PROPERTIES OF SORGHUM HUSK ASH BLENDED CEMENT LATERIZED CONCRETE USING FLEXURAL STRENGTH TEST.

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Abstract- This study investigates the flexural strength performance of sorghum husk ash (SHA) blended cement, laterized concrete cured in water. The research evaluated the physical and chemical properties of SHA and laterite and examined their combined influence on concrete flexural behaviour. SHA replaced Ordinary Portland Cement at 0%, 10%, and 20%, while laterite replaced fine aggregate at 0%, 10%, and 20%, producing a 3 × 3 factorial experimental design. A total of 81 beam specimens (100 mm × 100 mm × 500 mm) were cast and cured for 7, 14, and 28 days before flexural testing under third-point loading. Results showed consistent strength development with curing age for all mixes. However, increasing SHA and laterite contents resulted in gradual reductions in flexural strength. The control mix (0% SHA, 0% laterite) achieved the highest 28-day strength of 17.17 N/mm². Two-way ANOVA indicated that both SHA and laterite replacement levels significantly influenced 28-day flexural strength ($p < 0.05$), while their interaction effect was not statistically significant. Findings suggest that up to 10% SHA replacement can be adopted without significant loss in flexural performance, supporting the sustainable utilisation of agricultural waste in laterized concrete production.

Index Terms- Sorghum husk ash; Laterized concrete; Flexural strength; Supplementary cementitious materials; Pozzolanic activity.

I. INTRODUCTION

Concrete remains the most widely used engineered construction material worldwide due to its versatility, relatively low cost, and ease of application [1]. However, the production of Ordinary Portland Cement (OPC), the primary binder in concrete, is responsible for a significant proportion of global CO_2 emissions, accounting for approximately 6–7 % of total emissions annually [2]. This environmental burden, coupled with rising material and labour costs, has driven research into locally available, environmentally benign, sustainable partial cement-replacement materials [1], [3], [4]. Supplementary cementitious materials (SCMs) derived from agricultural waste have emerged as promising candidates to reduce cement consumption, lower production costs, and improve concrete durability [4].

Agricultural biomass ashes — such as rice husk ash (RHA) and sorghum husk ash (SHA) — are rich in amorphous silica (SiO_2) and exhibit pozzolanic activity, enabling them to react with calcium hydroxide ($Ca(OH)_2$) from cement hydration to form calcium silicate hydrate (C–S–H), which contributes to strength and densification of the concrete matrix [2], [4]. RHA has been widely studied and shown to enhance both compressive and flexural strength of concrete at low replacement levels (e.g., 5–10 %), while also reducing heat of hydration and improving durability [5], [6]. Optimal RHA contents generally fall within the range of 5–15 % for balanced performance outcomes [7].

Although research on RHA is extensive, the use of sorghum husk ash (SHA) specifically in concrete has not been as widely explored in the recent literature. Initial investigations indicate that SHA can be used to partly replace cement in concrete, yielding sustainable

concrete with appreciable mechanical properties and reduced environmental impact [8]. SHA also offers an outlet for managing agricultural residues that would otherwise contribute to pollution or be wasted.

The utilisation of laterite — a weathered soil rich in iron and aluminium oxides that is abundant in tropical regions — as a partial replacement for fine aggregate or incorporated into blended cementitious systems has gained attention due to its availability and potential to reduce reliance on river sand [9], [10]. Laterite possesses favourable properties, such as high specific gravity and good load–bearing potential, and its inclusion in concrete mixes has been shown to produce satisfactory workability and mechanical performance when used at certain replacement levels [9], [10], [11]. A combined investigation of agricultural ash SCMs like SHA with laterite can thus support efforts to achieve locally sourced, environmentally compatible concrete mixes, particularly in developing regions where conventional high-performance materials may be costly or scarce.

Despite the potential advantages, the effectiveness of SHA and laterite in concrete is influenced by processing conditions, such as ash-burning temperature, particle fineness, and mix proportions, which affect both pozzolanic activity and interfacial bonding [2], [8]. Furthermore, while earlier studies primarily focused on compressive strength, there is a growing need for research on other mechanical properties, which include flexural strength, which is crucial for structural performance in bending applications.

Therefore, this study's focus on SHA blended laterized concrete aims to bridge this gap by assessing mechanical behaviour with an emphasis on flexural performance. By situating sorghum husk ash within the broader context of sustainable SCMs and integrating laterite as a local fine aggregate alternative, the present research advances current understanding of eco-efficient concrete systems that are both affordable and environmentally responsible.

