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Investigating the suitability of *sakasaka* sand as replacement of natural aggregates in concrete for low volume pavement construction

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Abstract. The demand for access roads to vital services is on the high side in rural areas. This demand face much challenge due to the cost of construction. However, having the opportunity to use non-conventional materials that are naturally available in meeting this demand will ease people living in such environs. It is on this note that an investigation was carried out on an indigenous, naturally available sand popularly known as Sakasaka by Ilesha indigenes to ascertain its suitability for pavement construction. The Sakasaka collected from Ilesha borrow site, Ilesha West Local Government Area of Osun State, was used to produce concrete cubes that were tested after curing for 7, 14, 21, 28, 56, and 112 days respectively to know the strength of the material and compared to theoretical strength. Prior to the cubes production, some investigations such as chemical analysis, Sieve analysis, Specific gravity and so on were carried out on the sand. The study investigates the physical properties, chemical components of Sakasaka as well as the compressive strength properties of the concrete produced at ratio 1:2:4 using Cements A, B, and C 3x brand. The total numbers of cubes cast were 162 with a concrete cube size of 150x150x150mm. Sieve analysis, specific gravity, slump tests were also carried out for different water-cement ratios for the three cement. The concrete cubes were tested at the ages of 7, 14, 21, 28, 56, and 112 days. The effects of cements (A, B, and C) on the all-in-aggregate was investigated with respect to compressive strength at different curing age. From the results obtained, the compressive strengths of cubes were 17.76 N/mm², 19.92 N/mm² and 20.5N/mm² which was in line with the standard compressive strength of concrete mix 1:2:4 at 28days.

Keywords: Low volume roads, alternative materials, concrete, compressive strength, chemical analysis.

1. Introduction

Low-volume roads (LVR) roads link rural communities with planned road networks, in addition to important general services such as schools, hospitals, farms, and markets. They comprise a significant portion of the African road network, which can be up to 80-90% of the overall network length [1]. These roads are roads with traffic volumes of not more than 400 vehicles per day. They have huge effects on economies, communication, and social interaction [2]. Use of un-conventional materials in constructing these roads depend on the technical, commercial, and environmental state of that neighbourhood [3]. Most rural areas do not have access to conventional due to the cost involved. However, there is a need to connect to important services for ease in living. To create access for locals, the only alternative is the construction of low volume roads at a minimal cost. People living in the suburbs, as well as their governing sectors, possess less finance for sophisticated roads, and this posse a big challenge to such locality.



In emergent nations where concrete is largely employed, the huge and rapid increase in cost of concrete has made construction high-priced. High-pricing as well as negative environmental effects from producing concrete, induced researches on diverse materials for replacing constituents of concrete. Many attempts have been made in search for novel materials, which is a combination of two or more materials. Singh, Ransinchung, Debbarma, and Kumar [4] made use of reclaimed asphalt aggregates and wastes from sugarcane mills for asphaltic mix in the construction of low volume roads. It was discovered that 10% of the alternative materials improved the mechanical and durability properties of the concrete. Mahgoub, and Mohamady, and Abdel-Motaleb, [5] worked on recycled building materials for Asphalt Pavement in low-volume agriculture roads and also found out that 25% of the concrete aggregates could be successfully replaced with maintained desired pavement properties. According to Modupe, Olayanju, Atoyebi, Aladegboye, Awolusi, Busari, and Modupe, [6], integrating cow bone ash into asphaltic concrete for hot mix asphalt as filler improved the stability as well as the flow of the asphaltic concrete. However, these studies and many others involve the processing of proposed alternative materials, which might induce additional cost. In order to eliminate additional cost that may be incurred, this study looks at investigating possible utilization of indigenous non-conventional materials like Sakasaka in Ilesha, Osun state, for low volume roads.

Sakasaka is a type of sand that mere looking at it could be classified as all-in aggregate. It is prominent and locally available in areas like Ilesha, Osun State. It has been in use by the locals as materials for the purpose of building construction since sharp sand is not readily available for use. In this study, some engineering properties were checked to determine its suitability for use as a total replacement for sharp sand. To achieve desired target strength, A, B, and cement C were used at different water-contents maintaining a mix design ratio of 1:2:4. The choice of these cements were made with the most suitable and available product in mind.

