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Optimization Of Locally Sourced Coarse Aggregates In Anambra State for Concrete Production

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ABSTRACT: *In order to determine whether coarse aggregates from Ukpor, Onitsha, and Nkwelle-Ezunaka in Anambra State, Nigeria, are suitable as alternatives to traditional granite, this study examines the compressive strength behavior of concrete made with these aggregates. The goal is to promote the economical and sustainable use of regional resources in the production of structural concrete. Concrete cubes were cured for seven, fourteen, and twenty-one days after being cast using a mix ratio of 1:2:4 and a water–cement ratio of 0.6. Sieve analysis, slump, and compressive strength tests were among the laboratory experiments carried out in compliance with ASTM and BS standards. The impact of aggregate source and curing time on compressive strength was statistically assessed using Response Surface Methodology (RSM) and Two-Way Analysis of Variance (ANOVA).The aggregate source and curing period both had a substantial influence ($p < 0.001$), according to the ANOVA results; however, their interaction was not statistically significant ($p > 0.05$). Following Onitsha (18.03 N/mm²) and Nkwelle-Ezunaka (17.48 N/mm²), concrete manufactured with Ukpor aggregates achieved the highest mean compressive strength of 19.65 N/mm² at 21 days, according to Tukey's post-hoc comparison. With a high coefficient of determination ($R^2 = 0.9242$) and a strong quadratic relationship ($\beta = 0.7167$, $p = 0.0028$), the RSM model demonstrated that compressive strength increases with curing time. At approximately 38 days of curing and an aggregate quality index of 1.8, the optimal condition was predicted. The results show that, because of their higher strength performance, Ukpor aggregates are a dependable and readily available substitute for granite in reinforced concrete construction.*

KEYWORDS: *Coarse aggregate, Curing time, Compressive strength, Two-Way ANOVA, and Response Surface Methodology (RSM)*

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I. INTRODUCTION

The strength, durability, and versatility of concrete in a wide range of structural applications make it one of the most widely used construction materials (Neville, 2011; Mehta and Monteiro, 2014). To ensure the safety and longevity of buildings and other engineering structures, adequate compressive strength must be verified before construction (Shetty, 2013). Compressive strength, which is a key property for quality control and structural design, defines the capacity of hardened concrete to resist loads without failure (Ogunjiofor *et al*., 2023a; Ogunjiofor *et al.,* 2023b; Ogunjiofor *et al.,* 2023c)

Aggregates constitute approximately 70–80% of the total volume and weight of concrete, and their characteristics significantly influence the properties of both fresh and hardened concrete (Mamlouk and Zaniewski, 2019). The mineral composition, particle shape, surface texture, and grading of the aggregates have major effects on the strength, stiffness, and durability of concrete

(Neville, 2011; Shetty, 2013). Strength development and long-term durability depend on the bond between the cement paste and the aggregate particles, which is controlled by the quality of the aggregates (Mehta and Monteiro, 2014). Studies have shown that increasing the proportion of coarse aggregates enhances compressive strength up to an optimum level; beyond that point, excessive content may lead to voids and poor compaction, which reduce strength (Ogunjiofor *et al*., 2023a).

Concrete continues to be the foundation of global industrial and infrastructure growth, and current research has concentrated on enhancing its performance by optimizing its component materials (Anene *et al.,* 2025; Ogunjiofor *et al*., 2023d). Particularly, coarse aggregates have been found to be an important factor in determining mechanical behavior, affecting durability, shrinkage, modulus of elasticity, and compressive strength (Abubakar and Waziri, 2021). Recent findings on natural fibre additives, such as coconut and oil palm fibres, have demonstrated notable improvements in tensile and compressive strength, confirming their potential for sustainable concrete enhancement (Ogunjiofor *et al*., 2024; Ogunjiofor *et al.,* 2025).

A movement toward the use of locally sourced aggregates to reduce carbon emissions related to material transportation and promote economic self-reliance has also been brought about by the increased interest in sustainable construction (Oyekan and Kamiyo, 2023). This aligns with studies on concrete produced using different aggregate types that have enhanced the mechanical stability and sustainability of construction materials (Adebayo and Yusuf, 2021). According to studies, locally accessible aggregates can produce compressive strengths that are on par with or even higher than those of imported granites when they are correctly graded and tested (Abubakar and Waziri, 2021; Oyekan and Kamiyo, 2023) This validates the dependability of local materials for the construction of structural concrete.

According to previous studies conducted in Anambra State, Nigeria, locally accessible building materials have varying technical qualities based on their geological origins (Anene *et al*., 2025; Ogunjiofor *et al.,* 2023d). The performance of concrete and other building materials throughout the region is greatly impacted by these differences (Anene *et al.,* 2025). However, different geological formations have quite different aggregate properties. For example, river-washed gravels are more workable but have weaker interfacial bonds, whereas basaltic aggregates have greater density and crushing strength than sedimentary limestone aggregates (Ogunjiofor *et al*., 2025). Because of regional differences in mineralogy and weathering trends, aggregate deposits in Nigeria vary, which results in uneven concrete performance. Evidence from geotechnical studies in the state demonstrates significant variation in soil particle composition and engineering behavior among different localities, reinforcing the need for thorough site-based material characterization to support safe and effective engineering design (Ogunjiofor *et al.,* 2025).