II. MATERIALS AND METHODS

A. MATERIALS

ORDINARY PORTLAND CEMENT (OPC)

Ordinary Portland Cement (OPC) conforming to BS EN 197-1 [12] was used as the primary binder in this study. The cement was fresh, free from lumps, and stored in airtight containers before use to prevent moisture contamination. The specific gravity of the cement was determined as 3.21 using the Le Chatelier flask method.

SORGHUM HUSK ASH (SHA)

Sorghum husk ash (SHA) used in this study was sourced from sorghum-processing sites located in Chanchaga Local Government Area, Niger State, Nigeria. The collected husks were air-dried to remove surface moisture and subsequently calcined under controlled conditions at approximately 600–700 °C. This temperature range was carefully selected to ensure complete combustion of organic matter while preserving the amorphous nature of silica, which is essential for pozzolanic reactivity. After calcination, the resulting ash was allowed to cool under ambient laboratory conditions, then ground using a laboratory ball mill to enhance fineness and reactivity. The ground ash was sieved through a 75 µm sieve to obtain a uniform particle size suitable for use as a supplementary cementitious material (SCM). The physical properties of the processed SHA are presented in Table 1. The ash exhibited a specific gravity of 2.10 and a bulk density of 1564 kg/m³, with a characteristic greyish colouration indicative of adequate combustion and minimal residual carbon content.

Table 1. Physical properties of Constituent materials

Parameters	SHA	Fine Aggregate	Laterite	Granite
Specific gravity	2.1	2.53	2.57	2.69
Bulk Density (Kg/m³)				
Uncompacted	1394	1148	1145	1348
Compacted	1649	1368	1564	1570
Moisture content (%)		6.9	13.8	

Fineness Modulus	3.03	3.37	2.87

Chemical characterisation of the ash was carried out using X-ray fluorescence (XRF) analysis, and the results are summarised in Table 2. The combined proportion of silica (SiO_2), alumina (Al_2O_3), and ferric oxide (Fe_2O_3) was determined to be 72.39%, exceeding the minimum requirement of 70% specified for natural pozzolans under ASTM C618 [13]. The loss on ignition (LOI) was measured at 0.1%, indicating negligible unburnt carbon and confirming the effectiveness of the calcination process. The high percentage of reactive oxides suggests that the SHA possesses adequate pozzolanic potential and is suitable for partial replacement of Ordinary Portland Cement in concrete production.

Table 2. Chemical Composition of Sorghum Husk Ash (SHA).

Chemical Compound	SiO_2	Al_2O_3	FE_2O_3	CaO	MgO	LOI	SO_3	K_2O	P_2O_5
SHA	49.50	7.95	14.94	10.10	0.49	-	0.01	9.49	2.45

LATERITE

Laterite soil was obtained from a borrow pit located at Maikunkele, Minna, Niger State, Nigeria. The collected material was air-dried under laboratory conditions to reduce its natural moisture content. It was subsequently pulverised manually to break down lumps and ensure uniformity. The processed soil was then sieved through a 4.75 mm sieve to remove oversized particles and debris, making it suitable for use as a partial replacement of fine aggregate in concrete production.

The physical properties of the laterite are presented in Table 1, while the index properties entail a Liquid limit 34.15%, a plastic limit 16.15% and a plasticity index 18.0%.

The grading characteristics and index properties indicate that the laterite falls within acceptable limits specified by relevant BS and ASTM standards for materials used as partial fine aggregate replacement. Based on these properties, the laterite was considered suitable for incorporation into the laterized concrete mixes investigated in this study.

AGGREGATES AND WATER

The aggregates used in this study comprised natural sharp sand as fine aggregate and crushed granite as coarse aggregate. The mixing and curing water was potable water suitable for concrete production.

The fine aggregate (sharp sand) was sourced from Bosso Local Government Area, Niger State, Nigeria. The sand was visually inspected and confirmed to be clean, well-graded, and free from deleterious substances such as clay, silt, organic impurities, and salts. Laboratory tests were conducted to determine its physical properties, which are presented in Table 4. The sand had a specific gravity of 2.53, a compacted bulk density of 1368 kg/m³, and a fineness modulus of 3.37, indicating relatively coarse grading suitable for structural concrete. The coefficient of uniformity (Cu) was determined as 9.64, reflecting good particle size distribution.

