Nigerian Journal of Technology (NIJOTECH)
Vol. 43, No. 1, March, 2024, pp.2 - 13
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v43i1.2

COMPRESSIVE, BENDING AND SHEAR PROPERTIES OF REINFORCED CONCRETE BEAMS CONTAINING SAWDUST ASH AS PARTIAL REPLACEMENT OF CEMENT

AUTHORS:
O. E. Osanyinlokun[1,*], C. A. Fapohunda[2], and O. M. Olaniyan[3]

AFFILIATIONS:
[1]Department of Civil Engineering, Bamidele Olumilua University of Education, Science, and Technology, Ikere-Ekiti, Nigeria
[2]Department of Civil Engineering, Federal University Oye-Ekiti, Nigeria
[3]Department of Computer Engineering, Federal University Oye-Ekiti, Nigeria

***CORRESPONDING AUTHOR:**
Email: osanyinlokun.oluwatoyin@bouesti.edu.ng

ARTICLE HISTORY:
Received: 28 January, 2024.
Revised: 02 March, 2024.
Accepted: 11 March, 2024.
Published: 31 March, 2024.

KEYWORDS:
Bending behaviour, Partial cement replacement, Reinforced concrete beams, Sawdust ash, Shear behaviour.

ARTICLE INCLUDES:
Peer review

DATA AVAILABILITY:
On request from author(s)

EDITORS:
Chidozie Charles Nnaji

FUNDING:
None

Abstract
Reinforced concrete (RC) beams are a fundamental component of modern construction, providing structural support and stability to buildings and infrastructure. This article critically examines the impact of partially replacing cement with sawdust ash (SDA) on RC beams' bending and shear performance. It explores its potential as a sustainable solution for the construction industry, offering valuable insights for researchers and construction professionals. Concrete cubes (150x150x150 mm) and reinforced structural-grade 25 N/mm^2 concrete beams (150x150x600 mm for the bending test and 150x150x450 mm for the shear test) specimens were used for this investigation. The concrete cube and RC beam specimens had SDA as a partial cement replacement within the range of 0%–10% by weight of cement at 2.5% intervals. 120 RC beam specimens were cast, followed by curing and testing at 28, 60, 90, and 180 days. Using the 4-point loading method, the bending and shear responses of the beams and associated parameters, like the formation and growth of cracks, were determined during the testing. The impact of SDA replacement on the characteristics of fresh and hardened concrete was also assessed using 105 cube specimens cast, cured, and tested at 7, 14, 21, 28, 60, 90, and 180 days. A concrete mix ratio of 1:1.3:2.4 and a constant water/binder ratio of 0.50 at optimum 5% SDA replacement produced (25 N/mm^2) the required compressive strength. The results show that workability decreases as the SDA percentage increases. Generally, the values of concrete's densities containing SDA in the mix were in the range of standard weight applications. At 28 days, samples up to 5% recorded a higher compressive, bending, and shear strength development rate than the control mix. The results show that cement partially replaced with up to 5% SDA can produce RC that meets the requirements for concrete for structural application.

1.0 INTRODUCTION
Concrete, the bedrock of modern construction, holds immense value for its versatility, strength, and affordability. Its ubiquitous presence shapes our cities, roads, and homes. Regarding global acceptability, no other construction material has come close to concrete. Its acceptability was based on many factors, including the availability of materials for its production at every location, the ability to produce any desired specified strength, the ability of the engineers and builders to play with any geometric shapes, and excellent durability properties, among others [1]. The demand for structural concrete continued to increase due to the myriad construction activities vital to maintaining present-day civilisation. It sought to address housing requirements for low-income earners,

HOW TO CITE:
Osanyinlokun, O. E., Fapohunda, C. A., and Olaniyan, O. M. "Compressive, Bending and Shear Properties of Reinforced Concrete Beams containing Sawdust Ash as Partial Replacement of Cement", *Nigerian Journal of Technology*, 2024; 43(1), pp. 2 – 13; *https://doi.org/10.4314/njt.v43i1.2*

who comprise most of the population, and to provide structures of various forms, ranging from religious to institutional buildings.