Several studies have highlighted how crucial it is to comprehend how aggregate origin affects concrete qualities in order to achieve consistent quality control, especially when materials are acquired from diverse locations (Asante *et al.,* 2022; Falade *et al*., 2020). The significance of appropriate soil and geotechnical design prior to beginning any structural or infrastructural building has also been highlighted by recent studies (Anene *et al.,* 2023). Achieving adequate and effective foundation performance and overall structural stability requires an understanding of the soil profile and material behavior.

Despite these advancements, a large number of indigenous builders and craftspeople in Anambra State continue to rely on unreliable aggregate suppliers without conducting adequate testing, which leads to uneven concrete quality and occasional structural failures (Shetty, 2013). In order to ensure safe and sustainable construction practices, it is now crucial to locate trustworthy and locally accessible aggregate sources that can offer sufficient strength and durability (Mamlouk and Zaniewski, 2019). Ukpor, Onitsha, and Nkwelle-Ezunaka represent three distinct geological formations in Anambra State: Onitsha is known for its fluvial aggregates from River Niger deposits, Ukpor for its angular sedimentary rock fragments, and Nkwelle-Ezunaka for lateritic-derived materials with comparatively high clay content (Obot and Udoh, 2020).

These differences frequently affect the density, absorption rate, and bonding properties of concrete aggregates, which in turn influence compressive strength at various curing periods. Only a few studies have systematically compared the strength performance of coarse aggregates from these specific zones using statistical modeling tools such as Analysis of Variance (ANOVA) and Response Surface Methodology (RSM). Prior research in adjacent regions has primarily focused on fine aggregates and soil mechanics (Okoye and Mbonu, 2023; Ogunjiofor and Ayodele, 2023). In recent researches, efforts are on top gear to find alternative sustainable materials such as geopolymer materials, palm kernel shells, and coal ash in concrete production in order to mitigate the impacts of climate change (Ogunjiofor *et al.,* 2023; Obi *et al*., 2023; Ogunjiofor and Okpala, 2025).

This study examines and compares the compressive strength of concrete produced in Anambra State using coarse aggregates from Ukpor, Onitsha, and Nkwelle-Ezunaka. By evaluating the impact of aggregate origin on workability and compressive strength, the goal is to identify the most suitable aggregate source for structural concrete applications. The results will provide engineers, contractors, and builders with data-driven recommendations for selecting affordable and durable aggregates suitable for sustainable development in the region.

The current study, which aims to establish a quantitative relationship between aggregate source and compressive-strength development in concrete, is justified by this existing knowledge gap. By combining statistical modeling with laboratory experimentation, the research provides a data-driven methodology for selecting the most appropriate local aggregates for structural applications. The outcome will promote resource efficiency and sustainability in Nigeria's construction industry while supporting cost-effective and reliable infrastructure development.

II. MATERIALS AND METHODS

A. Materials for the Study

The materials utilized for this study comprised water, fine aggregate, coarse aggregate and Ordinary Portland Cement (OPC).

1. Cement: Dangote 3X Ordinary Portland Cement (Grade 42.5) was the main binder used in this investigation. It was purchased from a reliable dealer in Uli, Anambra State, and stored in a dry condition before use to prevent premature hydration.

2. Fine Aggregate: Natural river sand obtained from the riverbed of River Niger in Onitsha, Anambra State, was used as the fine aggregate for this investigation. In accordance with BS 882 (1992) specifications for fine aggregates used in concrete production, it was clean, well-graded, and free from deleterious or organic impurities.

3. Coarse Aggregate: The coarse aggregates used in this investigation were obtained from three locations in Anambra State, Nigeria—Ukpor, Onitsha, and Nkwelle-Ezunaka. These areas represent different aggregate characteristics and geological formations. The samples were designated as follows: Sample A – Ukpor aggregate; Sample B – Onitsha aggregate; and Sample C – Nkwelle-Ezunaka aggregate. The aggregates were suitable for use in structural concrete as they were clean, angular, and well-graded.

4. Water: Potable water obtained from the Civil Engineering Laboratory of Chukwuemeka Odumegwu Ojukwu University, Uli, was used for mixing and curing the concrete.