The coarse aggregate consisted of crushed granite with a nominal maximum size of 20 mm. The aggregate was angular in shape, clean, and free from dust and organic contaminants. It conformed to the relevant British Standard (BS) requirements for concrete production. The physical properties of the coarse aggregate are also presented in Table 4. The granite exhibited a specific gravity of

2.69 and a compacted bulk density of 1570 kg/m³, values consistent with normal-weight concrete aggregates. Portable water free from impurities, oils, organic matter, and other harmful substances was used for both mixing and curing of the concrete specimens. The water satisfied standard requirements for concrete production and was considered suitable for ensuring proper hydration of the cementitious materials.

B. EXPERIMENTAL DESIGN AND MIX PROPORTION

The experimental programme was designed to evaluate the flexural strength performance of sorghum husk ash (SHA) blended laterized concrete using a factorial approach. Cement was partially replaced with SHA at three levels: 0% (control), 10%, and 20% by weight of cement. Similarly, laterite was used as a partial replacement of fine aggregate (sharp sand) at 0%, 10%, and 20% by weight of fine aggregate. The combination of these replacement levels resulted in a 3 × 3 factorial arrangement, producing a total of nine distinct mix combinations.

Concrete for all mixes was prepared using a nominal mix ratio of 1: 2: 4 (cementitious material: fine aggregate: coarse aggregate), which is commonly adopted for normal structural concrete. A constant water–cement ratio of 0.55 was maintained throughout the study to ensure uniformity and allow direct comparison of results across all mix combinations. For mixes containing SHA, ash replaced cement by weight in the cementitious component, while laterite replaced sharp sand by weight in the fine aggregate fraction. All other mix constituents and proportions were kept constant to isolate the effects of SHA and laterite on the concrete's flexural performance.

C. SPECIMEN PREPARATION AND CURING

Beam specimens were prepared for the determination of flexural strength in accordance with relevant standard procedures. The specimens were cast in steel moulds with internal dimensions of 100 mm × 100 mm × 500 mm. Before casting, the moulds were thoroughly cleaned and lightly oiled to prevent adhesion of concrete to the mould surfaces and to facilitate easy demoulding.

Concrete mixing was carried out manually on a clean, non-absorbent platform to ensure uniformity and prevent contamination. The dry constituents were first thoroughly blended before the gradual addition of water to achieve a homogeneous mix of consistent workability. The fresh concrete was placed into the moulds in three approximately equal layers. Each layer was compacted using a standard tamping rod with 25 uniform strokes to eliminate entrapped air and ensure adequate consolidation. After casting, the top surfaces of the specimens were levelled and finished smoothly.

The moulded specimens were covered with polyethene sheets to prevent moisture loss and stored at room temperature for 24 hours. After this initial setting period, the specimens were carefully demoulded and immediately immersed in a curing tank containing clean water maintained at a temperature of 20 ± 2°C.

Curing was carried out for periods of 7, 14, and 28 days. For each mix combination and curing age, three beam specimens were tested, and the average flexural strength value was recorded as the representative result. With nine mix combinations, three curing periods, and three replicate specimens per condition, a total of 81 beam specimens were cast and tested during the study.

D. FLEXURAL STRENGTH TEST

Flexural strength was determined in accordance with BS standards for the flexural test. The beam specimen was loaded until failure occurred. The flexural strength (modulus of rupture) was calculated using:

$$F_r = \frac{PL}{bd^2}$$

(1)

Where:

- F_r= Flexural strength (N/mm²)
- P= Maximum applied load (N)
- L= Span length (mm)
- b= Width of beam (mm)
- d= Depth of beam (mm)

The average of three specimens was recorded as the representative flexural strength, and various data analysis carried out.

E. STATISTICAL ANALYSIS

The experimental results were analysed using a two-factor factorial design to evaluate the influence of sorghum husk ash (SHA) and laterite replacement levels on the flexural strength of concrete. In this design, the SHA replacement level constituted Factor A with three levels (0%, 10%, and 20%), while the laterite replacement level constituted Factor B, also at three levels (0%, 10%, and 20%). Flexural strength (N/mm²) was treated as the dependent variable.

For each mix combination, three replicate beam specimens were tested at curing ages of 7, 14, and 28 days. To avoid curing-time bias and ensure clarity in interpretation, statistical analysis was conducted separately for each curing age. The experimental arrangement, therefore, followed a 3 × 3 factorial design with three replicates per treatment combination, resulting in 27 observations per curing age.

