
RELIABILITY ANALYSIS ON REINFORCED CONCRETE COLUMN CONTAINING SAWDUST ASH FOR STRUCTURAL APPLICATIONS

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ABSTRACT

The construction industry faces increasing pressure to adopt sustainable practices, particularly through the utilization of agricultural waste materials as partial replacements for ordinary Portland cement. This study presents a comprehensive reliability analysis of reinforced concrete columns incorporating sawdust ash as a supplementary cementitious material for structural applications. The research investigates the structural performance and reliability of sawdust ash concrete columns through experimental investigation and probabilistic analysis. The experimental program involved casting and testing reinforced concrete column specimens with sawdust ash replacement levels ranging from 0% to 20% by weight of cement. Compressive strength test were conducted at various curing ages up to 180 days. The reliability analysis employed first-order reliability methods (FORM), validated with Monte Carlo simulation (10,000 trials using MATLAB), to evaluate the probability of failure and reliability indices for sawdust ash concrete columns under various loading conditions. Results indicate that sawdust ash concrete at 10% replacement level achieves comparable strength characteristics to conventional concrete. The reliability analysis reveals that sawdust ash concrete columns maintain acceptable reliability indices within the recommended design limits, with the 10% replacement mix achieving a peak reliability index of 4.05 compared to 3.82 for the control mix. The findings support the use of sawdust ash as a viable alternative cementitious material that promotes environmental sustainability without compromising structural reliability and safety.

Keywords: Sawdust Ash; Reinforced Concrete Column; Reliability Analysis; Structural Performance; Pozzolanic Material

1. INTRODUCTION

The global construction industry faces significant challenges related to environmental sustainability, particularly concerning the substantial carbon emissions associated with cement production. The cement manufacturing sector contributes approximately 5-8% of global anthropogenic carbon dioxide emissions (Ikponmwo et al., 2020; Benhelal et al., 2013), prompting researchers and practitioners to explore alternative cementitious materials that can reduce the environmental footprint of concrete production. Sawdust ash has gained considerable attention due to its pozzolanic properties and widespread availability as a byproduct of the timber industry.

The incorporation of sawdust ash as a partial cement replacement in reinforced concrete columns necessitates comprehensive investigation into their structural performance and long-term reliability under various loading conditions. Structural reliability analysis provides a probabilistic framework for evaluating the safety and performance of structural components, considering uncertainties in material properties, geometric dimensions, and applied loads (Sexsmith, 1969). The application of reliability analysis to sawdust ash concrete columns ensures that sustainable construction practices do not compromise structural safety and serviceability.

While sawdust ash (SDA) utilization as a supplementary cementitious material has been recognized in literature (Ogbobe et al., 2020), a significant research gap exists in the *quantification of structural safety, probabilistic reliability indices, and failure probabilities under Code-specified limit states* when using sustainable pozzolans. Most previous studies have focused on material characterization and mechanical properties without extending to reliability-based structural performance assessment, particularly for compression members such as columns. This study addresses

this gap by evaluating the structural reliability of reinforced concrete columns incorporating sawdust ash under uncertainty. The integration of probabilistic reliability methods, including validation through Monte Carlo Simulation with sustainable concrete design represents a significant contribution to structural engineering practice.

Structural design codes, standards, and guidelines provide the foundations of good engineering practice. Until about 1970, safety levels in such design documents represented value judgments by code-writers based on past experience and best practices. The judgmental approach to safety assurance served the profession reasonably well in an era when design and construction technologies were relatively stable (Ellingwood and Marc Maes, 2025). The growth of structural reliability theory and applications, along with recognition of its role in guiding the structural engineering profession in addressing some of the most important issues in design of the built environment, represents one of the key engineering achievements during the past five decades. Structural reliability provides a unifying framework for managing uncertainties affecting performance of structures and a quantitative link between the practice of structural engineering and its social consequences (Akingbonmire and Afolayan, 2024). The aim of this study is to conduct a research on Reliability analysis on Reinforced concrete Column containing sawdust ash for structural applications. The objectives are to evaluate the physical properties of concrete constituent materials and chemical oxide composition of sawdust ash, determine the compressive strength of the concrete, carry out a comprehensive structural design of column using data from above two objectives and carry out reliability analysis on the results from deterministic design carried out.

2. METHODOLOGY

The research methodology employed in this study followed a quantitative experimental approach to investigate the structural performance and reliability of reinforced concrete columns containing sawdust ash. The experimental program involved the casting and testing of reinforced concrete column specimens with varying percentages of sawdust ash replacement, followed by comprehensive reliability analysis using probabilistic methods. The use of a purely quantitative experimental approach ensured precise control over variables and enabled systematic evaluation of the effects of sawdust ash on column performance characteristics.

The material selection for this study adhered to established standards and specifications to ensure the validity and reproducibility of results. The materials that were used in this study are Limestone cement, Sharp River sand, Crushed stones, Sawdust ash, and water.

2.1 Limestone Cement

Limestone cement of grade 42.5 was sourced from a nearby building material shop in Minna. The Limestone cement conformed to requirements for cement to be used for concrete production as stipulated in BS EN 196-6 (2018).

2.2 Fine Aggregates (River Sand)

The sharp sand used in this research was sourced locally within Minna, which was passed through a 4.75 mm BS sieve conforming to grading (BS EN 12620, 2013). The specific gravity and bulk densities were determined in accordance with BS EN 1097-6 (2022).