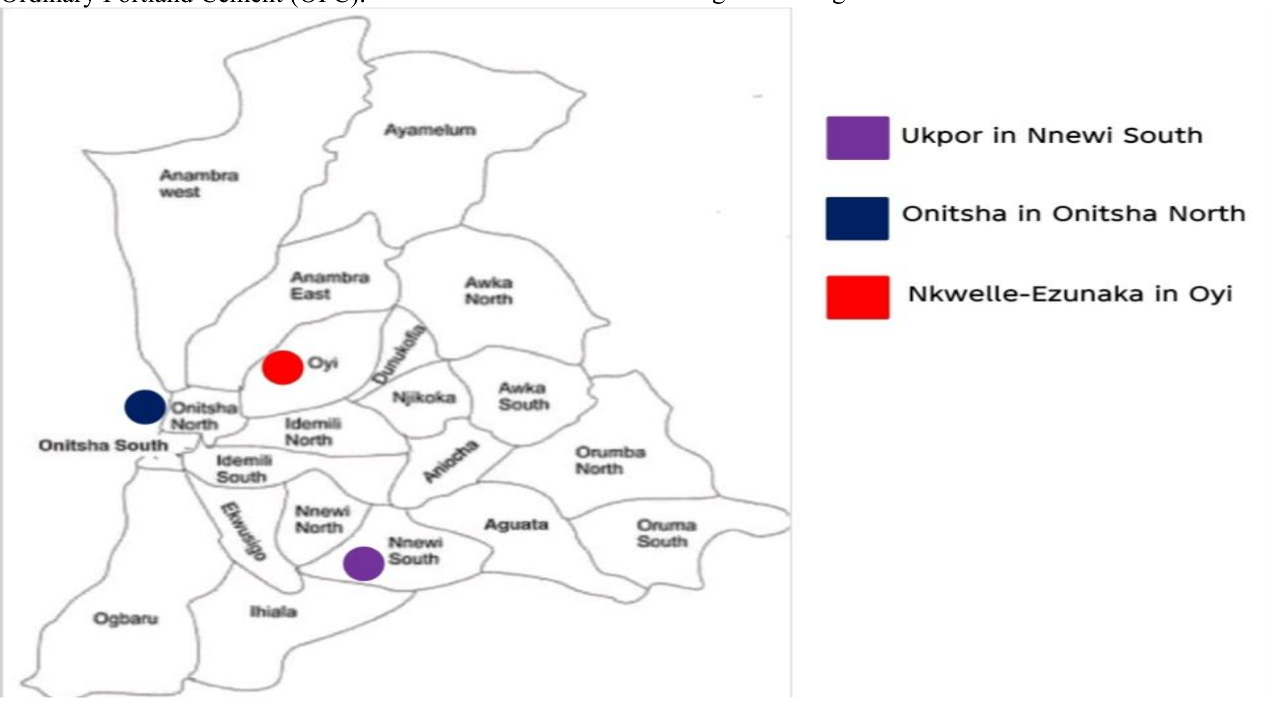

Fig.1 : Map of Anambra State showing the three sample collection locations: Ukpor, Onitsha, and Nkwelle-Ezunaka

B. Physical and Geotechnical Aggregate Testing: In accordance with ASTM and British Standard (BS 812) specifications, a comprehensive laboratory analysis was conducted to determine the suitability of the fine and coarse aggregates for concrete production.

1. Sieve Analysis: To determine the particle-size distribution of the aggregates, they were mechanically sieved for 15 minutes after being oven-dried at 110 ± 5 °C. The particle-size distribution curves were plotted based on the percentage retained on each sieve. Sieve sizes of 40 mm, 20 mm, 12.5 mm, 10 mm, and 4.75 mm were used for the coarse aggregates, while 1.18 mm, 600 µm, and 300 µm sieves were used for the fine aggregates.

2. Moisture Content and Bulk Density: The moisture content of each sample was determined by comparing the wet and dry weights of the aggregates after oven drying. To evaluate the degree of particle packing and the corresponding void ratio, the bulk density was measured under both loose and compacted conditions.

3. Specific Gravity and Water Absorption: The specific gravity test was performed using the pycnometer method in accordance with BS 812: Part 109 (1990). Water absorption was determined by immersing oven-dried aggregate samples in water for 24 hours and recording the corresponding weight increase.

4. Fine Aggregate Atterberg Limits: The fine aggregate was classified using the Unified Soil Classification System (USCS) by calculating the Plasticity Index (PI = LL − PL) and determining the Liquid Limit (LL) and Plastic Limit (PL). To ensure that the aggregates satisfied the requirements for concrete production, all test results were compared with the relevant standard specification limits.

C. Mixing, Casting, and Curing of Concrete: Representative samples were prepared and tested to evaluate the effect of coarse aggregate source on the compressive strength of concrete. All experimental procedures were conducted in accordance with British Standard (BS 1881) for concrete testing.

1. Proportion of Mix: A mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) was adopted with a water–cement ratio of 0.6. To ensure consistency and uniformity of the concrete mix, each component was accurately weighed.

2. Mixing: The mixing process was carried out manually on a clean, waterproof, and non-absorbent platform to obtain a homogeneous blend. After thoroughly combining the dry constituents, water was gradually added until the desired workability was achieved.

3. Casting and Compaction: Fresh concrete was poured into steel cube molds measuring 150 × 150 × 150 mm in three equal layers. To ensure proper compaction and eliminate entrapped air, each layer was tamped with 25 blows of a standard tamping rod. After casting, the top surfaces were immediately leveled and finished smoothly.

4. Curing: After 24 hours, the concrete cubes were demolded and placed in a curing tank containing clean water maintained at a temperature of 27 ± 2 °C. The specimens were cured for standard strength-development periods of 7, 14, and 21 days. A total of 27 cubes—nine from each aggregate source—were prepared to enable a reliable comparative analysis.

D. Concrete Tests (Fresh and Hardened): Two main tests were conducted to evaluate the performance of concrete produced with different coarse aggregate sources—the compressive strength test on hardened concrete to assess structural performance, and the slump test on fresh concrete to determine workability. All tests were performed in accordance with British Standard (BS 1881) specifications.

1. Slump Test (Workability): The workability of the fresh concrete was assessed in accordance with BS 1881: Part 102 (1983). The slump cone was filled in three equal layers, each compacted with 25 blows of a tamping rod. After filling, the cone was carefully lifted vertically, and the decrease in the concrete's height was measured to determine the slump value. This measurement provided an indication of the uniformity and ease of placement of the fresh concrete.

2. Compressive Strength Test: The compressive strength of the cured concrete cubes was determined in accordance with BS 1881: Part 116 (1983) using a Compression Testing Machine (CTM). Each cube was cleaned and centrally positioned between the machine's loading plates before testing. The load was applied uniformly and continuously at a rate of 140 kN/min until failure occurred. The compressive strength (f_n) of each specimen was calculated using the following relation:

$$f_c = P/A \quad \text{.......... (1)}$$

Where:

P is the maximum load at failure (kN), and A is the cross-sectional area of the cube (mm^2).