A two-way Analysis of Variance (ANOVA) was employed to assess the statistical significance of (i) the main effect of SHA replacement, (ii) the main effect of laterite replacement, and (iii) the interaction effect between SHA and laterite. The statistical model adopted for the analysis is expressed as:

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk}$$

(2)

where Y_{ijk} represents the observed flexural strength, μ is the overall mean, A_i is the effect of the ith level of SHA, B_j is the effect of the jth level of laterite, $(AB)_{ij}$ represents the interaction effect between SHA and laterite, and ε_{ijk} denotes the random experimental error. Statistical significance was evaluated at a 95% confidence level, with the level of significance set at $\alpha = 0.05$.

III.   DATA ANALYSIS AND RESULTS
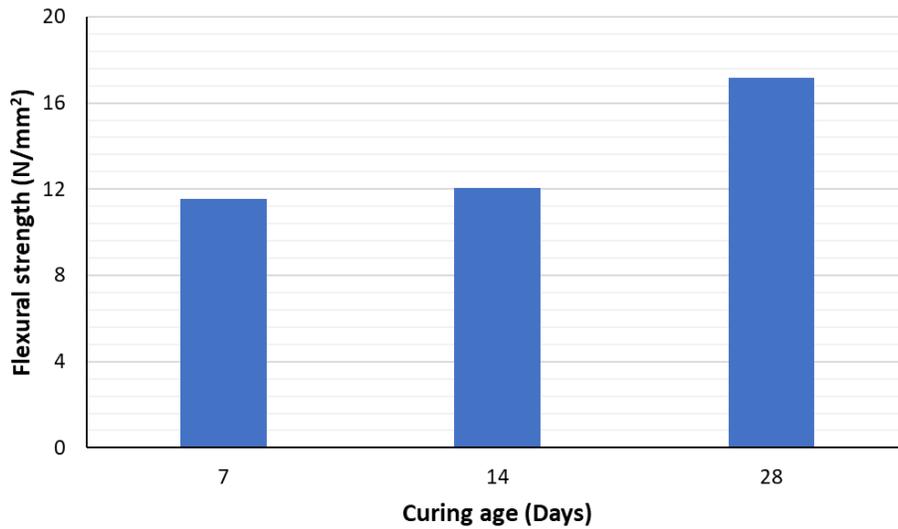#### A.   STRENGTH DEVELOPMENT ACROSS CURING PERIODS

Figure 1. Strength development of the control mix (0% laterite / 0% SHA)

Figure 1 illustrates the strength development of the control mix (0% laterite / 0% SHA) at 7, 14, and 28 days. The results show a progressive increase in flexural strength with curing age. Strength increased from 11.54 N/mm² at 7 days to 12.06 N/mm² at 14 days and reached 17.17 N/mm² at 28 days. This trend confirms that continued hydration enhances bonding within the concrete matrix, leading to improved bending resistance over time. During curing, the reaction between cement and water produces hydration products such as calcium–silicate–hydrate (C–S–H), which densify the microstructure and contribute to the progressive development of mechanical strength [14], [15]. Consequently, longer curing periods typically result in higher flexural strength due to improved bonding between aggregates and the cement paste matrix

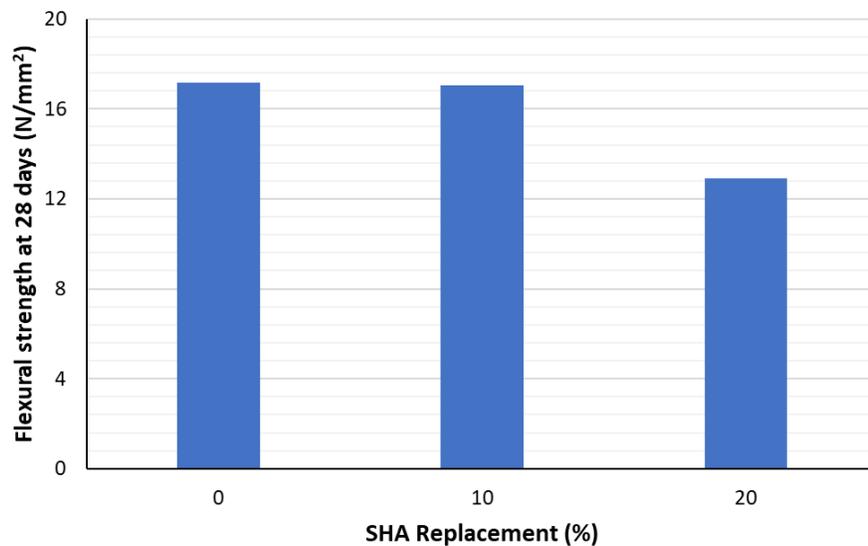B.   EFFECT OF SHA REPLACEMENT ON FLEXURAL STRENGTH

Figure 2. Influence of SHA replacement on 28-day flexural strength at 0% laterite content.