The fundamental materials used to produce concrete are sand, cement, water, and gravel. Cement is not only the most expensive [2], but its production consumes non-renewable natural materials, leading to greenhouse gases like CO_2 emissions. The exhaustion of natural resources by construction activities also calls into question the sustainability of structural concrete manufacturing—sustainability is seen as a significant issue due to the use of high volumes of cement and other aggregates, which raises costs and has negative environmental consequences. In an era of diminishing natural resources, ozone layer damage, rising pollution, and concerns about the greenhouse effect, any discussion of engineering and building that does not include environmental issues is meaningless.

Furthermore, the excessive usage of non-renewable materials in construction depletes natural resources and adds to environmental problems [3, 4, 5]. In addition, cement manufacture, a key component of concrete mixtures, contributes to roughly 5% to 8% of global carbon dioxide emissions [6, 7, 8], necessitating exploring alternatives. Replacing a portion of cement with supplementary cementitious materials (SCMs) offers a viable strategy for mitigating the environmental impact of concrete. Researchers have thus looked into anthropogenic wastes from industrial and agricultural activities for potential sources of SCM. Many agricultural wastes that have been found suitable as SCM include cassava peel ash (CPA), sawdust ash (SDA), rice husk ash (RHA), and so on [9].

Sawdust ash, in particular, emerges as a promising candidate, reducing reliance on cement and lowering the carbon footprint of concrete [10]. Sawdust ash, possessing pozzolanic action, reacts with calcium hydroxide from cement hydration to create extra cementitious compounds and potentially improve concrete properties. Sawdust is a byproduct of mechanical processing or milling wood (timber) into different sizes and shapes [11]. It is abundant in Nigeria, where the study is conducted (Ekiti State), and other parts of the world [12]. Sawmills in Nigeria generated over 1,000,000 m^3 of wood waste in 2010, while about 5000 m^3 was generated in plywood mills. Nigeria generates about 1.8 million tons of sawdust annually and 5.2 million tons of wood waste [13]. Sawmills generate much sawdust, and getting rid of it is typically a hassle. As a result, mountains of sawdust accumulate in landfills around sawmill enterprises (Figure 1).

Figure 1: Typical Sawdust Heaps in an Ado-Ekiti Sawmill Industry

Finding a way to dispose of this waste product prompted a study into its application in manufacturing plain and reinforced concrete. Sawdust ash is gaining popularity as a partial substitute for cement in reinforced concrete beams due to its potential environmental and economic benefits. Several studies have shown that adding sawdust ash to concrete can positively and negatively affect the mechanical properties of reinforced concrete beams; on the one hand, sawdust ash can decrease compressive strength owing to its weaker pozzolanic activity than cement [14]. However, this decrease can be mitigated by optimising the mix design and using appropriate admixtures.

On the other hand, adding sawdust ash can improve the bending and shear behaviour of RC beams. It was discovered that sawdust ash can increase concrete beams' bending strength and ductility, especially at early ages [15]. This improvement is attributable to the ash's pozzolanic reaction, which enhances the bond between the cement matrix and the reinforcing steel. Regarding shear behaviour, sawdust ash can also enhance the reinforced concrete beams' shear strength. The ash particles serve as the filler ingredient, filling the voids in the concrete matrix and improving its overall density and cohesion [16]. This increases the beams' shear capability.

According to [17], the ash's pozzolanic action leads SDA-concrete to develop fast strength at later ages. The tannins and soluble carbohydrates in sawdust-ash concrete took a long time to set and harden. As a result, sawdust ash can enhance the characteristics of concrete, joint-less flooring, and roofing tiles [18]. Cheah and Ramli [19] studied wood waste ash as a partial replacement material for cement-producing mortar and structural-grade concrete. Elinwa *et al.*

[20] examined the fresh-state characteristics of self-compacting concrete that contained sawdust ash. Elinwa & Mahmood [21] investigated ash from wood waste as a cement substitute material. Cheah and Ramli [19] concluded that, generally, incorporating wood ash as a partial cement replacement element in concrete mix composition diminishes its mechanical strength. However, there were hopeful findings that using wood ash at low cement replacement levels improved compressive strength in concrete mixes.