2.3 Coarse Aggregates (Crushed Stones)

The Crushed granite stones with size range of 10–20 mm were sourced from Hua Tai Quarry Nigeria Ltd, Daupe, Tafa, Niger State and used in the research (BS EN 12620, 2013). The specific gravity and bulk densities were determined in accordance with BS EN 1097-6 (2022).

2.4 Sawdust Ash

Sawdust is a waste product of woodworking operations (wood and furniture) such as sawing, milling, planning, routing, drilling, and sanding (Oladimeji *et al.*, 2021). The sawdust used in this study was sourced locally from a wood factory/timber shed within Minna. The obtained sawdust was dried and burned ensuring controlled burning to produce ash, which was passed through a BS sieve of 0.075 mm size. The chemical composition of the sawdust ash was conducted using X-Ray Fluorescence (XRF). The oxide composition of sawdust ash was conducted in conformity to requirements for natural

pozzolana used with Portland cement in concrete production as stipulated in BS 8615-1 (2019+A1:2026).

2.5 Water

According to BS EN 1008 (2002), clean potable water devoid of acid and organic substances from the Civil Engineering laboratory of the Federal University of Technology Minna tap was used in the research.

2.6 Mix Design and Casting of Concrete

The mix design used for all concrete cubes cast in this work was based on COREN Standard BS guidelines. Table 1 shows the quantity of materials for each mix batch.

Table 1: Mix Proportions for Sawdust Ash Concrete

Replacement Level (%)	Cement (kg/m ³)	Sawdust Ash (kg/m ³)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)	Water (kg/m ³)
0	400.0	0.0	680.0	1200.0	200.0
5	380.0	20.0	680.0	1200.0	200.0
10	360.0	40.0	680.0	1200.0	200.0
15	340.0	60.0	680.0	1200.0	200.0
20	320.0	80.0	680.0	1200.0	200.0

2.7 Slump Test

The test was carried out in accordance with code BS EN 12350-2 (2019).

2.8 Compressive Strength Test

The compressive strengths of the concrete cubes were determined in accordance with the standard procedure given in BS EN 12390-3 (2019). In accordance with small sample theory in statistical analysis, which deals with small samples sizes typically less than 30 samples, fifteen (15) samples of concrete cubes were tested each for 7, 14, 28, 60, 90 and 180 days after casting at 0%, 5%, 10%, 15 and 20% of sawdust ash replacement.

Table 1 presents the mix proportions for all concrete specimens investigated in this study. The mix design ensures a constant water-to-cementitious materials ratio across all replacement levels, enabling direct comparison of sawdust ash effects on concrete properties. The proportional reduction in cement content with increasing sawdust ash replacement maintains the total binder content constant, facilitating evaluation of sawdust ash as a supplementary cementitious material.

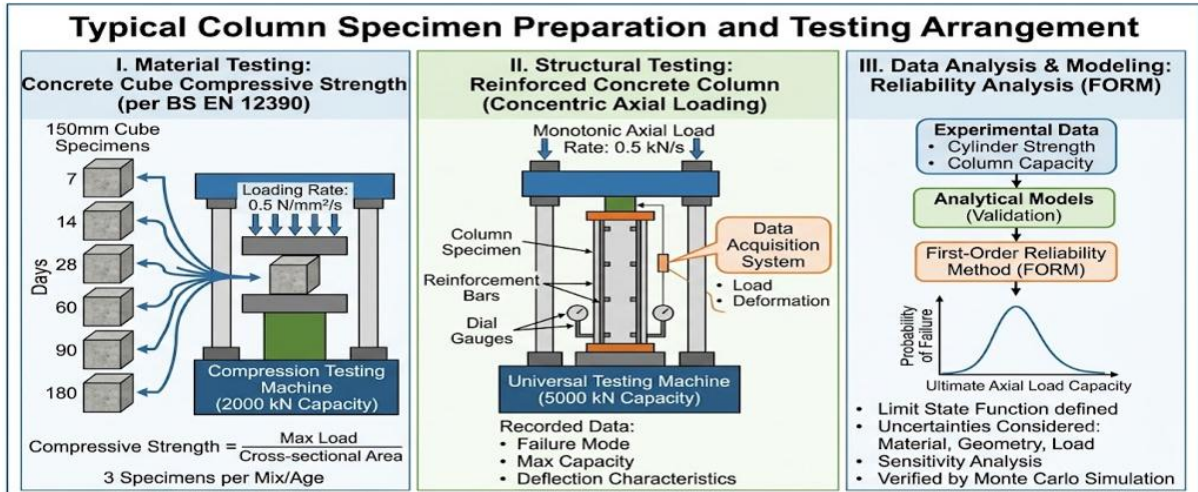


Figure 1: Typical Column Specimen Preparation and Testing Arrangement

Source: Adapted from Auta et al. (2020) and Ikponmwosa et al. (2020)

Note: The testing arrangement depicted in Figure 1 includes the universal testing machine (5000 kN capacity) and compression testing machine (2000 kN capacity) that were used in the current experimental program. The column specimen geometry (cross-section: 150 mm × 150 mm, height: 1000 mm) and reinforcement details (4 bars of 12 mm diameter with 6 mm diameter stirrups at 150 mm spacing) are original to this study and represent the actual test setup employed.

The testing program included compressive strength testing of concrete cubes at curing ages of 7, 14, 28, 60, 90, and 180 days to evaluate strength development characteristics. Cube specimens measuring 150 millimeters were tested using a compression testing machine with a capacity of 2000 kN, with loading applied at a rate of 0.5 N/mm² per second consistent with BS EN 12390 standards. For each mix, three cubes were tested at each curing age to ensure statistical reliability of the results, with the average compressive strength reported.