Average compressive strength values were then computed after 7, 14, and 21 days of curing to evaluate the strength development trend for each aggregate source.

E. Modeling and Statistical Analysis: The experimental results were analyzed using statistical and modeling techniques to establish the relationship between aggregate source, curing time, and compressive strength. Response Surface Methodology (RSM) and Two-Way Analysis of Variance (ANOVA) were employed in the analytical process for model development and validation.

1. Two-Way Analysis of Variance (ANOVA): This method was employed to evaluate the effects of two independent factors—aggregate source and curing time on the compressive strength of concrete. The statistical analysis was carried out to determine whether variations in aggregate source or curing duration had a significant influence on the strength of the concrete. The study also examined the interaction between the two factors. A significance level of $p < 0.05$ was adopted to identify statistically significant differences among the samples.

2. Response Surface Methodology (RSM): A quadratic regression model was developed using the Response Surface Methodology (RSM) to describe the influence of aggregate source and curing time on the compressive strength of concrete. The model parameters were evaluated using Analysis of Variance (ANOVA) to determine the prediction accuracy, model significance, and adequacy of fit.

The general quadratic model is expressed in equation (2):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} X_1{}^2 + \beta_{22} X_2{}^2 + \beta_{12} X_1 X_2$$

Where:

Y = predicted compressive strength (N/mm^2)

X_1 = curing time (days)

X_2 = aggregate source (coded variable)

β_0 = constant term

β_1, β_2 = linear coefficients

β_{11}, β_{22} = quadratic coefficients

β_{12} = interaction coefficient

ε = random error term

3. Software and Model Evaluation: All statistical analyses were performed using Minitab 19 software. The adequacy and reliability of the developed model were verified using statistical indicators such as the coefficient of determination (R^2), adjusted R^2, and p-values. The predictive validity of the model was further confirmed by comparing the experimental compressive strength results with the model's predicted values. This analytical approach provided an accurate understanding of how aggregate source and curing time jointly influence the development of concrete compressive strength.

III. RESULTS AND DISCUSSION

A. Results

This section presents the findings obtained from the laboratory investigations on the fine and coarse aggregates used in concrete production. It discusses the physical properties of the materials, the performances of both fresh and hardened concrete, and the statistical modeling of the compressive strength results. Tables and figures are employed to illustrate variations, correlations, and trends observed among the tested samples, providing a comprehensive understanding of the behaviour and suitability of the materials for structural applications.

Table 1: Grain size distribution and Atterberg Limit Results of fine aggregate.

Aggregate	Sieve Analysis				Atterberg Limits & Gradation Parameters					
	Sieve Size	% Passing	Mass Retained (g)	% Retained	LL	PL	PI	CU	CC	FM
Sharp sand	1.18 mm	42.2	411	20.55	12.9	–	–	7.2	2	2.33
	600 µm	16.5	79	3.95						
	300 µm	1.5	521	26.05						

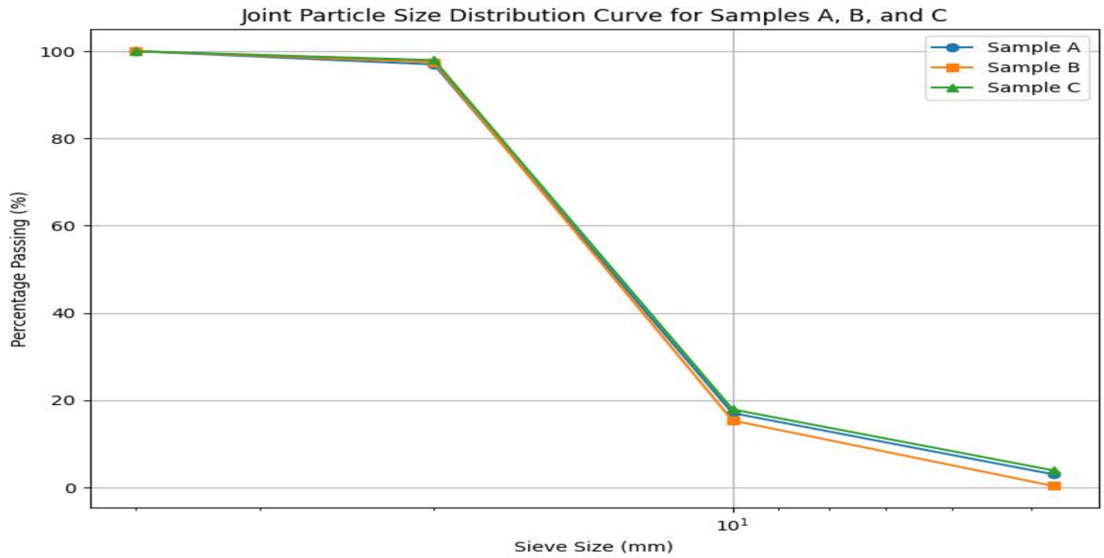

Fig. 2: joint particle size distribution curve for samples A,B and C

The Unified Soil Classification System (USCS): The Unified Soil Classification System (USCS) analysis classified the tested fine aggregate as SW–SM**,** indicating well-graded silty sand. This means the material consists mainly of sand with a wide range of particle sizes and a small proportion of silt. The well-graded nature of the material suggests good particle size distribution, which generally enhances compaction characteristics and improves the engineering performance of the aggregate in construction applications.