Wood ash can be used as a partial substitute for OPC at up to ten per cent of the total binder weight to create structural-grade concrete or mortar with acceptable strength qualities. Auta *et al.* [22] investigated the bending strength of reinforced vibrated concrete beams containing SDA as a partial substitute for cement. Their findings were as follows: First, the bending strength of concrete with a five per cent SDA cement substitution is somewhat lower than that with zero per cent SDA (control) for revibrated beams, but it is still more than that of the control specimen (zero per cent SDA) non-revibrated concrete beam. Second, at all SDA % levels, the bending strength of non-revibrated SDA concrete is dramatically reduced; cement replacement. The researchers concluded that adding up to five per cent Sawdust Ash to concrete and re-vibration for up to 20 minutes would raise the bending strength of RC beams.

According to a critical analysis of existing studies on sawdust ash concrete, the following are the advantages of incorporating sawdust ash into concrete: (i) cleaning the environment, (ii) reducing cement use, (iii) reducing resource depletion, (iv) reducing high green gas emissions, (v) reducing high energy consumption, and (vi) assisting in the sustainability of concrete production. Several research studies were conducted on the partial substitution of cement with SDA in concrete, which makes it a suitable pozzolan for cement replacement. Research has been done to assess the bending and shear behaviour of RC beams separately. However, work has yet to be done on combining the bending and shear performance of RC beams using sawdust ash as a partial replacement for cement. Its usage in reinforced concrete will only be possible with an understanding of the combination of its bending and shear responses.

Thus, the study aims to bridge this gap by comprehensively investigating the influence of sawdust ash as a partial cement substitution on the combination of reinforced concrete beams' bending and shear behaviour. Specific objectives include the bending and shear responses of the beams and associated parameters, like the formation and growth of cracks, crack loads, crack patterns, failure load, and failure mode.

2.0 MATERIALS AND METHODS

2.1 Materials

Cement, sawdust ash, sand, granite, water, and steel reinforcement bars were used. The cement utilised in this experiment was conventional Portland cement Type I, which fulfils the [23] and [24] standards. In addition, Dangote grade 42.5 N Portland limestone cement was utilised since it meets both standards. This cement was used in the production of concrete and laboratory tests. Sawdust was gathered from sawmill industries in Ekiti State, Nigeria. They were sun-dried to reduce moisture before being burned in an electric furnace at a predetermined temperature and duration. Optimum conditions of temperature and duration were utilised to produce reactive sawdust ash, which is the condition of sawdust ash possessing the highest content of pozzolanic properties.

Sawdust was collected from sawmill industries in Ekiti State, Nigeria. They were sun-dried to decrease moisture before being burned in an electric furnace at a predetermined temperature (500℃, 600℃, and 700℃) for varied burning durations (30 minutes, 60 minutes, and 90 minutes). The respective ash was then sieved through a 600 μm sieve to produce ash with the same fineness as cement.

A chemical test was then conducted on the sieved ash; from the chemical composition of the SDA ash produced at these various temperatures, the highest amorphous silica content was observed at 600℃ for 60 minutes. At these optimum calcination conditions, combined silica, alumina, and ferric content are marked to be above 70%; this meets [25]. These optimum conditions of temperature and duration (state of sawdust ash possessing the highest content of pozzolanic properties) were utilised to produce reactive sawdust ash for concrete production.