2. Materials Properties and Preparation

Cement brands A, B and C were used as binder material for the various concrete mixes. Concrete mix ratio of 1:2:4 was used with varying water/cement ratios of 0.7, 0.75, and 0.8. Granite aggregate passing through 19mm sieve and retained on 14mm sieve was used as coarse aggregate, and Sakasaka was used as a fine aggregate pass through 4.75 mm and retained on 0.075mm sieve with a maximum size of 12.5mm and potable water was used for mixing. Table 1 shows brands of cement with their manufacturer and grade.

Table 1. Brands of cement with their corresponding manufacturer and grades

Brand	Manufacturer	Type	Grade
Power Max	Lafarge WAPCO Nigeria Plc	CEM II	42.5N
Dangote 3X	Dangote Cement Plc	CEM II	42.5R
Super Set	Lafarge WAPCO Nigeria Plc	CEM II	32.5R

2.1 Aggregate

Sakasaka, found in Ilesha environ, Osun State, was used as fine aggregates, with particle sizes ranging from 75 μ m – 4.75mm in diameter, was in place with the requirements of BS 882 [7] and BS EN 12620:[8]; Specific gravity test was performed on the samples in accordance to BS 812; part 2 [9] and EN 12620:2002; A1:2008. The aggregate used in the concrete mix was air-dried to remove all forms of moisture in the sand.

2.1.1. Coarse Aggregate

The crucial requirements for an aggregate to be acceptable for concrete includes it being strong, durable, and inert. The sole fragment ideally is expected to be of equal shape and be uniformly graded from coarse to fine within its particular grading size fraction. Granite with particles passing through the 19mm sieve satisfying these requirements was used for this research work. Specific gravity test was done on the sample in line with ASTM C 128-88, BS 812; part 1 1975 and EN 12620:2002; A1:2008 [7], grain size distribution test was performed on the sample based on BS 1377; part 2 [9], BS EN ISO 17892-1 [10].

2.2 Water

Water is vital as the strength of concrete results from the hydration process which takes place during the cementitious gel formation. Potable water was used in all the works carried out and had no physical impurities. It was also free from acids, organic matter suspended solids, and alkalis, which, when present, may have an adverse effect on the strength of concrete. It conformed to BS 3148 [11] requirements.

2.3 Concrete Mix and Batching

Batching was done by weight, and a concrete mix of 1:2:4 was used for producing concrete cubes. Three water-cement ratio regimes were used. These were; 0.65, 0.7, and 0.75 by weight. In determining the suitability of the aggregates (fine and recycled coarse aggregate) for concrete production, sieve analysis was conducted on the aggregates as prescribed by BS 1377 Parts 1 and 2. The grading for the aggregates and their relative combinations were determined and expressed in terms of grading coefficient: Coefficients of uniformity (C_u) and curvature (C_c). The concrete was used in preparing concrete cubes for compressive test, prior to which slum and compacting factor tests were carried out. Sixty-three cubes each was cast for each cement brand with various percentage of water content. The cubes were tested in sets of nine at 7 days, 14 days, 21 days, 28 days, 56 days, 91 days, and 112 days, making a total of one hundred and eighty-nine cubes.

2.4 Experimental Steps

The following experimental steps and preliminary tests were carried out sequentially, and all tests were conducted according to relevant standards and specifications:

- Sample Pre-treatment
- Particle size distribution of coarse and fine aggregates.
- Concrete Workability Tests.
- Casting of Concrete specimens.
- Curing of Specimen.
- Compressive strength Test-Crushing of concrete cubes.

2.4.1 Sample Pre-treatment

The aggregate samples were maintained dry and free from moisture by air drying. The 50kg cement bags were kept on a dry raised platform to keep them dry and avoid caking, and once a bag was opened, it was used up within 24 hours after opening. The water used was potable water supplied to the laboratory from the University of Lagos Works department.

2.4.2. Compressive Strength of Concrete Cubes

The compressive strength test was carried out on the cubes for the varying cement brands and water-cement ratios adopted for this study. The cubes were cured for 7, 14, 21, 28, 56, and 112 days respectively.