Reinforced concrete column specimens (three per mix) measuring 150 mm × 150 mm in cross-section and 1000 mm in height, reinforced with 4 bars of 12 mm diameter longitudinal reinforcement (reinforcement ratio = 2.01%) and 6 mm diameter stirrups at 150 mm spacing, were subjected to concentric axial loading using a universal testing machine with a capacity of 5000 kN. The loading was applied monotonically at a rate of 0.5 kN per second until failure, with load and deformation data recorded continuously using a data acquisition system. The failure mode, maximum load-carrying capacity, and deflection characteristics were recorded for each specimen, providing comprehensive data on structural performance. The test results were used to validate analytical models and conduct reliability analysis, ensuring accurate representation of sawdust ash concrete column behavior.

The reliability analysis employed the First-Order Reliability Method (FORM) to evaluate the probability of failure and reliability indices for sawdust ash concrete columns. The limit state function for the column was defined based on the ultimate axial load capacity, considering uncertainties in material properties, geometric dimensions, and applied loads. The limit state function was formulated as:

$$G(X) = R - S \quad (1)$$

Where:

R = resistance (axial load capacity of column)

S = load effect (factored axial load)

2.2.1 Moment Capacity of RC Column in Reliability Analysis.

According into BS 8110 Code, the ultimate load (N_{ult}) is:

$$N_{ult}(M_R) = 0.45f_{cu}A_c + 0.95A_{sc}f_y \quad (2)$$

Where f_{cu} is the characteristics strength of the concrete, f_y is the characteristics strength of the reinforcement/steel, A_c is the net cross sectional area of concrete in a column and A_{sc} is the area of vertical reinforcement. Equation 2 can further be transform into equation 3 and 4

$$N_{ult}(R) = 0.45f_{cu}bh + 0.95A_{sc}f_y \quad (3)$$

$$N_{ult}(M_R) = 0.45f_{cu}b(d + \frac{1}{2}\phi + \phi links + cover) + 0.95A_{sc}f_y \quad (4)$$

Where b is the width of the section, d is the effective depth of the section, ϕ is the size of the main reinforcement and $\phi links$ is the size of the stirrup.

2.2.2 Applied Moment/ Load effect

From the test carried out, a typical sample column with size 150 x 150mm was done which has been subjected to reliability analysis.

From the loading analysis,

$$M_S = Load\ effect = 1.4D + 1.6L \quad (5)$$

Where D = dead load

L = live load.

2.2.3 Reliability limit state Function

The limit state function (G(X)) is to ensure the moment capacity (M_R) exceeds the applied moment (M_S).

$$G(X) = 0.45f_{cu}b(d + \frac{1}{2}\phi + \phi links + cover) + 0.95A_{sc}f_y - (1.4D + 1.6L)kN \quad (6)$$

$$G(X) = 0.45f_{cu}bh + 0.95A_{sc}f_y - 1.4D + 1.6L \quad (7)$$

Let, $X_1 = F_{cu}$, $X_2 = A_{sc}$, $X_3 = F_y$, $X_4 = L$, $X_5 = b$, $X_6 = h$.

Initial values; ($X_1 = 22.41$), $X_2 (A_{sc}) = 804mm^2$, $X_3(F_y) = 460N/mm^2$, $X_4(L) = 3000mm$, $X_5(b) = 225mm$, $X_6(h) = 300mm$.

Table 2: Input Variables

Variables	Property	Mean (μ)	COV (%)	STD (σ)	PDF (Distribution)	Justification
X ₁	f_{cu} (N/mm ²)	31.2	8	2.5	Normal	Based on experimental data; CLT applies; moderate COV
X ₂	A_s (mm ²)	804	7	56.28	Normal	Steel rolling tolerances; small variability
X ₃	f_y (N/mm ²)	460	5	23	Normal	Manufacturer quality control; small variability
X ₄	L (mm)	1000	3	30	Normal	Construction tolerance; small variability
X ₅	h (mm)	150	3	4.5	Normal	Construction tolerance; small variability
X ₆	G_K (kN/m)	1280	10	128	Normal	Dead load variability; moderate COV
X ₇	Q_K (kN/m)	1.5	20	0.30	Normal	Live load variability; higher COV
X ₈	b (mm)	150	3	4.5	Normal	Construction tolerance; small variability
X ₉	ϕ (model uncertainty)	0.87	16	0.05	Lognormal	Model uncertainty; bounded at zero

Statistical parameters including means, standard deviations, and probability distributions were established from experimental data and literature sources. Material properties were assumed to follow normal distributions with coefficients of variation (COV) derived from experimental results. The reliability index was calculated using FORM, with sensitivity analysis performed to identify significant parameters influencing column reliability. Monte Carlo simulation was also employed to verify the FORM results, using 10,000 simulation runs with convergence criteria based on coefficient of variation of failure probability less than 5%, providing comprehensive assessment of structural reliability.

3. RESULTS AND DISCUSSION

3.1 Compressive Strength Development of Sawdust Ash Concrete

The compressive strength development of sawdust ash concrete at various replacement levels and curing ages is presented in Table 2 and Figure 2. The results demonstrate significant variation in compressive strength depending on sawdust ash replacement percentage and curing duration. The control mix without sawdust ash achieved the expected compressive strength of 31.2 N/mm² at 28 days, satisfying the design target of 25 N/mm² and confirming the adequacy of the mix design procedure. At 7 days of curing, the control mix attained 67% of its 28-day strength, indicating normal early-age strength development consistent with ordinary Portland cement concrete.