Table 2: Fine Aggregate Sample Physical Properties

Trial sample	Bulk density (kg/m^3)		Specific gravity (kg/m^3)		
	loose	compacted	OD	SSD	Apparent
Fine aggregate	1465	1570	2.55	2.67	2.74
ASTM Benchmark	1120 – 1920		2.40 – 3.00		

■OD = Oven Dry, SSD = Saturated Surface Dry

Table 3: Two-Way ANOVA Summary of the Effects of Aggregate Source And Curing Duration On Concrete Compressive Strength

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Sample	2	53.53	26.77	37.857	3.56e-07
Day	2	129.16	64.58	91.340	3.76e-10
Sample × Day	4	4.11	1.03	1.453	0.258
Residuals	18	12.73	0.71		

Table 4: Tukey HSD Post-Hoc Comparison of Compressive Strength across Aggregate Sources, Curing Days, and Their Interaction

(a) Pair wise Comparison by Aggregate Source (Sample)

Comparison	Mean Diff	Lower CI	Upper CI	Adjusted p-value
Onitsha – Nkwelle	0.756	-0.256	1.767	0.1660
Ukpor – Nkwelle	3.292	2.281	4.304	0.0000
Ukpor – Onitsha	2.537	1.525	3.548	0.0000

(b) Pair wise Comparison by Curing Duration (Day)

Comparison	Mean Diff	Lower CI	Upper CI	Adjusted p-value
14 – 7	3.067	2.055	4.078	1.1e-06
21 – 7	5.338	4.326	6.349	< 2e-16
21 – 14	2.271	1.259	3.283	5.6e-05

(c) Significant Interactions between Sample and Day (Selected Results)

Comparison	Mean Diff	Lower CI	Upper CI	Adjusted p-value
Ukpor:7 – Nkwelle:7	3.680	1.274	6.086	0.0011
Ukpor:14 – Nkwelle:7	7.217	4.811	9.622	0.0000
Ukpor:21 – Onitsha:7	7.017	4.611	9.422	0.0000
Ukpor:14 – Onitsha:14	3.527	1.121	5.932	0.0018
Ukpor:14 – Nkwelle:14	4.030	1.624	6.436	0.0004

