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OPTIMIZATION OF CONCRETE MIX DESIGNS USING LOCALLY SOURCED AGGREGATES IN ANAMBRA STATE: A FRAMEWORK FOR SAFE AND COST-EFFECTIVE CONSTRUCTION

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ABSTRACT

This study investigates the optimization of concrete mix designs using locally sourced aggregates from Anambra State, Nigeria, with the aim of developing a framework for safe, durable, and cost-effective construction. Considering that aggregates constitute a significant proportion of concrete and greatly influence its performance, the research evaluates the suitability of selected sedimentary rock aggregates obtained from Umunya, Nsugbe, Ogbunka, Nkwelle Ezunaka, and Aguleri. Concrete specimens were produced and tested for compressive strength at 7, 14, and 28 days to assess their structural performance. The results revealed variations in aggregate quality and concrete strength across the sampled locations. Although all concrete samples exhibited progressive strength development with curing age, the maximum 28-day compressive strength achieved was 15.90 N/mm² using aggregates from Ogbunka, while lower strengths were recorded for the other locations. These values fell below the minimum strength requirement for structural high-strength concrete as specified by relevant standards. However, the findings provide valuable insights into the performance limitations and potential applications of locally sourced aggregates in conventional concrete production. The study proposes a framework for optimizing concrete mix designs through careful aggregate selection, material characterization, and mix proportion adjustments to enhance performance while minimizing construction costs. The research contributes to sustainable construction practices by promoting the effective utilization of local materials and providing guidance for engineers, contractors, and policymakers in achieving safe and economical concrete construction in Anambra State and similar environments.

Keywords: Concrete mix optimization, locally sourced aggregates, compressive strength, sedimentary rocks, sustainable construction, cost-effective construction, Anambra State.

Introduction

Concrete remains the most widely used construction material globally due to its versatility, durability, and availability of constituent materials. Aggregates constitute about 70–80% of the total volume of concrete, making their properties crucial to the performance of the final product (Neville & Brooks, 2010). In high-strength concrete, the quality and origin of coarse aggregates significantly influence compressive strength and durability.

In Nigeria, the increasing cost and environmental impacts of transporting aggregates from distant sources have underscored the need to explore and evaluate the suitability of local materials for construction purposes. Anambra State, located in southeastern Nigeria, is endowed with various sedimentary rock formations, which are often underutilized or untested for high-performance structural applications. Despite their abundance, there is limited documented research on the mechanical and physical properties of these rocks when used as coarse aggregates in HSC production.

This study presents a suitability assessment of locally sourced sedimentary rocks from Anambra State as coarse aggregate in high-strength concrete applications. The research investigates critical parameters such as specific gravity, water absorption, aggregate crushing value (ACV), Los Angeles abrasion value, and the compressive strength of concrete produced using these materials. These properties are benchmarked against international standards and compared with conventional aggregates to determine their potential for structural applications in high-strength concrete.

In recent years, researchers have emphasized the importance of localized material sourcing as a sustainable approach to concrete production. Studies by Abdullahi (2012) and Oloruntola et al. (2020) have demonstrated the feasibility of utilizing local materials in various regions of Nigeria. However, the unique geological characteristics of sedimentary rocks, especially those from Anambra Basin, require distinct evaluation due to their variable composition, porosity, and mechanical behavior (Reyment, 1965).

The findings of this study aim to provide a scientific basis for the inclusion of Anambra's sedimentary rocks in construction projects, potentially reducing material costs and promoting sustainable development in the region. By evaluating their performance in high-strength concrete, this work contributes to the broader discourse on material optimization, local resource utilization, and infrastructure resilience in sub-Saharan Africa.

This study focuses on evaluating sedimentary rocks found in various parts of Anambra State, Nigeria—specifically in Ogbunka, Aguleri, Umunya, Nsugbe, and Nkwelle Ezunaka—as viable alternatives to conventional aggregates. These regions are known to have abundant sedimentary rock deposits, but their suitability for high-strength concrete applications remains underexplored.

