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Effect of Partial Replacement of Crushed Granite with Local Coarse Aggregate in Concrete

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ABSTRACT

This study investigated the effect of partially replacing crushed granite with locally available sandstone (locally referred to as “wili-wili stone”) on selected fresh and hardened properties of concrete. The experimental programme was conducted at the Civil Engineering Laboratory of Nnamdi Azikiwe University, Awka, using Ordinary Portland Limestone Cement, sharp sand, crushed granite and local sandstone aggregate. Granite was replaced with sandstone at 0%, 10%, 20% and 30% levels. Concrete mixtures of 1:1:2, 1:2:4, 1:3:6 and 1:4:8 were investigated. Slump, 28-day compressive strength and aggregate water absorption were determined. The results showed a consistent reduction in slump as the sandstone content increased. For the 1:1:2 mixture, slump decreased from 76 mm at 0% replacement to 56 mm at 30% replacement; corresponding reductions were observed for the other mix proportions. The water absorption of sandstone was 1.76%, compared with 1.13% for granite, indicating greater water demand associated with the local aggregate. The compressive strength response depended strongly on the mix proportion. In the 1:2:4 mixture, the mean 28-day strength increased from 7.32 N/mm² for the control to 9.33 N/mm² at 10% replacement, but declined at 20% and subsequently recovered to 8.41 N/mm² at 30%. In the richer 1:1:2 mixture, strength increased progressively to 12.45 N/mm² at 30% replacement. Conversely, the 1:3:6 mixture remained below the control at all replacement levels, while the 1:4:8 mixture showed an irregular response. These results demonstrate that a single universal optimum replacement percentage cannot represent the suitability of local sandstone; performance is strongly dependent on mixture proportion and aggregate moisture condition. For the conventional 1:2:4 mix investigated, 10% replacement provided the highest measured 28-day compressive strength and a relatively small loss of workability. The study concludes that properly characterized local sandstone can serve as a partial coarse-aggregate replacement, provided its higher absorption is considered during mix proportioning and quality control.

KEYWORDS: Concrete, crushed granite, local sandstone, wili-wili stone, coarse aggregate, partial replacement, slump, compressive strength, water absorption

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1. Introduction

Concrete is one of the most widely used construction materials because it can be produced from relatively abundant mineral constituents and can be tailored to a wide range of applications. Aggregates occupy a major proportion of concrete volume and therefore have a substantial influence on its fresh and hardened

properties. The increasing demand for construction materials has intensified interest in alternative aggregate sources that can reduce pressure on natural resources while maintaining acceptable engineering performance. Recent environmental assessments also show that aggregate production and transportation can contribute materially to the environmental burden associated with concrete production (Roh et al., 2020).

Crushed granite is widely used as coarse aggregate because of its strength, durability and angular particle characteristics. Nevertheless, its cost can become significant where quarry products have to be transported over long distances. The use of suitable local aggregate can potentially reduce transportation requirements and diversify the supply of coarse aggregate. Such substitution must, however, be based on laboratory evidence because aggregate mineralogy, particle shape, grading, porosity, surface texture and cleanliness can significantly influence concrete behaviour.

Sandstone is a sedimentary rock whose engineering performance varies with mineral composition, cementation, porosity and geological origin. Consequently, sandstone should not be treated as a uniform aggregate type. Published investigations have shown that selected quartz-sandstone aggregates can be used in concrete at partial replacement levels when their properties and grading are properly controlled (Kumar, Gupta, Shrivastava, Csetenyi, et al., 2016; Kumar, Gupta, & Shrivastava, 2016). A Nigerian study by Olanike and Adeyemi (2016) also examined the strength properties of concrete containing sandstone coarse aggregate, demonstrating the relevance of sandstone as a locally available aggregate material.

Previous work on partial replacement of granite with washed gravel found that workability decreased as gravel content increased, while compressive strength reached a maximum at 20% replacement before declining at higher replacement levels (Echeta et al., 2013). This illustrates that the optimum replacement level is material- and mix-specific rather than universal.