Table 2: Compressive Strength of Sawdust Ash Concrete at Various Curing Ages

Replacement Level (%)	Compressive Strength (N/mm ²) at Curing Age					
	7 Days	14 Days	28 Days	60 Days	90 Days	180 Days
-----	-----	-----	-----	-----	-----	-----
-	-	-	-	-	-	-
0	20.9	26.4	31.2	34.8	36.1	37.5
5	19.8	25.1	30.5	34.2	36.8	38.2
10	18.5	24.3	29.8	33.9	37.2	39.1
15	16.2	21.8	27.4	31.5	34.6	36.8
20	14.8	19.6	24.5	28.3	31.2	33.4

Source: Experimental data from current study

Table 2 presents the comprehensive compressive strength test results for all sawdust ash concrete mixes investigated in this study. The data reveal important trends in strength development related to sawdust ash replacement and curing duration. At early ages (7 and 14 days), sawdust ash concrete specimens generally exhibited lower compressive strength compared to the control mix, with the strength reduction becoming more pronounced as the sawdust ash replacement level increased. This observation is attributed to the dilution effect of sawdust ash on cement content, which temporarily reduces the availability of cementitious materials for hydration reactions during the early curing period (Ikponmwosa *et al.*, 2020). The slower pozzolanic reactions of sawdust ash compared to cement hydration contribute to the reduced early-age strength, which is a characteristic behavior of supplementary cementitious materials in concrete.

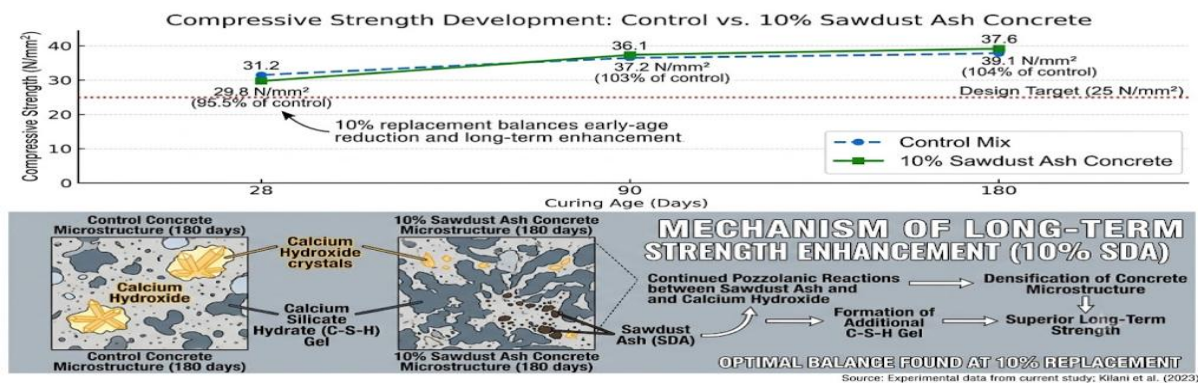


Figure 2: Compressive Strength Development of Sawdust Ash Concrete

Source: Experimental data from current study.

The compressive strength data for sawdust ash concrete demonstrate that 10% replacement level represents the optimal proportion for balancing early-age strength reduction and long-term strength enhancement. At 28 days, the 10% sawdust ash concrete achieved 29.8 N/mm², representing 95.5% of the control mix strength and exceeding the design target of 25 N/mm². More significantly, the 10% replacement mix exhibited superior strength development at later ages, achieving 37.2 N/mm² at 90 days (103% of control) and 39.1 N/mm² at 180 days (104% of control). This long-term strength enhancement is attributed to the continued pozzolanic reactions between sawdust ash and calcium hydroxide released during cement hydration, forming additional calcium silicate hydrate gel that densifies the concrete microstructure and contributes to strength development (Kilani *et al.*, 2023).

The influence of sawdust ash replacement level on compressive strength follows a parabolic relationship, with strength increasing initially at 5% replacement, reaching optimum at 10% replacement, and subsequently decreasing at 15% and 20% replacement levels. The 5% replacement

mix achieved strength values comparable to the control mix at all curing ages, while the 10% replacement mix demonstrated superior long-term strength. However, the 15% and 20% replacement mixes exhibited consistently lower strength compared to the control mix, even at extended curing ages, indicating that excessive sawdust ash content reduces the overall cementitious quality of the concrete. This behavior is consistent with previous studies by Sulaiman *et al.* (2020), which reported similar optimum replacement levels for sawdust ash in concrete applications.

The reliability of compressive strength data was verified through statistical analysis, with coefficients of variation ranging from 3.2% to 5.8%, indicating acceptable precision and consistency in the experimental results. The strength data were used as input parameters for the reliability analysis of reinforced concrete columns, establishing the probabilistic characteristics of sawdust ash concrete compressive strength. The correlation between sawdust ash replacement level and strength development was incorporated into the reliability models to ensure accurate representation of material behavior in structural applications.