The compressive strength is computed from the formula below

$$\text{Compressive Stress} = \frac{\text{applied load (N)}}{\text{cross sectional area of specimen (mm}^2\text{)}} \text{ (N/mm}^2\text{)} \quad (1)$$

3. Results and Discussions

3.1. Particle size distribution of sakasaka sand

ASTM C 33 [12] and AASHTO M 6 [13] specifies limits based sieve sizes that fine aggregates must meet before they can be used in the production of concrete. Table 2 gives these standard limits.

Table 2. Fine-Aggregate Grading Limits (ASTM C 33/AASHTO M 6).

Sieve sizes (mm)	Percentage passing sieves by mass
9.5	100
4.75	95 - 100
2.36	80 - 100
1.18	50 - 85
600 μm	25 - 60
300 μm	5 - 30 (AASHTO 10 - 30)
150 μm	0 - 10 (AASHTO 10 - 30)

Figure 1 shows the particle size distribution curve of sakasaka sand used for this research. The graph shows the plot of the sieve size analysis and hydrometer analysis.

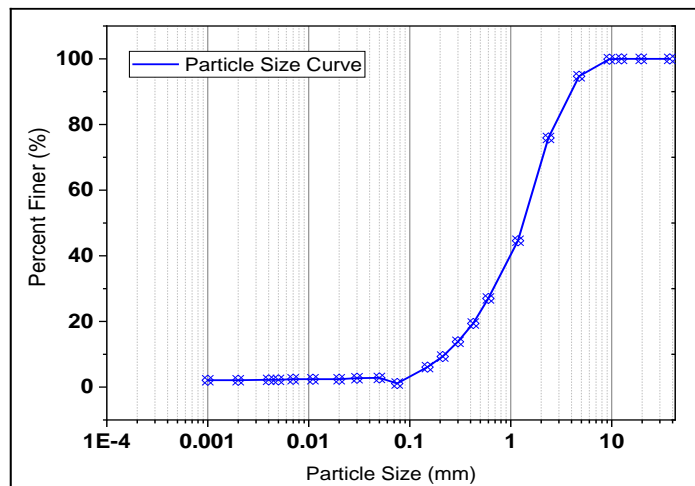


Figure 1. Particle Size Distribution of Sakasaka sand.

From the particle size graph, the fine aggregate just falls within the upper and lower limits specified by the ASTM standard, i.e. 99.9 % passed sieve No. 4 and 6.1 % passed sieve No. 100. Although, 75.9 % passed sieve No. 8, just a little short of the standard specified range of 80 – 100, the remaining six standards were met, making the sand just suitable for use in the production of concrete based on these criteria.

Table 3 shows the percentage gravel, percentage sand, percentage silt, percentage clay, coefficient of uniformity, and coefficient of curvature of the sand.

Table 3. properties of sakasaka sand.

Sand Property	Value
Percentage gravel (%)	37
Percentage sand (%)	54
Percentage silt (%)	7
Percentage clay (%)	2
coefficient of uniformity	9.83
coefficient of curvature	1.25

Based on unified soil classification system, USCS, the sand is classified as a well-graded gravel, GW, or gravel – sand mix having small or none fines since C_u is > 4 and C_c is less than 3. Though the sand is classified as a GW soil it has percentage fines (silt + clay) greater than 5 % maximum allowable value for pure sand classification and percentage gravel greater than 15 % [14]. This excess in percentage fines and gravel may have implications on the workability of concretes produced and can only be improved by the addition of mineral mixtures to mitigate this problem [15]. The specific gravity of sakasaka sand was obtained as 2.76, which is within the standard range set by ASTM of between 2.4 – 3 for sands.

3.2 Aggregate Size

Figure 2 shows the particle size distribution used in the mixing of the concrete.