The present study therefore evaluates a locally available coarse aggregate, identified in the source study as sandstone or “wili-wili stone,” as a partial replacement for crushed granite. The investigation focuses on slump, aggregate water absorption and 28-day compressive strength for four concrete mix proportions and four replacement levels.

2. Aim and Objectives

The aim of this study is to assess the effect of partial replacement of crushed granite with local sandstone coarse aggregate on the performance of concrete.

- Determine the water absorption of the crushed granite and local sandstone aggregates.
- Evaluate the effect of sandstone replacement on the workability of fresh concrete.
- Determine the 28-day compressive strength of concrete containing 0%, 10%, 20% and 30% sandstone replacement.
- Compare the performance of the different concrete mix proportions.
- Identify a practically suitable replacement level for the investigated conventional mix while considering both strength and workability.
- Discuss the potential economic and environmental significance of using locally sourced aggregate.

3. Review of Related Literature

3.1 Role of Aggregate in Concrete

Aggregates form the major volume fraction of conventional concrete and influence packing, workability, density, strength and durability. Neville (2011) emphasizes that aggregate characteristics such as grading, shape, surface texture, strength and porosity affect concrete performance. Aggregate quality is therefore an essential consideration when introducing an alternative coarse aggregate.

3.2 Sandstone as Coarse Aggregate

The suitability of sandstone for concrete depends on its geological and physical characteristics. Kumar, Gupta, Shrivastava, Csetenyi, et al. (2016) investigated quartz sandstone as a partial replacement of conventional coarse aggregate and emphasized the importance of clay content, particle morphology and combined aggregate grading. In a related study, Kumar, Gupta, and Shrivastava (2016) reported that selected quartz-sandstone aggregates could replace conventional coarse aggregate at levels up to 40% without considerable loss of the preferred strength under the conditions studied. These results should not be generalized to all sandstone sources because sandstone properties vary considerably.

3.3 Partial Replacement of Crushed Granite

Echeta et al. (2013) investigated washed gravel as a partial replacement for crushed granite in 1:2:4 concrete with a water-cement ratio of 0.65. They reported decreasing workability with increasing gravel content and a maximum 28-day compressive strength at 20% replacement. The difference between those findings and the present results reinforces the importance of source-specific experimental characterization.

3.4 Sustainability and Local Materials

The use of locally available aggregates can contribute to more resource-efficient construction when the material satisfies the required technical specifications. Roh et al. (2020) demonstrated that aggregate choice can affect the environmental and economic performance of concrete, although the environmental benefit of an alternative aggregate depends on its processing, transport distance and other life-cycle factors. Therefore, claims of sustainability should be supported by actual local supply and processing conditions.

4. Materials and Methodology

4.1 Materials

The materials used were Portland limestone cement, sharp sand, crushed granite, local sandstone coarse aggregate (locally referred to as “wili-wili stone”) and clean drinking water. The cement was reported in the source document as Dangote Portland Cement, Grade 42.5R, purchased from a dealer at Amaenyi, Awka. The fine aggregate was sharp sand obtained from the same area. Both the crushed granite and local sandstone were approximately 0.5 inch nominal size and were obtained from a dealer at Amaenyi, Awka. Water used during the laboratory work was potable water obtained within Nnamdi Azikiwe University, Awka.



Figure 1; Crushed Granite (wili wili)



Figure 2 local coarse aggregate (wili wili)

4.2 Experimental Programme

The study considered four replacement levels: 0%, 10%, 20% and 30% of the crushed granite by the local sandstone. Four nominal mix proportions were investigated: 1:1:2, 1:2:4, 1:3:6 and 1:4:8. The 0% mixture served as the control for each mix proportion.

Replacement level	Granite (%)	Sandstone (%)
0%	100	0
10%	90	10
20%	80	20
30%	70	30



Figure 3: Casting of concrete cubes



Figure 4: Concrete cubes in moulds

4.3 Slump Test

Slump was determined to assess the consistency and workability of the fresh concrete. A cleaned slump cone was placed on a level, non-absorbent surface. Fresh concrete was placed in three approximately equal layers, with each layer tamped 25 times using a tamping rod. The surface was struck off and the cone was lifted vertically. The difference between the original cone height and the height of the slumped concrete was recorded as the slump.