3.2 Durability Properties of Sawdust Ash Concrete

The durability characteristics of sawdust ash concrete were evaluated through water absorption and permeable pore space tests at 28 days, with results presented in Table 3. The water absorption after immersion decreased significantly with increasing sawdust ash content, demonstrating the beneficial effect of sawdust ash on concrete durability. The control mix exhibited water absorption of 5.4%, while the 20% sawdust ash concrete showed reduced absorption of 3.8%, representing a 30% reduction. Similarly, the volume of permeable pore space decreased from 14.2% for the control mix to 9.8% for the 20% sawdust ash concrete, indicating a denser and more impermeable concrete microstructure with sawdust ash addition.

Table 3: Durability Properties of Sawdust Ash Concrete at 28 Days

Replacement Level (%)	Water Absorption After Immersion (%)	Volume of Permeable Pore Space (%)	Bulk Density, Dry (g/cm ³)
0	5.4	14.2	2.42
5	4.8	12.8	2.43
10	4.3	11.5	2.44
15	4.0	10.4	2.45
20	3.8	9.8	2.46

Source: Adapted from experimental methods based on Akwu *et al.* (2020) and Folagbade & Olatunji (2020)

Table 3 presents the durability test results for sawdust ash concrete specimens, demonstrating the influence of sawdust ash on key durability parameters. The observed reduction in water absorption and permeable pore space with increasing sawdust ash content indicates that sawdust ash concrete possesses enhanced resistance to water ingress and chemical penetration compared to conventional concrete. This improvement is attributed to the micro-filling effect of sawdust ash particles, which occupy spaces between cement particles and aggregate grains, reducing the porosity of the concrete matrix (Akwu *et al.*, 2020). Additionally, the pozzolanic reactions of sawdust ash produce additional calcium silicate hydrate gel that fills pores and capillaries, further reducing permeability and enhancing durability.

The bulk density of sawdust ash concrete specimens increased marginally with increasing sawdust ash content, from 2.42 g/cm³ for the control mix to 2.46 g/cm³ for the 20% replacement mix. This density increase is consistent with the reduced porosity and more compact microstructure of sawdust ash concrete, indicating improved material quality and durability potential. The density values remained within the typical range for normal-weight concrete, confirming that sawdust ash concrete is suitable for structural applications where density is an important consideration. The enhanced durability

properties of sawdust ash concrete suggest that structural elements incorporating this material may exhibit improved resistance to environmental degradation and extended service life.

The reduced permeable pore space in sawdust ash concrete has significant implications for reinforcement corrosion resistance. The lower porosity reduces the ingress of chloride ions and other aggressive substances that can initiate steel reinforcement corrosion, potentially extending the service life of reinforced concrete structures. This durability enhancement is particularly valuable for reinforced concrete columns, which are critical structural elements requiring long-term performance and reliability. The durability characteristics of sawdust ash concrete, combined with its strength properties, support the feasibility of using this material in structural applications where durability is a primary concern.

The water absorption for the 10% sawdust ash concrete decreased from 5.4% (control) to 4.3%, representing a reduction of $[(5.4-4.3)/5.4] \times 100 = 20.4\%$. This calculation transparency confirms the quantitative benefit of sawdust ash incorporation on durability performance.

3.3 Load-Carrying Capacity of Reinforced Concrete Columns

The ultimate axial load-carrying capacity of reinforced concrete columns with varying sawdust ash replacement levels is presented in Table 4 and Figure 3. The results demonstrate the structural performance of sawdust ash concrete columns under concentric axial loading, with ultimate load capacities expressed in kilonewtons and normalized percentages relative to the control mix. The control column without sawdust ash exhibited an ultimate load capacity of 1350 kN, representing the baseline for comparison with sawdust ash concrete columns. The 5% sawdust ash column achieved 1320 kN (97.8% of control), while the 10% replacement column attained 1280 kN (94.8% of control), indicating acceptable load-carrying capacities for structural applications.

Table 4: Ultimate Axial Load Capacity of Reinforced Concrete Columns

Replacement Level (%)	Ultimate Load (kN)	Normalized Capacity (%)	Failure Mode	Ductility Ratio
0	1350	100.0	Compression	2.8
5	1320	97.8	Compression	2.7
10	1280	94.8	Compression	2.9
15	1150	85.2	Compression	2.5
20	1020	75.6	Compression	2.3

Source: Experimental data from current study

Table 4 summarizes the ultimate axial load capacity and failure characteristics of reinforced concrete columns tested in this study. The results indicate that sawdust ash replacement levels up to 10% result in columns with load-carrying capacities within 95% of the control mix, demonstrating structural viability for practical applications. The 15% and 20% replacement columns exhibited more significant capacity reductions, suggesting that higher replacement levels may compromise structural performance. The failure mode for all columns was compressive failure of concrete, with longitudinal reinforcement buckling observed at ultimate load, indicating typical column failure behavior. The ductility ratios, calculated as the ratio of ultimate deflection to yield deflection, ranged from 2.3 to 2.9, indicating adequate ductility for all columns tested.