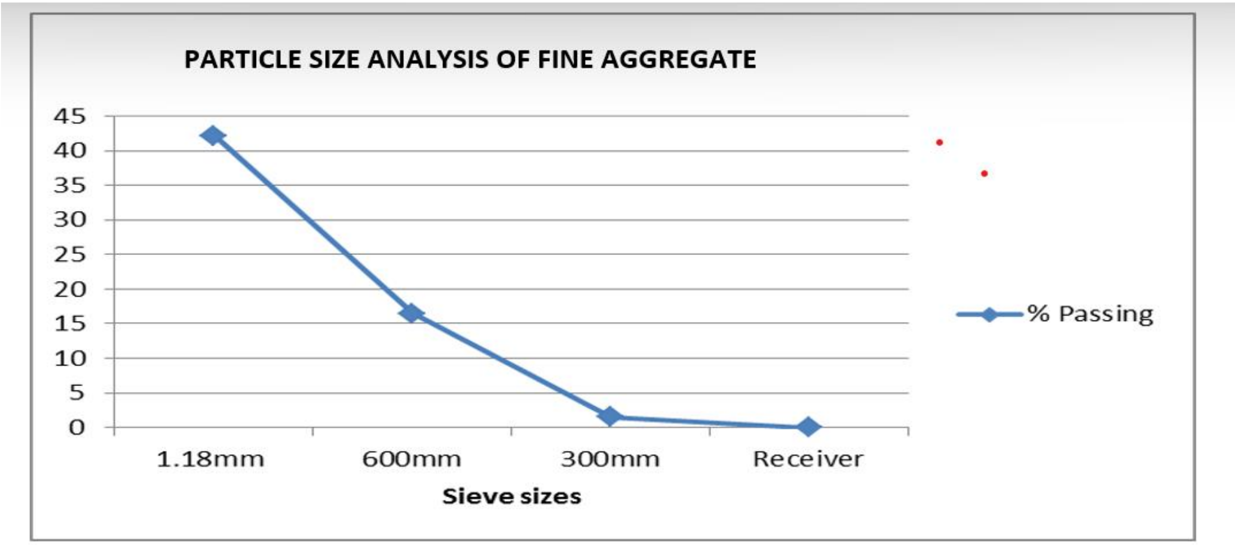

Fig. 3: Sieve analysis of the fine aggregate

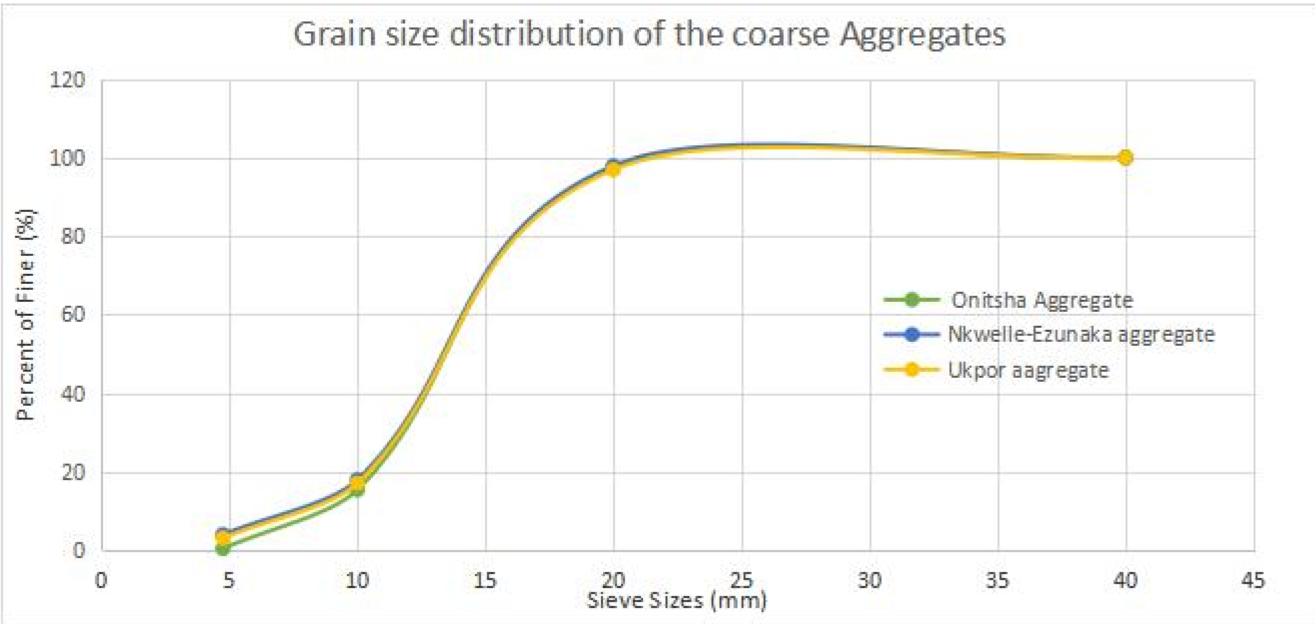

Fig.4: Sieve analysis of the coarse aggregate

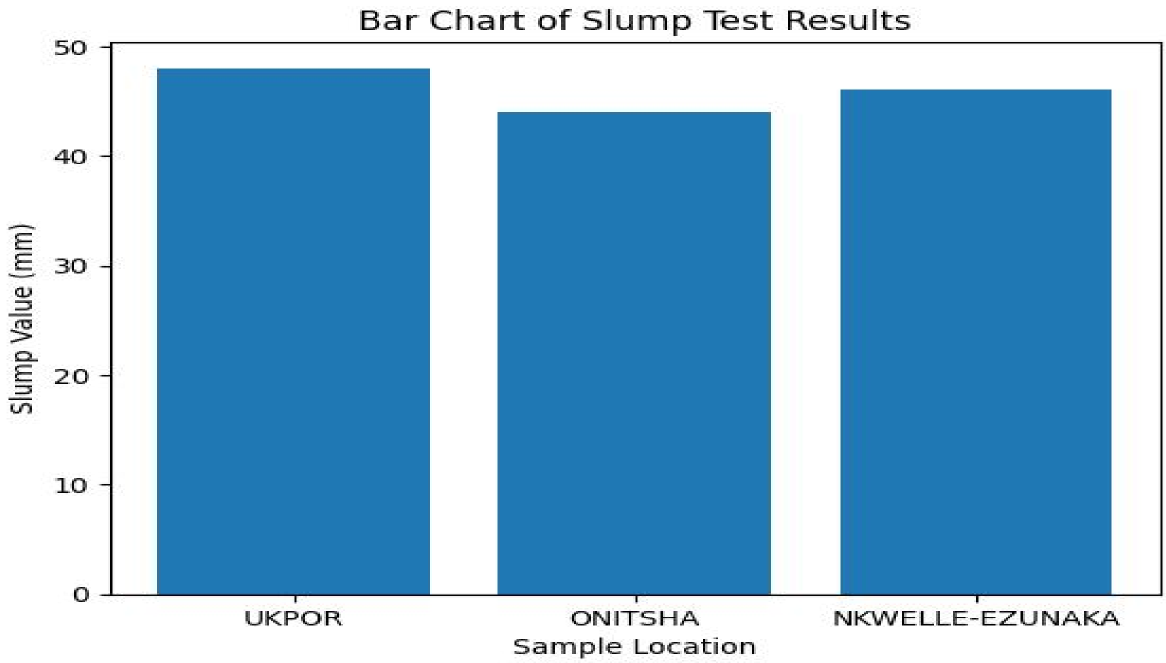

Fig.5: Bar Chart Representation of Slump Value for Concrete Mixes from Different Aggregate Sources