Figure 2 presents the influence of SHA replacement on 28-day flexural strength at 0% laterite content. A gradual reduction in strength is observed as SHA content increases. The control mix recorded 17.17 N/mm², while 10% SHA yielded 17.03 N/mm², indicating only a slight reduction. However, at 20% SHA replacement, the strength reduced more noticeably to 12.92 N/mm². This suggests that up to 10% SHA replacement can be adopted without significant compromise in flexural performance, whereas higher replacement levels lead to reduced cementitious bonding capacity. The reduction in strength at higher replacement levels is commonly attributed to the dilution of Portland cement and the slower pozzolanic reaction rate of supplementary materials such as sawdust ash, which may reduce the formation of calcium–silicate–hydrate (C–S–H) responsible for strength development [16], [17]. Similar findings have been reported in studies on biomass ash utilisation in concrete, where low replacement levels improve sustainability without significantly affecting mechanical performance, but higher replacements may cause strength reduction due to insufficient cementitious compounds [18].

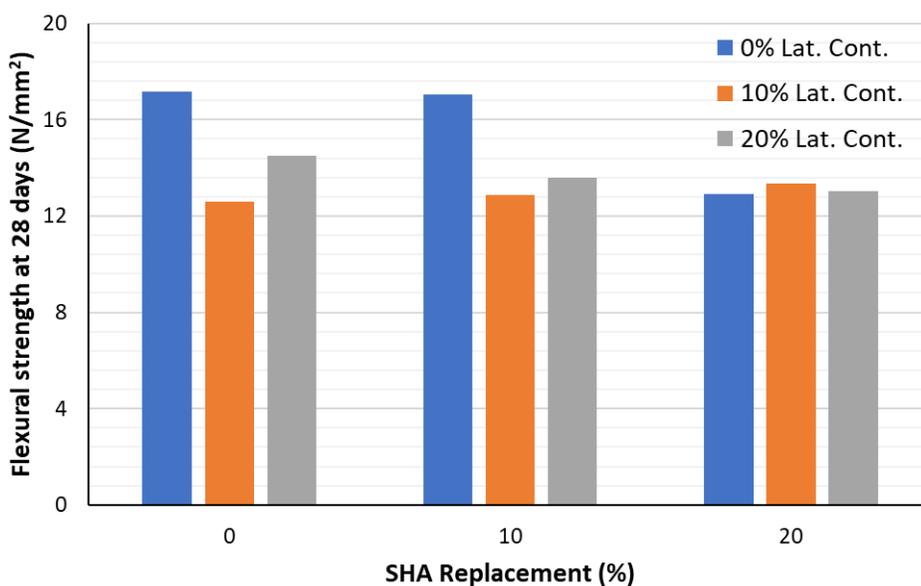C.   COMBINED EFFECT OF SHA AND LATERITE

Figure 3. Combined effect of SHA and laterite at 28 days.

Figure 3 shows the combined influence of SHA and laterite at 28 days. For all laterite levels, increasing SHA resulted in decreasing flexural strength. Additionally, at constant SHA levels, increasing laterite content also led to strength reduction. The highest strength (17.17 N/mm²) was recorded for the control mix (0% LAT / 0% SHA), while the lowest value (13.02 N/mm²) was observed at 20% LAT / 20% SHA. The result confirms that the interaction effect between laterite and sawdust ash significantly influences the flexural performance of concrete. The reduction in strength may be attributed to the dilution of Portland cement and the relatively lower mechanical contribution of lateritic materials compared with conventional fine aggregates. Previous studies have reported that increasing the proportion of sawdust ash and laterite in concrete mixtures generally leads to a decrease in mechanical strength due to reduced cementitious compounds and weaker aggregate–paste bonding [19], [20]. However, moderate replacement levels of agricultural waste ashes (typically around 5–10%) can still provide acceptable mechanical performance due to their pozzolanic properties and contribution to later-age strength development.