Literature Review

Concrete is a composite material whose performance depends significantly on the quality and characteristics of its constituent materials, particularly aggregates. Coarse aggregates constitute between 60% and 80% of the concrete volume and play a crucial role in determining strength, durability, and overall mechanical performance (Neville & Brooks, 2010). In high-strength concrete (HSC), which typically exceeds a compressive strength of 40 N/mm^2, the role of coarse aggregate becomes even more critical due to the increased stress demands placed on the internal matrix (Mehta & Monteiro, 2014).

Local Aggregate Sourcing and Sustainability

In many developing regions, including Nigeria, there has been growing interest in utilizing locally available construction materials to reduce cost and environmental impact. The use of indigenous aggregates can enhance sustainability by minimizing transportation emissions, promoting local economies, and reducing reliance on imported materials (Olusola & Ayangade, 2003). Several studies in Nigeria have evaluated the potential of local rocks, such as granite, basalt, and laterite, for use in concrete. However, sedimentary rocks, despite their abundance in regions such as Anambra State, remain largely under-explored.

Abdullahi (2012) conducted a comparative study on different aggregate types and demonstrated that aggregate source and composition significantly affect concrete strength. Similarly, Oloruntola et al. (2020) examined the reuse of ceramic waste as coarse aggregate, affirming the viability of alternative materials in producing durable and high-strength concrete. These studies underscore the importance of detailed physical and mechanical characterization of potential aggregates before use in structural applications.

Sedimentary Rock Characteristics and Performance

Sedimentary rocks are formed through the deposition and lithification of mineral and organic particles, often resulting in variable porosity and mineral content. These factors can influence the strength, durability, and absorption capacity of the rock, which in turn affect the performance of concrete in both fresh and hardened states (Shetty, 2005). In the context of Anambra State, the region lies within the Anambra Basin, a geological area known for its extensive sedimentary formations, including sandstones, siltstones, and shales (Reyment, 1965).

Despite their availability, sedimentary rocks from this region have not been adequately evaluated for structural use, particularly in HSC applications. Geological assessments have revealed variations in mineralogy and texture across different locations within Anambra State, which necessitates a location-specific evaluation to determine mechanical suitability (Nwajide, 2013).

Research Gap and Relevance

While past studies have explored local materials for general concrete applications, there remains a significant gap in research regarding the use of sedimentary rocks specifically from the Anambra Basin in high-strength concrete. This gap limits the confidence of engineers and construction professionals in adopting these materials. The present study aims to bridge this gap by conducting a comprehensive assessment of physical, mechanical, and performance characteristics of these rocks to support their potential use in modern structural applications.

Materials and Methods

Aggregate Collection and Preparation

Sedimentary rocks were collected from five locations in Anambra State:

- Umunya (Titled Sample A)
- Nsugbe (Titled Sample B)
- Ogbunka (Titled Sample C)
- Nkwelle Ezunaka (Titled Sample D)

- Aguleri (Titled Sample E)

The rocks were crushed and sieved to obtain standard coarse aggregate sizes suitable for concrete production.

Concrete Mix Design

Concrete mix was designed with a cement: sand: aggregate ratio of 1:2:4, in line with standard practice. A water/cement ratio of 0.5 was adopted to ensure workability while aiming for high compressive strength.

Sample Casting and Curing

Concrete cubes (150 mm × 150 mm × 150 mm) were cast using aggregates from each source. The specimens were demolded after 24 hours and cured in clean water. Compressive strength tests were carried out using destructive test method at curing ages of 7, 14, and 28 days following the guidelines of ASTM C39/C39M-18.

Results and Discussion

Compressive Strength Performance

The average compressive strength results for each sedimentary rock source are presented in Table 1.