Figure 5: Slump cone



Figure 6: filling the slump cone



Figure 7: measuring of slump

4.4 Compressive Strength Test

Concrete cubes measuring 150 mm × 150 mm × 150 mm were cast. The fresh concrete was placed in three layers and compacted by tamping. The specimens were demoulded after approximately 24 h and cured in water at approximately 27 ± 2°C for 28 days. Three cubes were tested for each mixture. The maximum load at failure was recorded and compressive strength was calculated from:

$f_c = P/A$

where f_c is compressive strength (N/mm²), P is the maximum applied load (N), and A is the loaded cross-sectional area (mm²). For a 150 mm cube, A = 22,500 mm².

The original document contained unit-notation errors in this calculation; the corrected engineering units are N and mm², giving compressive strength in N/mm².

4.5 Water Absorption of Aggregates

Water absorption was determined after washing and immersing aggregate samples, followed by surface drying and oven drying. The absorption was calculated as:

Water absorption (%) = [(WSSD − WOD) / WOD] × 100

Where WSSD is the saturated-surface-dry mass and WOD is the oven-dry mass. This is consistent with the general principle of aggregate absorption determination specified in BS EN 1097-6 (British Standards Institution, 2012) and ASTM C127 (ASTM International, 2023).



Figure 8: Water absorption test machine



Figure 9: immersed basket + aggregate samples

5. Results and Discussion

5.1 Slump Results

Mix ratio	0%	10%	20%	30%
1:1:2	76 mm	70 mm	61 mm	56 mm
1:2:4	64 mm	60 mm	50 mm	45 mm
1:3:6	52 mm	43 mm	30 mm	21 mm
1:4:8	45 mm	37 mm	32 mm	18 mm

The results show a consistent decrease in slump as sandstone replacement increased. For the 1:1:2 mixture, slump decreased from 76 mm at 0% replacement to 56 mm at 30%, representing a 26.3% reduction. For 1:2:4, the reduction was from 64 mm to 45 mm (29.7%); for 1:3:6, from 52 mm to 21 mm (59.6%); and for 1:4:8, from 45 mm to 18 mm (60.0%).

The increasingly pronounced loss of workability in the leaner mixtures indicates that the response is influenced not only by aggregate replacement but also by paste content. The measured water absorption of the sandstone (1.76%) was higher than that of granite (1.13%), so the sandstone could demand more mixing water if its moisture condition is not corrected. Aggregate particle characteristics can also influence fresh concrete behaviour. Similar reductions in workability with increasing alternative coarse aggregate content have been reported by Echeta et al. (2013).

The slump classification in the source data should be interpreted cautiously. A shear slump can indicate non-uniform behaviour, and slump type alone should not be treated as a direct measure of strength. For field application, the required workability should be specified according to the placing and compaction method rather than by adopting a single generic slump range.

5.2 Water Absorption

Aggregate	Water absorption
Crushed granite	1.13%
Local sandstone (wili-wili stone)	1.76%

The sandstone recorded 1.76% absorption compared with 1.13% for granite, an increase of approximately 55.8% relative to the granite value. This indicates that the sandstone is more absorptive under the test conditions. Higher aggregate absorption can alter the effective water-cement ratio if aggregate moisture condition is not properly accounted for. Consequently, the aggregate should be brought to a known moisture condition or appropriate batch-water corrections should be made during mix proportioning.

The observed difference is consistent with the broader literature showing that sandstone properties can vary with porosity, mineral composition and geological origin (Kumar, Gupta, Shrivastava, Csetenyi, et al., 2016; Kumar, Gupta, & Shrivastava, 2016). The absorption result therefore supports the need for source-specific characterization rather than assuming that all local sandstone will behave like conventional granite.

5.3 Compressive Strength at 0% Replacement

Mix ratio	Mean 28-day strength (N/mm²)
1:1:2	7.62
1:2:4	7.32
1:3:6	7.90
1:4:8	2.45

The control mixtures provide the reference against which all replacement levels were evaluated. The 1:1:2, 1:2:4 and 1:3:6 mixtures produced mean strengths between 7.32 and 7.90 N/mm², whereas the 1:4:8 mixture produced only 2.45 N/mm². The very low strength of the 1:4:8 mixture is consistent with its low cement content and demonstrates that nominal mix ratio is a major determinant of strength.