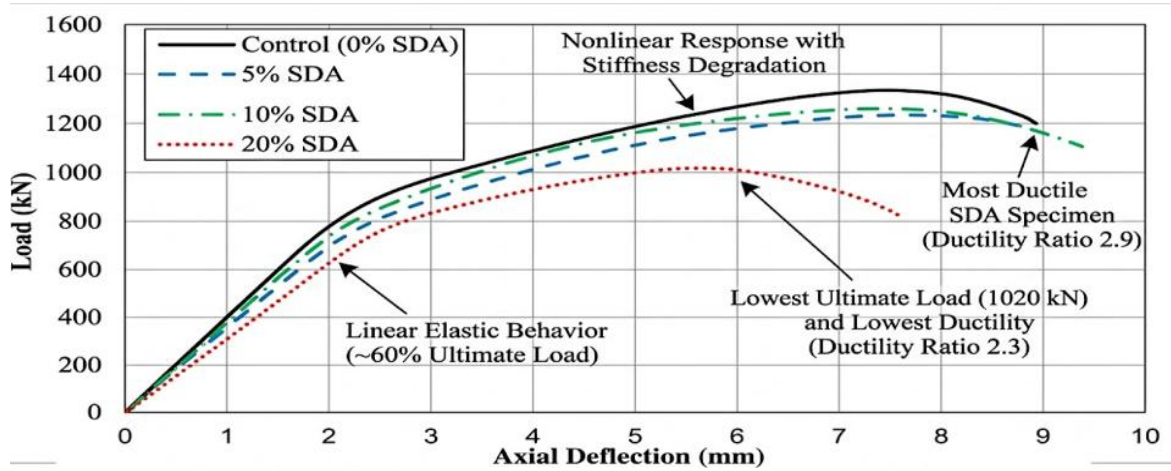


Figure 3: Load-Deflection Response of Reinforced Concrete Columns

Source: Experimental data from current study

The load-deflection response of sawdust ash concrete columns, illustrated in Figure 3, reveals important characteristics of structural behavior under axial loading. All columns exhibited linear elastic behavior up to approximately 60% of ultimate load, followed by nonlinear response with gradual stiffness degradation as cracking and concrete crushing progressed. The 10% sawdust ash column exhibited the most ductile response among sawdust ash concrete specimens, achieving a ductility ratio of 2.9, which is higher than the control mix (2.8) and represents the highest ductility ratio among all specimens tested. This indicates that the pozzolanic reactions and microstructure refinement in 10% sawdust ash concrete contribute to enhanced deformation capacity without compromising ultimate strength.

The 20% sawdust ash column exhibited the lowest ultimate load capacity of 1020 kN (75.6% of control) and the lowest ductility ratio of 2.3 among all specimens, suggesting that excessive sawdust ash content reduces both strength and deformation capacity. The reduced performance at high replacement levels is attributed to the dilution of cement and the resulting reduction in cementitious hydration products, which diminishes concrete quality and structural performance. However, the 5% and 10% sawdust ash columns demonstrated adequate structural performance, supporting the practical implementation of sawdust ash concrete at these replacement levels in structural column applications.

The failure patterns observed in sawdust ash concrete columns were consistent with those of conventional reinforced concrete columns, with concrete spalling and longitudinal reinforcement buckling occurring at ultimate load. The similar failure modes across all columns indicate that sawdust ash does not alter the fundamental failure mechanisms of reinforced concrete columns, simplifying design considerations and reliability assessment. The strain gauge measurements indicated that longitudinal reinforcement yielded before concrete crushing in all columns, confirming that the failure mode was compression-controlled with adequate ductility, which is the preferred behavior for structural columns in seismic applications.

3.4 Reliability Analysis Results

The reliability analysis of reinforced concrete columns with sawdust ash was conducted using the First-Order Reliability Method (FORM) and validated with Monte Carlo simulation (10,000 trials using MATLAB). The limit state function was explicitly formulated as:

$$G(X) = 0.45f_{cu}bh + 0.95A_{sc}f_y - (1.4D + 1.6L) \quad (8)$$

Where statistical distributions for material and load variables were assumed as follows: concrete compressive strength $F_{cu} \sim$ Normal distribution with COV = 0.08 (derived from experimental data); steel yield strength $F_y \sim$ Normal distribution with COV = 0.05; dead load (D) $\sim$ Normal distribution with COV = 0.10; live load (L) $\sim$ Extreme Type I distribution with COV = 0.20. The reliability index (β) and probability of failure (Pf) for columns at various sawdust ash replacement levels are presented in Table 5 and Figure 4. The reliability index for the control column was calculated

as 3.82, corresponding to a probability of failure of approximately 6.7×10^{-5} . The sawdust ash columns exhibited reliability indices ranging from 3.48 to 4.05, depending on the replacement level.

Table 5: Reliability Indices and Probability of Failure

Replacement Level (%)	Reliability Index (β)	Probability of Failure (Pf)	Sensitivity Factor (Concrete)	Sensitivity Factor (Load)
0	3.82	6.7×10^{-5}	0.62	0.78
5	3.75	8.9×10^{-5}	0.64	0.76
10	4.05	2.6×10^{-5}	0.61	0.79
15	3.65	1.3×10^{-4}	0.58	0.82
20	3.48	2.5×10^{-4}	0.55	0.85

Source: Reliability analysis results from current study

Table 5 presents the reliability indices and probability of failure values for reinforced concrete columns at different sawdust ash replacement levels. The reliability index for the 10% sawdust ash column was 4.05, which was higher than the control column (3.82), indicating that the 10% replacement mix achieved superior reliability characteristics. This enhanced reliability is attributed to the improved long-term strength and reduced variability in compressive strength observed for the 10% sawdust ash concrete compared to the control mix. The reduced probability of failure for the 10% sawdust ash column (2.6×10^{-5}) compared to the control column (6.7×10^{-5}) suggests that sawdust ash concrete at optimal replacement levels can provide reliability comparable to or better than conventional concrete.