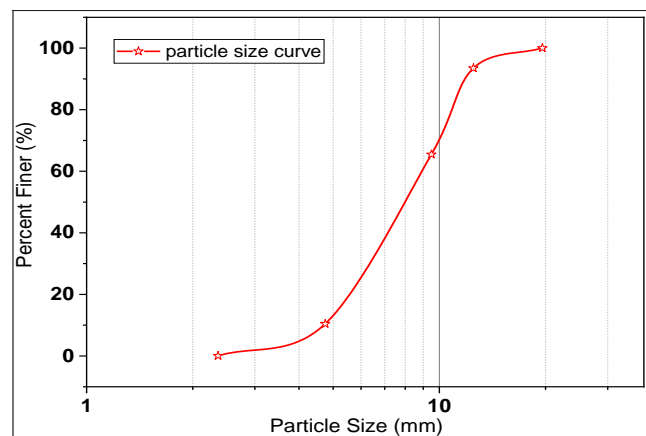


Figure 2. Particle Size Distribution of coarse aggregate

Aggregates that are retained on sieve No. 4 (4.75 mm) are known as coarse aggregates [16, 17]. 99.97% of the coarse aggregates used for this research were retained on sieve No. 4, meeting the ASTM C 33 [13] and AASTHO M 80 [18] grading requirements for coarse aggregates.

3.3 Concrete Workability Tests.

Concrete workability as defined by ACI Standard 116R-90 [19] is a property of freshly mixed concrete that portrays the ease and homogeneity to which it is mixed, placed, compacted and cured. The workability of a concrete mix is determined by performing the slump test [20] [21]. The slump test results of the freshly prepared concrete using the 3 brands of cement and different water-cement ratios, are presented in Table 4.

Table 4. Slump test results.

Cement brand	Water/Cement Ratio	Slum Value	Slump Type	Workability Class
B	0.7	0	True Slump	Low
	0.75	50	True Slump	Low
	0.8	85	Medium Slump	High
A	0.7	70	True Slump	Low
	0.75	92	True Slump	medium
	0.8	102	True Slump	High
C	0.7	10	True Slump	Low
	0.75	50	True Slump	Low
	0.8	135	True Slump	High

The slump was observed to increase with increasing water-cement ratios for all mixes. Workability is known to be directly proportional to water-cement ratio. As the water content increased, the

workability increased. The workability class ranged from low to medium for the mixes and w/c ratio used. All slumps were true slumps as there was no record of shear or collapsed slump. Segregation and bleeding were not experienced as this is usually expected at high workability classes.

3.4 Compacting Factor Test

To further confirm the workability of the fresh concrete at 0.7 water-cement ratio, compaction factor test was done on the fresh concrete. The outcomes obtained are shown in Table 5.

Table 5. Compacting Factor Test @ 0.7wcr.

Weight of cylinder + concrete(kg)	17.11
Weight of cylinder + vibrated concrete(kg)	18.20
Weight of cylinder (kg)	5.96
Compacting Factor of Lafarge C	0.94
Compacting Factor of C	0.89
Compacting Factor of A	0.9

The specified range for compacting factor values are 0.7 to 0.98, value below or above this range is considered improper. At 0.7 water cement ratio that recorded no slump values, the compacting factor for all mix with different cement types were within the specified range making the water cement ratio an appropriate one.

3.5. Test on Hardened Concrete

Figures 3 – 5 show the variation of the compressive strength with time for the three brands of cements used in the casting of concrete at varying water-cement Ratio

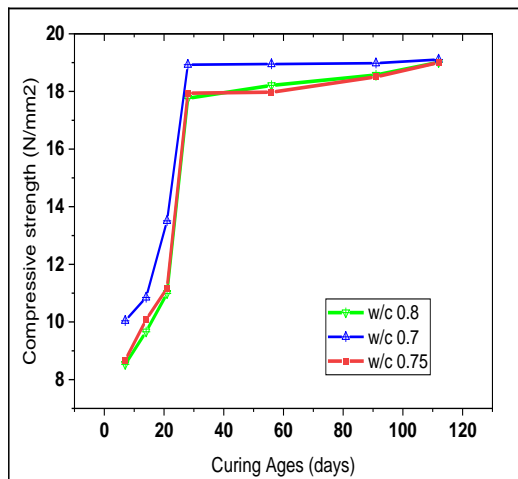


Figure 3. Variation of the compressive strength with Time for cement B samples at varying water – cement Ratio.

