aginam et al., 2013; Onwasigwe & Onodagu, 2024; Salman et al., 2021), the present investigation reports aggregate properties, workability, compressive strength and flexural behaviour for river gravel and crushed granite concrete batched at the same proportions and cured under the same conditions, using aggregates available in Makurdi, Nigeria.

The study has several limitations. The number of specimens was small (ten cubes and five beams per aggregate type); the test age of individual cubes was not recorded; only one mix proportion was examined; both coarse aggregates were single-sized and both mixtures had low workability; the effective water–cement ratio was higher than the design value; flexural behaviour was compared through the failure loads of beams of identical size; and durability, modulus of elasticity and cost were not evaluated. The findings therefore provide comparative evidence to guide aggregate selection rather than design values.

CONCLUSION

This study comparatively evaluated the performance of concrete produced using crushed granite and river gravel as coarse aggregates by examining their physical properties, workability characteristics, compressive strength, and flexural strength performance under identical mix-design and curing conditions.

The physical characterization results showed that both aggregates possessed suitable specific gravity and bulk density values for normal-weight concrete production. River gravel exhibited slightly higher workability, achieving a slump of 15 mm compared with 14 mm for crushed granite concrete; both mixtures were of low workability and the difference between them was negligible. However, the slightly better workability did not translate into superior mechanical performance.

The crushed granite cubes had a mean compressive strength of 33.32 MPa, 11.41% higher than the 29.90 MPa of the river gravel cubes ($p = 0.047$). At 28 days, the crushed granite beams failed at a mean load of 11.0 kN compared with 7.0 kN for the river gravel beams, corresponding to a 57.14% higher flexural strength ($p = 0.004$).

The superior strength performance of crushed granite concrete was attributed to its angular particle shape, rough surface texture, improved aggregate interlocking, stronger aggregate–paste bond, and enhanced interfacial transition zone characteristics, which collectively contributed to more efficient stress transfer and greater resistance to crack propagation.

These conclusions are subject to the small number of specimens tested, the unrecorded test age of the cubes, and the use of a single mix proportion with an effective water–cement ratio of 0.52, and to the absence of durability, stiffness and cost data. Crushed granite is recommended where higher compressive and flexural strengths are required, but its use in heavily loaded structural members should be supported by design-code compliance and by further testing on larger specimen sets at known ages; durability and cost assessments are recommended for future work.

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