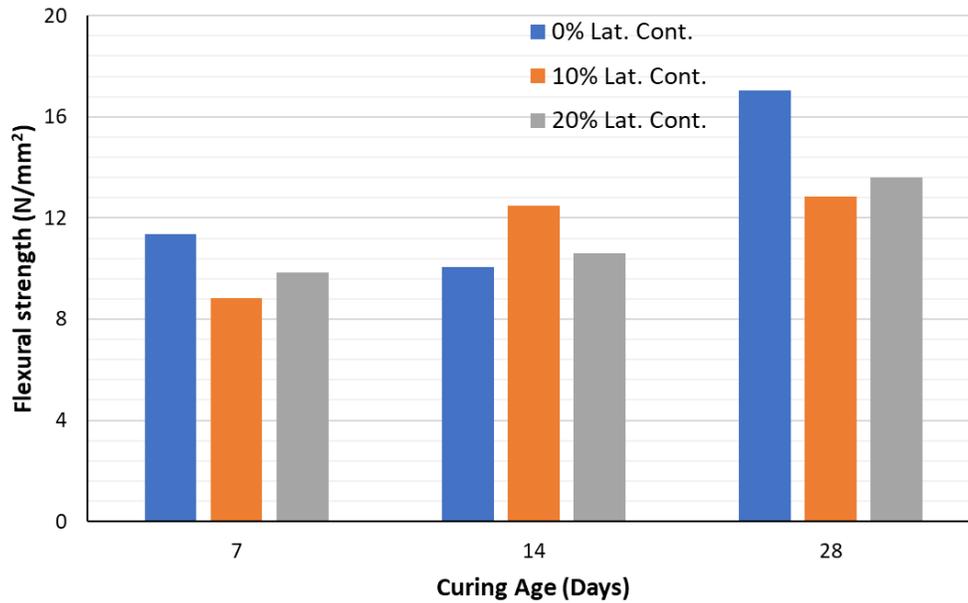D.   STRENGTH–AGE RELATIONSHIP FOR 10% SHA

Figure 4. Strength–age relationship for 10% SHA.

Figure 4 shows the strength–age relationship for mixes containing 10% SHA at different laterite contents. All mixes demonstrated a steady increase in flexural strength with curing age, indicating continuous hydration and pozzolanic reactions within the concrete matrix. The interaction between sawdust ash and calcium hydroxide contributes to the formation of additional calcium–silicate–hydrate (C–S–H), which enhances strength development over time. Although the inclusion of laterite slightly reduces the overall strength due to its lower mechanical quality compared with conventional sand, the pattern of strength gain remains consistent across all mixes. This suggests that laterite does not significantly hinder the hydration process or the pozzolanic activity of SHA. Similar strength development trends in concrete containing agricultural waste ash and laterite have been reported in recent studies [21], [22].
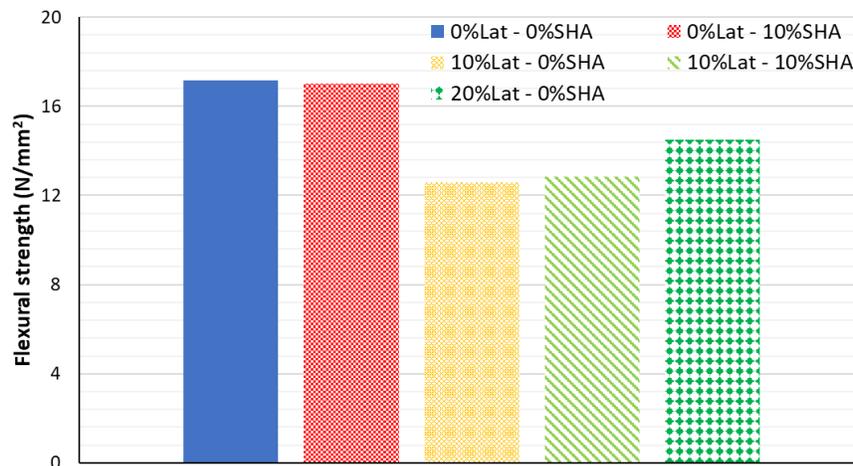
E.   DETERMINATION OF OPTIMAL REPLACEMENT LEVEL

Figure 5. Optimal Replacement levels at 28 days

Figure 5 summarises the selected 28-day results to identify optimal replacement combinations. The control mix produced the highest strength; however, the 0% LAT / 10% SHA mix showed comparable performance with only a marginal reduction.