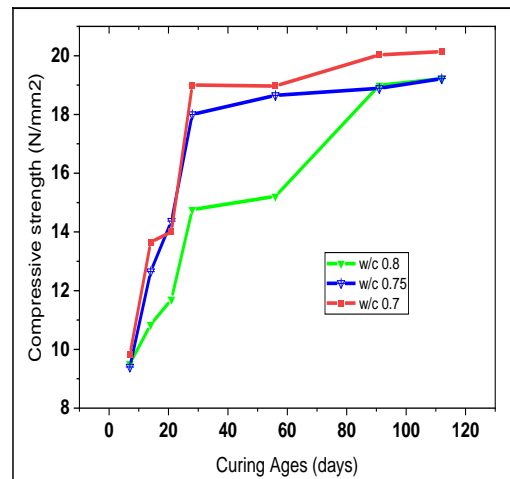


Figure 4. Variation of the compressive strength with Lafarge cement A concrete samples at varying water – cement Ratio.

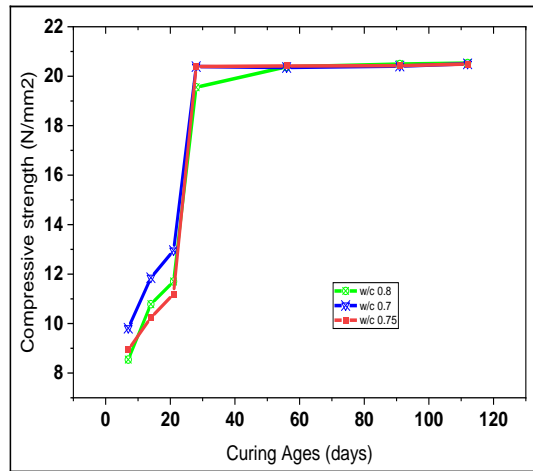


Figure 5. Variation of the compressive strength with Time for Cement C Concrete at varying water-cement Ratio.

From the figures above, it was observed that there was a continual rise in the strength gained for various samples of concrete from 7days to 28 days at various water cement ratio. However, 0.7 w/c appears to produce higher average strength of 20.97N/mm² follow by 0.75 w/c which gave average strength of 18.10N/mm² and then 0.8w/c gave average strength of 17.76N/mm². Cement B for Grade 25 produced higher strength at lower water cement ratio.

Cement A and C seem to follow the same trend with B as shown in the figures, 0.7w/c for all the cement brand produced higher concrete strength compared to strength obtained for water cement ratio 0.75w/c, and 0.8 w/c.

It can be observed from the graph also that cement C samples gained more strength than the rest at 7 days and 28days for various water cement ratio, followed by cement B and then Cement A samples.

Table 6 shows the compressive strength test on cements (N/mm²)The strength produced by Cement A and B is lower than the required strength at 28 days for various water cement ratio while strength produced by Cement C appeared ok at 28 days.

Cement C samples achieved more strength of 102.9% at 28 days for 0.7 w/c and 96.3% at 28 days for 0.8 w/c. Cement C produced the highest strength with lower w/c. The concrete strength decrease with increase in water percentage.

Table 6. Compressive Strength Test on Cements (N/mm²)

CEMENT TYPE	CURING AGES(DAYS)		
	3	7	28
B	12.07	16.5	39.21
C	11.42	13.5	33.85
A	13.09	18.5	41.52

4. Conclusions

From the investigations made during this research, the following conclusions can be deduced:

- Sakasaka is classified as a well Graded gravelly soil (GW), according to the unified classification system.
- Cement C appear to have highest comprehensive strength of 20.5N/mm² with Sakasaka only at 28 days and 21N/mm² at 112days with minimum water cement ratio of 0.7, based on this research.
- All the cements brands A, B and C used for the purpose of this research, gave strength close to that specified in BS110 and CPU 110 which specified required concrete strength for grade 25 at 7days and 28 days to be 65% and 100% respectively with minimum water cement ratio.
- Both Chemical and metallic composition of Sakasaka justified that if improved upon, it can achieve desired strength.

Recommendations

From this research work done so far, the following recommendations can be made:

- Sakasaka can be used with cement C with minimum water cement ratio of 0.7 for grade 25 concrete where total replacement is required.
- Partial replacement instead of total replacement can be done to improve on the strength.
- Concrete made from Sakasaka can be used for Local Street where the expected wheel load is low.

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