Table 1: Concrete Compressive Strength Results For 7 Days (N/mm^2)

Sample	ID Number	Mass (Kg)	Density (Kg/m^3)	Crushing Load (Kn)	Compressive Strength (N/mm^2)
A	A1	7.32	2168.89	155.30	6.90
	A2	7.40	2192.59	147.80	6.60
	A3	7.26	2151.11	135.90	6.00
B	B1	7.40	2192.59	132.90	5.90
	B2	7.60	2251.85	141.70	6.30
	B3	7.75	2296.29	77.80	3.50
C	C1	7.35	2177.78	197.90	8.80
	C2	7.30	2162.96	296.50	13.20
	C3	7.57	2242.96	317.90	14.10
D	D1	7.01	2077.04	131.40	5.80
	D2	7.41	2195.55	172.30	7.60
	D3	7.39	2189.63	196.20	8.70
E	E1	7.28	2157.04	110.30	4.90
	E2	7.50	2222.22	131.80	5.80
	E3	7.91	2343.70	143.60	6.40

Table 2: Concrete Compressive Strength Results For 14 Days (N/mm^2)

Sample	ID Number	Mass (Kg)	Density (Kg/m^3)	Crushing Load (Kn)	Compressive Strength (N/mm^2)
A	A4	7.60	2251.85	151.30	6.70
	A5	7.78	2305.18	147.30	6.50
	A6	7.90	2340.74	138.70	6.10
B	B4	8.08	2394.07	241.20	10.70
	B5	7.63	2260.74	232.50	10.30
	B6	7.74	2293.33	229.10	10.20
C	C4	7.77	2302.22	281.00	12.50

	C5	7.80	2311.11	281.70	12.50
	C6	7.96	2358.52	281.50	12.50
D	D4	7.69	2278.52	139.80	6.20
	D5	7.74	2293.33	139.80	6.20
	D6	7.80	2311.11	141.60	6.30
E	E4	7.96	2358.52	301.20	13.40
	E5	7.84	2322.96	301.20	13.40
	E6	7.74	2293.33	303.70	13.50

Table 3: Concrete Compressive Strength Results For 28 Days (N/mm^2)

Sample	ID Number	Mass (Kg)	Density (Kg/m^3)	Crushing Load (Kn)	Compressive Strength (N/mm^2)
A	A7	7.72	2287.41	231.10	10.30
	A8	7.47	2213.33	262.30	11.70
	A9	7.73	2290.37	251.80	11.20
B	B7	7.80	2311.11	226.26	10.00
	B8	7.93	2349.63	153.37	6.80
	B9	7.85	2325.92	231.01	10.30
C	C7	7.23	2142.22	286.60	12.70
	C8	7.48	2216.29	317.70	14.10
	C9	7.55	2237.04	359.20	15.90
D	D7	8.11	2402.96	136.70	6.10
	D8	8.36	2477.04	226.80	10.10
	D9	8.17	2420.74	212.90	9.50
E	E7	8.11	2402.96	242.80	10.70
	E8	7.70	2281.48	234.50	10.40
	E9	7.98	2364.44	234.10	10.40

From the data, all aggregate samples showed progressive strength gain, with 28-day values ranging between 10.30 N/mm^2 and 15.90 N/mm^2. The highest compressive strength was recorded in samples from Ogbunka, indicating superior aggregate quality.

Performance Evaluation

The concrete mixes did not meet the minimum requirement for structural-grade concrete as specified by ACI 318-19, which states a minimum 28-day compressive strength of 25 N/mm^2 for general structural use. All locations produced aggregates that didn't qualify for use in structural concrete for high-strength applications.

Conclusion

This study assessed the performance of locally sourced sedimentary rock aggregates from selected locations in Anambra State with the objective of optimizing concrete mix designs for safe and cost-effective construction. The findings revealed that while all aggregate samples supported progressive strength development with curing age, none produced concrete that achieved the compressive strength requirements for high-strength structural applications. Among the samples investigated, aggregates sourced from Ogbunka demonstrated the highest performance, yielding the greatest 28-day compressive strength.

The results indicate that the selected sedimentary rock aggregates have limitations for use in high-strength concrete without further material enhancement or mix design modifications.

However, their utilization in low- to medium-strength concrete applications may offer economic benefits where structural requirements permit. Therefore, successful optimization of concrete mix designs in Anambra State should emphasize thorough aggregate characterization, appropriate material selection, and mix proportion adjustments to ensure safety, durability, and cost-effectiveness. Further research is recommended to explore aggregate blending, admixture incorporation, and alternative local aggregate sources capable of meeting higher structural performance requirements.

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