5.4 Compressive Strength at 10% Replacement

Mix ratio	0%	10%	Change at 10%
1:1:2	7.62	7.65	+0.4%
1:2:4	7.32	9.33	+27.5%
1:3:6	7.90	4.78	−39.5%
1:4:8	2.45	3.90	+59.2%

At 10% replacement, the 1:2:4 mixture produced the most notable improvement, increasing from 7.32 to 9.33 N/mm², approximately 27.5%. The 1:1:2 mixture remained essentially unchanged, while the 1:3:6 mixture showed a substantial reduction. The 1:4:8 mixture increased from a low control strength of 2.45 to 3.90 N/mm².

These contrasting responses demonstrate that replacement percentage cannot be evaluated independently of the overall mix proportion. The increase observed in the 1:2:4 mixture may be associated with improved particle packing or aggregate-paste interaction, but the present experiment did not include microstructural testing and therefore does not establish that mechanism directly.

5.5 Compressive Strength at 20% Replacement

Mix ratio	0%	20%	Change at 20%
1:1:2	7.62	11.36	+49.1%
1:2:4	7.32	6.12	−16.4%
1:3:6	7.90	4.61	−41.6%
1:4:8	2.45	5.73	+133.9%

At 20% replacement, the 1:1:2 mixture increased substantially to 11.36 N/mm², while the 1:2:4 and 1:3:6 mixtures fell below their respective controls. The 1:4:8 mixture also increased substantially relative to its low control value. The large percentage increase in the 1:4:8 mixture should not be interpreted as evidence that the mixture is structurally adequate; it reflects the very low strength of its control mixture.

5.6 Compressive Strength at 30% Replacement

Mix ratio	0%	30%	Change at 30%
1:1:2	7.62	12.45	+63.4%
1:2:4	7.32	8.41	+14.9%
1:3:6	7.90	5.87	−25.7%
1:4:8	2.45	2.76	+12.7%

The 30% replacement level produced the highest recorded strength for the 1:1:2 mixture, 12.45 N/mm², representing a 63.4% increase over the control. The 1:2:4 mixture also exceeded its control at 30%, reaching 8.41 N/mm². However, the 1:3:6 mixture remained below its control, and the 1:4:8 mixture showed only a small increase.

The results therefore contradict a blanket statement that 10% is the optimum replacement for every mixture. Instead, the optimum measured level is mix-dependent. For the conventional 1:2:4 mixture, 10% produced the highest measured 28-day strength; for 1:1:2, the highest value occurred at 30%. This distinction is important for a scientifically defensible interpretation of the experiment.

5.7 Overall Compressive-Strength Comparison

Mix ratio	0%	10%	20%	30%	Highest measured level
1:1:2	7.62	7.65	11.36	12.45	30%
1:2:4	7.32	9.33	6.12	8.41	10%
1:3:6	7.90	4.78	4.61	5.87	0%
1:4:8	2.45	3.90	5.73	2.76	20%

The strength data reveal a non-linear and mix-dependent response. The 1:2:4 mixture, which is commonly used as a nominal conventional concrete proportion in Nigerian construction practice, recorded its highest strength at 10% sandstone replacement. The 1:3:6 mixture performed worse than its control at every replacement level. This suggests that increasing the sandstone fraction does not automatically improve concrete strength; the interaction between aggregate properties, paste content and moisture condition is critical.

5.8 Comparison with Previous Research

The present results differ in detail from Echeta et al. (2013), who reported a maximum 28-day strength at 20% washed-gravel replacement in a 1:2:4 mixture. In the present 1:2:4 series, 10% sandstone replacement produced the highest mean strength of 9.33 N/mm², while 20% reduced strength to 6.12 N/mm². The difference is reasonable because the aggregates were different materials and sources. It reinforces the conclusion that replacement limits should be established experimentally for each local aggregate.