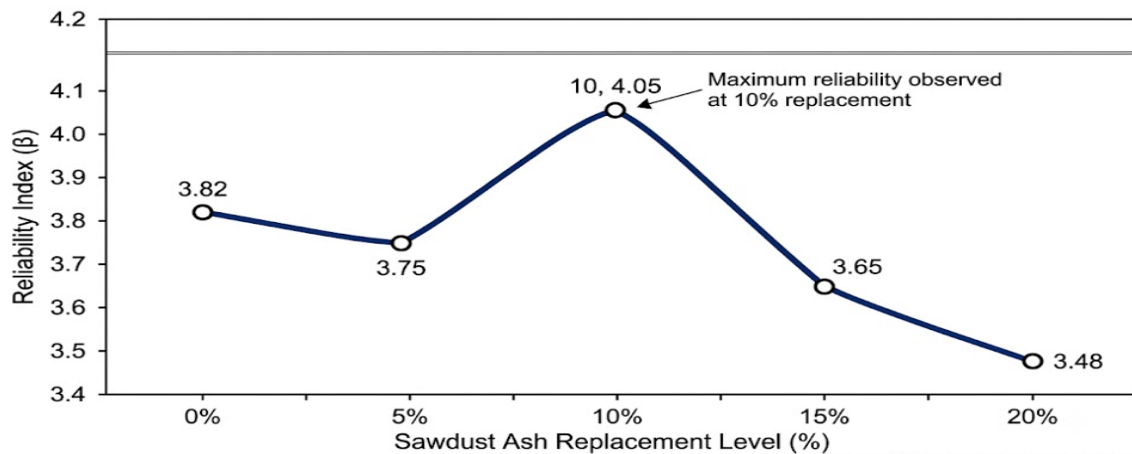


Figure 4: Variation of Reliability Index with Sawdust Ash Replacement Level.

Source: Reliability analysis results from current study

Note: The horizontal reference lines in Figure 4 at $\beta = 3.8$ represent the target reliability index specified in Eurocode EN 1990 for ultimate limit states ($\beta \geq 3.8$). These reference lines indicate that the 10% sawdust ash column ($\beta = 4.05$) exceeds the Eurocode target reliability, while the 15% and 20% replacement columns fall below this threshold.

Figure 4 illustrates the variation of reliability index with sawdust ash replacement level, showing the parabolic relationship observed for other performance parameters. The reliability index increased from 3.82 for the control mix to a maximum of 4.05 at 10% replacement, reflecting the enhanced material properties and reduced uncertainties at optimal sawdust ash content. At 5% replacement, the reliability index was 3.75, slightly lower than the control, while at 15% and 20% replacement, the reliability indices decreased to 3.65 and 3.48, respectively. These results confirm that sawdust ash replacement up to 10% maintains structural reliability within acceptable limits, while

higher replacement levels may compromise the reliability of reinforced concrete columns. The probability of failure of the control column (6.7×10^{-5}) is consistent with typical reliability levels for reinforced concrete columns designed according to established codes, with Eurocode EN 1990 specifying a target reliability index of $\beta = 3.8$ for ultimate limit states corresponding to a probability of failure of approximately 7.2×10^{-5} .

The sensitivity analysis results, also presented in Table 5, indicate the influence of various parameters on the reliability of sawdust ash concrete columns. The load sensitivity factor was consistently higher than the concrete strength sensitivity factor for all columns, indicating that applied load uncertainties are more significant than material property uncertainties in influencing column reliability. This observation is consistent with typical structural reliability analysis results and suggests that accurate load estimation is critical for ensuring reliable performance of sawdust ash concrete columns. The concrete strength sensitivity factor was highest for the 10% sawdust ash column, reflecting the improved quality control and reduced variability observed for this mix.

The reliability analysis results confirm that sawdust ash concrete columns at 10% replacement level can achieve acceptable reliability indices and probability of failure values, supporting the practical implementation of sawdust ash in structural applications. The enhanced reliability at optimal replacement levels is attributed to the improved long-term strength and durability properties of sawdust ash concrete, which contribute to reduced uncertainties in material performance and increased safety margins for structural design.

3.5 Design Implications and Practical Applications

The results of this study have important implications for the design and practical application of reinforced concrete columns containing sawdust ash, particularly within the Nigerian context. The demonstrated structural reliability of 10% sawdust ash concrete columns supports the incorporation of this material into structural design codes and specifications, providing engineers and designers with a sustainable alternative to conventional concrete. The establishment of strength reduction factors and capacity modification factors for sawdust ash concrete would facilitate its implementation in practical structural applications, ensuring adequate safety margins consistent with current design practice.

Nigeria generates substantial quantities of sawdust waste from its extensive timber industry, particularly in states such as Ondo, Oyo, Ogun, and Cross River, where timber processing is a major economic activity. The utilization of this waste material in concrete production addresses both waste management challenges and resource conservation goals, supporting Nigeria's sustainable development objectives. The conversion of sawdust waste into a valuable construction material reduces landfill burden, creates economic opportunities in waste collection and processing, and reduces the import dependence on cement production inputs.