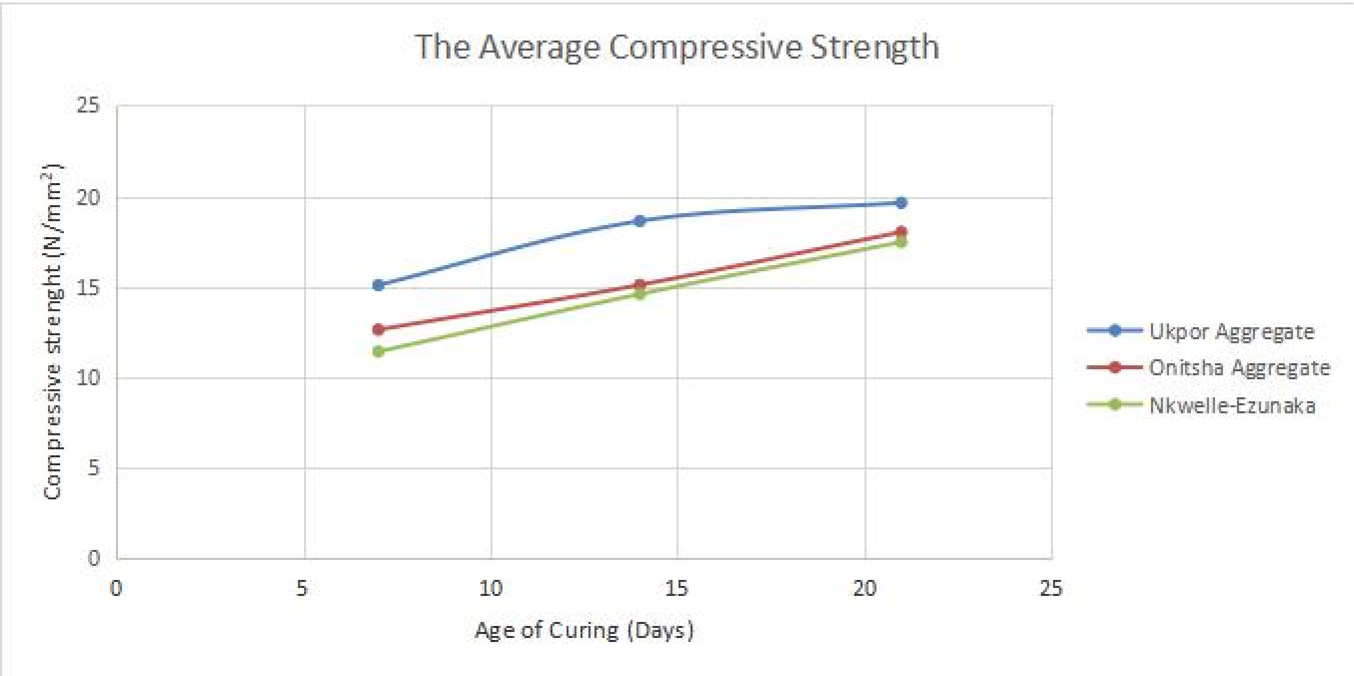

Fig. 6: Graphical Representation of the Average Compressive Strength

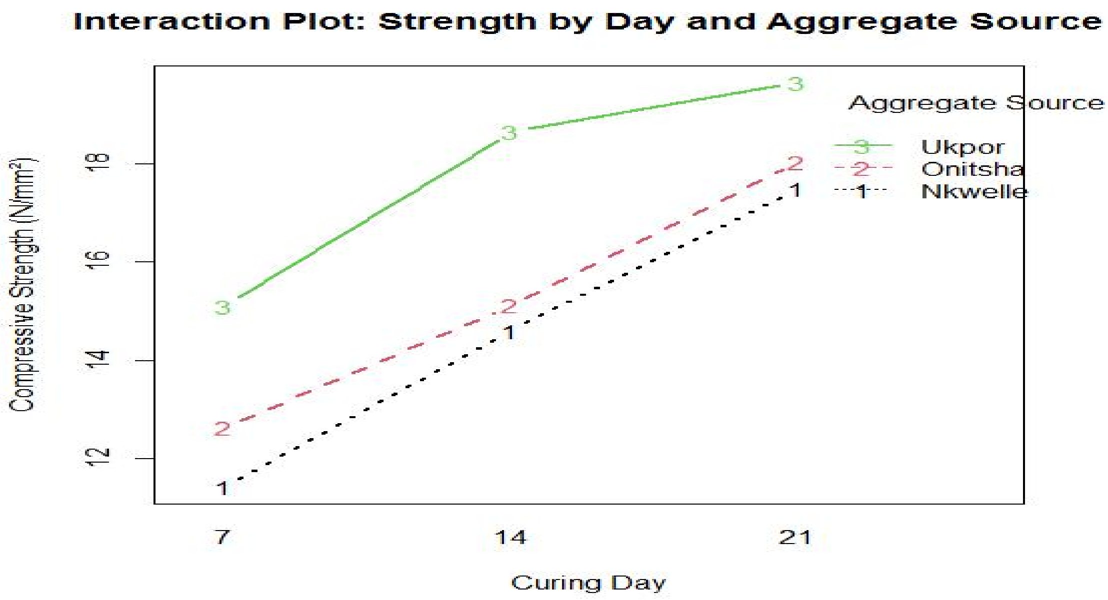

Fig.7: Interaction Plot of Compressive Strength by Curing Day and Aggregate Source

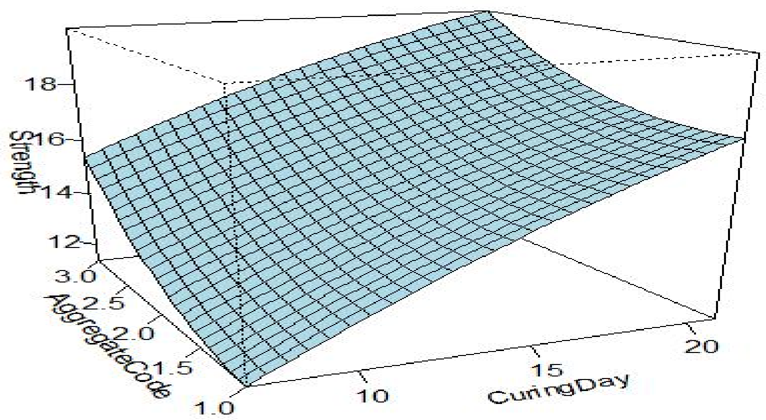

Fig. 8: 3D Response Surface Plot of Concrete Strength by Curing Day and Aggregate Source