The results are also consistent with the broader sandstone literature in one important respect: sandstone can be viable as a partial coarse aggregate, but its performance depends on its geological and physical

characteristics. Kumar, Gupta, Shrivastava, Csetenyi, et al. (2016) and Kumar, Gupta, and Shrivastava (2016) showed that selected quartz-sandstone aggregates can be used at partial replacement levels, while emphasizing the importance of grading, morphology and clay content. The current study similarly shows that water absorption and mix proportion must be considered when evaluating local sandstone.

6. Engineering Significance

The results indicate that the investigated local sandstone has potential for partial replacement of crushed granite, but its use should be controlled. The higher water absorption means that aggregate moisture must be considered during batching. Failure to account for absorption can change the effective water-cement ratio and consequently alter workability and strength.

For the 1:2:4 mixture, 10% replacement produced the highest measured 28-day compressive strength and reduced slump from 64 to 60 mm. On the basis of the present dataset, this represents a reasonable compromise between strength and workability for further investigation. Nevertheless, the measured strengths are below typical specified strengths for many structural concrete applications, so the results should not be interpreted as a recommendation to use these mixes indiscriminately in structural members.

From a sustainability perspective, local sourcing may reduce transportation requirements and dependence on quarry products. However, a complete environmental benefit would require a life-cycle assessment considering extraction, processing, transportation and service life (Roh et al., 2020).

7. Limitations of the Study

• The experimental programme reported only selected properties and did not include tensile, flexural, elastic, abrasion or long-term durability tests.

• The aggregate mineralogy and petrographic characteristics were not reported, so the exact geological basis of the sandstone behaviour cannot be established.

• Only 28-day compressive strength was reported in the source results; longer-term strength development was not evaluated.

• The study used nominal mix ratios rather than a fully optimized absolute-volume mix-design procedure.

• The number of replacement levels was limited to 0–30%, so the exact peak replacement level may lie between the tested values.

• Cost and environmental benefits were discussed qualitatively because no detailed local cost or life-cycle inventory was provided.

8. Conclusion

This study evaluated the effect of partially replacing crushed granite with locally available sandstone coarse aggregate in concrete. The investigation showed that replacement of granite with the local aggregate consistently reduced slump across all four mix proportions. The reduction became more pronounced as the replacement level increased, particularly in the leaner 1:3:6 and 1:4:8 mixtures.

The local sandstone exhibited a water absorption of 1.76%, compared with 1.13% for granite, confirming that it was more absorptive under the test conditions. This difference has practical implications for batching because aggregate moisture condition can significantly affect effective water availability and workability.

The compressive-strength results were strongly dependent on mix proportion. The 1:2:4 concrete recorded 7.32, 9.33, 6.12 and 8.41 N/mm² at 0%, 10%, 20% and 30% replacement, respectively. Thus, 10% replacement was the best-performing level for the 1:2:4 series. The 1:1:2 mixture, however, achieved its maximum measured strength of 12.45 N/mm² at 30% replacement. In contrast, the 1:3:6 mixture performed below the control at all replacement levels. These results show that there is no single universal optimum replacement percentage for the local sandstone.

Overall, the investigated sandstone can be considered a potentially useful partial coarse-aggregate material

where its properties are adequately characterized and controlled. For the 1:2:4 mixture investigated, 10% replacement provides the strongest basis for further development because it produced the highest measured strength while causing only a modest reduction in slump. Higher replacement levels should not be adopted for structural applications solely on the basis of the present results; they require additional strength and durability verification.

9. Recommendations

• Further laboratory investigations should use a controlled mix-design method and explicitly account for aggregate moisture and absorption.

• For the 1:2:4 mixture investigated, 10% sandstone replacement is recommended as the principal level for further experimental optimization.

• Before structural use, the local sandstone should be tested for crushing value, impact value, abrasion resistance, soundness, grading and deleterious materials.

• Future studies should determine splitting tensile strength, flexural strength, modulus of elasticity, permeability and long-term durability.

• Petrographic or mineralogical characterization should be undertaken to establish why the local sandstone behaves differently from granite.

• Detailed cost analysis should compare quarrying, transportation, processing and quality-control costs for granite and local sandstone.

• Where the aggregate is used in practice, routine moisture and grading checks should be maintained to ensure consistency of concrete production.

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