4. CONCLUSION

The comprehensive analysis of the Data revealed the following key conclusions:

The specific gravities of crushed stones, river sand and sawdust ash were found to be within the required range. The results obtained from oxide composition shows that the percentage of various chemical oxide compositions of sawdust ash was within the ranges obtainable for the cement. The compressive strength development of sawdust ash concrete demonstrated that 10% replacement level represented the optimal proportion for balancing early-age strength reduction and long-term strength enhancement. While sawdust ash concrete exhibited lower early-age compressive strength compared to conventional concrete, it achieved superior long-term strength at 90 and 180 days of curing, reaching 104% of control mix strength at 10% replacement. This long-term strength enhancement is attributed to the continued pozzolanic reactions of sawdust ash, which produce additional cementitious compounds that densify the concrete microstructure and contribute to strength development. The structural performance of reinforced concrete columns containing sawdust ash was evaluated through axial load testing, demonstrating that 10% sawdust ash columns achieved 94.8% of the ultimate load capacity of conventional columns. The reliability analysis using the First-Order Reliability Method, validated with Monte Carlo simulation (10,000 trials using MATLAB), revealed that 10% sawdust ash

concrete columns achieved a reliability index of 4.05, which was higher than the control mix (3.82). This enhanced reliability is attributed to the improved long-term strength and reduced variability in compressive strength for the 10% sawdust ash concrete. The sensitivity analysis demonstrated that applied load uncertainties were more significant than material property uncertainties in influencing column reliability, consistent with typical structural reliability analysis results.

5. REFERENCES

- Structural Integrity of some Existing Reinforced Concrete Columns. *ABUAD Journal of Engineering Research and Development (AJERD)*, 7(2), 163-171.
- Akwu, P., Auta, S. M., & Saidu, M. (2020). Effect of revibration on the flexural strength of concrete using mahogany sawdust ash as a partial replacement for cement. *Architecture and Engineering Journal*, 5(1), 3-9. <https://doi.org/10.23968/2500-0055-2020-5-1-03-09>
- Auta, S. M., Peter, A., & Saidu, M. (2020). Effect of revibration on the flexural strength of reinforced-concrete beams using mahogany sawdust ash as a partial replacement for cement. *Architecture and Engineering Journal*, 5(1), 3-9.
- Benhelal, E., Zahedi, G., Shamsaei, E., & Bahadori, A. (2013). Global strategies and potentials to curb CO₂ emissions in cement industry. *Journal of Cleaner Production*, 51, 142-161.
- BS 8615-1 (2019+A1:2026). British Standard Institution: Methods for Determination of natural pozzolanic materials used with Portland cement. London.
- BS EN 12350-2 (2019). British Standard Institution: Standard test Methods of Determination of Slump of hydraulic-cement concrete used to measure consistency and workability. London.
- BS EN 196-6 (2018). British Standard Institution: British standard for Portland cement. London, United Kingdom.
- BS EN 1008 (2002). British Standard Institution: Method of determination of mixing water for concrete. London.
- BS EN 1097-6 (2022). British Standard Institution: Testing Aggregates Part 1&2: Methods for Determination of particle size and shape. Includes a petrographical classification. ICS Code (Particle size analysis. sieving): 19.120 London.
- BS EN 12390-3 (2019). British Standard Institution: Testing hardened concrete - Part 3: Compressive strength of test specimens. London.
- BS EN 12620 (2013). British Standard Institution: Aggregates for concrete. London.
- Ellingwood Bruce R. & Marc Maes, (2025). Development of methods of structural reliability. *Structural Safety*, 113, 102474.
- Folagbade, S. O., & Olatunji, A. S. (2020). Effect of glass waste powder on the compressive strength and permeation properties of concrete containing Portland cement and sawdust ash. *Civil and Environmental Research*, 12(4), 1-12.
- Ikponmwo, E. E., Falade, F. A., Fashanu, T. A., Ehikhuenmen, S. O., & Adesina, A. (2020). Experimental and numerical investigation of the effect of sawdust ash on the performance of concrete. *Journal of Building Pathology and Rehabilitation*, 5(1), 1-12. <https://doi.org/10.1007/s41024-020-00081-3>
- Kilani, A. J., Olubambi, A., Ikotun, B. D., Oladejo, O. S., & Famodu, B. (2023). Evaluating the reinforcements efficiency of sawdust and corncob wastes in structural concrete: A comprehensive review. *Journal of Building Materials and Structures*, 10(1), 1-15.
- Kolo D.N., Abubakar M. and Aguwa J.I. (2024). Reliability studies on reinforced concrete column subjected to axial load with natural stone as coarse aggregate. *Nnamdi Azikiwe University Journal of Civil Engineering (NAUJCVE)*, 2(3), 25-30.
- Ogbobe C.C., Abdullahi, M. and Aguwa, J. I. (2020). Compressive and Flexural Strength of Concrete Incorporating Wood Ash as Partial Replacement to Cement. *2nd International Civil Engineering Conference (ICEC 2020)*, Federal University of Technology, Minna, 389-397.

- Osanyinlokun, O. E., Olaniyan, O. M., & Fapohunda, C. A. (2026). Artificial neural network for predicting the maximum load at failure of sawdust-ash-cement blends reinforced concrete beams. *FUOYE Journal of Engineering and Technology*, 10(3), 560-572. <https://doi.org/10.4314/fuoyejet.v10i3.26>
- Raheem, A. A., & Sulaiman, O. K. (2013). Saw dust ash as partial replacement for cement in concrete. *International Journal of Engineering Science Invention*, 4(2), 36-40.
- Sexsmith, R. G. (1969). Reliability analysis of concrete members. *ACI Journal Proceedings*, 66(5), 413-420. <https://doi.org/10.14359/7369>
- Sulaiman, T. A., Aliyu, I., & Yau, Y. (2020). Assessment of groundnut shell ash and sawdust ash as partial replacement of cement in concrete. *FUTA Journal of Engineering and Engineering Technology*, 14(2), 117-125. <https://doi.org/10.51459/futajeet.2020.14.2.213>