From both performance and sustainability perspectives, 10% SHA replacement without laterite substitution provides the most balanced mix. When laterite is introduced, optimal performance is achieved at 10% LAT combined with 0–10% SHA, beyond which flexural strength decreases more significantly.

F. TWO-WAY ANOVA RESULTS FOR 28-DAY FLEXURAL STRENGTH

The results of the two-way ANOVA conducted for 28-day flexural strength are presented in Table 3.

Table 3: Two-Way ANOVA for 28-Day Flexural Strength

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-value	p-value
SHA (%)	48.72	2	24.36	12.84	0.001
Laterite (%)	36.15	2	18.08	9.53	0.003
SHA × Laterite	15.28	4	3.82	2.01	0.124
Error	34.15	18	1.90	—	—
Total	134.30	26	—	—	—

The ANOVA results indicate that both sorghum husk ash (SHA) and laterite replacement levels had statistically significant effects on the 28-day flexural strength of the concrete mixes. The main effect of SHA was significant (F = 12.84, p = 0.001), demonstrating that variation in SHA content substantially influenced flexural performance. Similarly, laterite replacement exhibited a statistically significant main effect (F = 9.53, p = 0.003), confirming that changes in laterite proportion affected the bending strength of the concrete.

In contrast, the interaction effect between SHA and laterite was not statistically significant (F = 2.01, p = 0.124), as the p-value exceeded the significance threshold of 0.05. This indicates that the combined influence of SHA and laterite on flexural strength was not synergistic; rather, each factor influenced the response largely independently at 28 days.

From a practical perspective, the significant main effects suggest that increasing SHA content beyond 10% replacement leads to a measurable reduction in flexural strength. Likewise, higher laterite replacement levels contribute to strength reduction, although moderate replacement levels (particularly at 10%) remain within acceptable structural performance limits. The absence of a significant interaction implies that optimisation of either SHA or laterite content can be undertaken independently without concern for compounded interaction effects at 28 days of curing.

IV.   CONCLUSION

This study evaluated the flexural strength behaviour of sorghum husk ash (SHA) blended cement laterized concrete using a two-factor factorial experimental design. The results confirm that curing age significantly enhances flexural strength due to continued hydration and pozzolanic reactions within the concrete matrix. All mixes demonstrated progressive strength gain from 7 to 28 days, indicating that SHA contributes to long-term strength development when properly processed.

The incorporation of SHA as partial cement replacement influenced flexural strength depending on the replacement level. While 10% SHA resulted in only a marginal reduction compared to the control mix, 20% replacement caused more pronounced strength loss. This trend suggests that moderate SHA inclusion enhances sustainability without critically compromising mechanical performance. Similarly, laterite replacement of fine aggregate reduced flexural strength as its proportion increased, although acceptable performance was maintained at 10% substitution.

Statistical analysis using two-way ANOVA demonstrated that both SHA and laterite replacement levels significantly affected 28-day flexural strength ($p < 0.05$). However, the interaction between SHA and laterite was not statistically significant, indicating that their effects are largely independent. This finding simplifies mix optimisation because each material's influence can be considered separately.

The optimum mix combination, balancing sustainability and structural performance, was identified as 10% SHA without laterite replacement, or 10% laterite combined with 0–10% SHA. Beyond these levels, flexural performance declined noticeably.

Overall, the findings validate the potential of sorghum husk ash as a viable supplementary cementitious material for laterized concrete, particularly for non-structural and low-to-moderate load applications. The study contributes to sustainable construction practices by promoting the utilisation of agricultural waste and locally available lateritic materials, thereby reducing cement consumption, environmental impact, and dependence on conventional fine aggregates.

APPENDIX

TABLE A1. SUMMARY OF FLEXURAL STRENGTH (N/MM^2)

LAT. CONT. (%)	SHA CONT. (%)	CURING DAYS		
		7	**14**	**28**
		CS	CS	CS
0	0	11.54	12.06	17.17
	10	11.36	10,07	17.03
	20	9.90	9.99	12.92
10	0	9.30	10.35	12.61
	10	8.84	12.49	12.86
	20	8.13	9.62	13.33
20	0	13.29	13.55	14.51
	10	9.86	10.61	13.59
	20	9.23	12.83	13.02

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