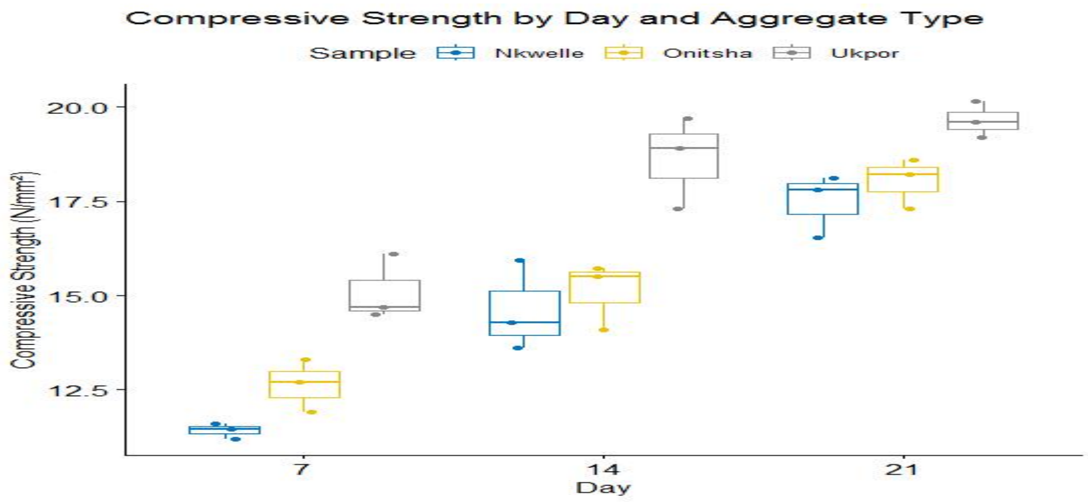

Fig. 9: Box plot of Compressive Strength of Concrete by Curing Day and Aggregate Type

B. Discussion

As shown in Table 1 and Figure 1, the fine aggregate was well graded with a fineness modulus of 2.33, coefficient of uniformity (Cu) of 7.2, and coefficient of curvature (Cc) of 2.0, meeting ASTM standards. The liquid limit of 12.9% in table 1, according to USCS classification shows that the fine aggregate is SW–SM, indicating well-graded silty sand with good particle size distribution and minor silt content.
Bulk densities of 1465 and 1570 kg/m³ (loose and compacted) and specific gravities between 2.55–2.74 (Table 2) were within standard limits. The laboratory test for organic impurities in the fine aggregate sample showed a lighter coloration**,** indicating that organic impurities were not present in the sample**.** This result suggests that the fine aggregate is clean and suitable for use in concrete production**,** as the absence of organic matter helps prevent interference with cement hydration and strength development. The coarse aggregate (figures 2 and 4) satisfied IS: 383 grading limits. Ukpor aggregates showed the most uniform curve, implying better packing, while Onitsha and Nkwelle-Ezunaka were slightly less consistent. Slump-test results (Figure 5) ranged from 44–48 mm, classifying the mixes as low-workability concrete (BS 1881 Part 102). The slightly higher slump for Ukpor indicated improved grading and cohesion.

Compressive strength (Figure 6) increased with curing age across all sources. Ukpor achieved 15.10, 18.64, and 19.65 N/mm² at 7, 14, and 21 days, while Onitsha and Nkwelle-Ezunaka recorded 12.63, 15.11, 18.03 N/mm² and 11.42, 14.60, 17.48 N/mm², respectively, following the trend Ukpor > Onitsha > Nkwelle-Ezunaka.

ANOVA results (Table 3) showed significant effects of aggregate source ($F = 37.857$, $p < 0.001$) and curing duration ($F = 91.340$, $p < 0.001$), but no significant interaction ($p = 0.258$). Tukey HSD (Table 4) confirmed Ukpor's superior performance (mean differences 3.29 N/mm² vs. Nkwelle and 2.54 N/mm² vs. Onitsha, $p < 0.001$). The interaction plot (Figure 5) showed parallel trends, and the response-surface model (Figure 8) revealed a strong positive relationship between curing time and strength ($R^2 = 0.9242$). The box plot (Figure 9) indicated that Ukpor aggregates had the highest median strength and least variability.
Overall, both aggregate source and curing time significantly affected compressive strength. Ukpor aggregates provided the best results due to superior grading and density, making them a durable and cost-effective local alternative to imported granite for structural applications in Anambra State.

IV. CONCLUSION AND RECOMMENDATION

The study found that the source of the aggregate and the length of the curing period had a substantial impact on the concrete's compressive strength. Because of their better grading, density, and bonding properties, concrete made with Ukpor aggregates showed the maximum strength at all curing ages, followed by Onitsha and Nkwelle-Ezunaka. These differences ($p < 0.001$) were validated by statistical analysis, which also revealed a substantial association ($R^2 = 0.9242$) between strength development and curing time. As a result, Ukpor aggregates can be considered a dependable local substitute for imported granite and offer superior structural performance.

For non-structural and moderate-strength concrete applications, Onitsha and Nkwelle-Ezunaka aggregates are suitable; however, for maximum strength, proper curing for 21–28 days is strongly recommended. These locally available aggregates will help reduce construction costs, enhance sustainability, and promote the use of indigenous materials in civil engineering works.

Because of their high strength and consistent quality, Ukpor aggregates are therefore highly recommended for the production of structural concrete in Anambra State. Their adoption will encourage sustainable construction practices, reduce dependence on imported materials, and promote the efficient utilization of local resources for infrastructural development.

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