Table 1 presents the results of the chemical analysis of the cement and sawdust as used, as determined from X-ray fluorescence (XRF) techniques. It shows the chemical composition of the cement oxides and the sawdust ash produced at 600°C for sixty minutes. Some physical properties of the cement and the sawdust ash are presented in Table 2.

https://doi.org/10.4314/njt.v43i1.2

Table 1: Chemical properties of sawdust ash (SDA) and ordinary Portland cement (OPC)

S/N	Basic Oxides	Formulae	% Composition SDA	% Composition OPC
1	Silicon Oxide	SiO_2	65.26	17.28
2	Aluminium Oxide	Al_2O_3	4.32	4.17
3	Lead Oxide	PbO	0.02	-
4	Calcium Oxide	CaO	9.20	61.67
5	Ferric Oxide	Fe_2O_3	3.15	2.24
6	Magnesium Oxide	MgO	3.19	1.05
7	Potassium Oxide	K_2O	2.81	0.42
8	Chromium Oxide	Cr_2O_3	0.04	-
9	Sodium Oxide	Na_2O	0.45	0.05
10	Phosphorus Oxide	P_2O_5	0.78	-
11	Sulphur Trioxide	SO_3	2.41	1.68
12	Manganese Oxide	MnO	0.36	-
13	Titanium Oxide	TiO_2	0.27	-
14	Zinc Oxide	ZnO	0.15	-
15	Copper Oxide	CuO	0.02	-
16	Loss of Ignition	LOI	7.25	0.03
17	Moisture Content	MC	2.42	-
18	Insoluble Residue	IR	0.23	-

Table 2: Effect of SDA on physical properties of ordinary Portland cement

SDA in the Mix (%)	Blain Value (m^3/kg)	Specific Gravity	Standard Consistency (%)	Setting Time (Minutes)		Retardation Relative to Control (Minutes)	
				Initial	Final	Initial	Final
Specification			25–35%	≥ 60mins	≤ 600mins		
0.00	348	3.10	32.00	75	195	0	0
2.50	345	2.95	32.60	98	216	23	21
5.00	340	2.90	33.10	130	224	55	29
7.50	337	2.87	33.70	141	229	66	34
10.00	335	2.85	34.20	152	243	77	48

Table 3: Physical properties of the fine aggregate (Sand) and coarse aggregate (Granite)

Properties	Results for Sand	Results for Granite	Specification	Remarks
Specific Gravity	2.61	2.66	2.6 – 2.8 (Both)	Satisfactory
Bulk Density (kg/m^3)	1678.50	1756.40	1280 – 1920 (Both)	Satisfactory
Water Absorption (%)	2.00	2.00	0 – 8 (Both)	Satisfactory
Moisture Content (%)	0.31	0.22	0-10 (Sand) 0 – 2 (Granite)	Satisfactory
Coefficient of Curvature (C_c)	1.10	1.09	1 – 3 (Both)	Well Graded
Coefficient of Uniformity (C_u)	6.01	4.34	≥ 6 (Sand) >4 (Granite)	Well Graded
Silt Content	0%		≤ 6% (Sand)	Satisfactory
Aggregate Impact Value		16.89%	10 – 20% (Granite)	Strong
Aggregate Crushing Value		22.23%	≤ 30% (Granite)	Satisfactory
Fineness Modulus	2,54	7.47	≤ 10% (Both)	Satisfactory
Grading	Zone 2	Predominantly between 9.5mm and 19mm	Zone 1 to Zone 3 (Sand)	Well Graded

The results of the physical properties test of the cement used all correspond to the specification for OPC, Type I of [26] and are satisfactory.

BS EN 12620 [27]-compliant natural sand was utilised as fine aggregate, with a maximum nominal size of 4.75 mm. The sharp sand used for this research was obtained from Ekiti State and tested before usage. In order to eliminate organic particles and clay, the sun-dried sand particles were sieved. According to ASTM D6913-04 [28], particles passing through a sieve number 200 (approximately 0.075mm) are generally classified as clay. Clay particles were deemed unsuitable in our specific experiment, which produced concrete cubes and reinforced concrete beam specimens due to their high water-holding capacity, impacting desired material properties. The coarse aggregate utilised was crushed stone with a maximum nominal size of 19 mm, which met the specifications of [27]. The coarse aggregate used for this research was obtained from Ekiti State, and the granite was tested before usage. The granite was also sieved to remove clay and organic impurities. The fine aggregate and coarse aggregate used for this research investigation are well-treated and tested; the results of the physical properties test are presented in Table 3.

This experiment's concrete mixes were made with potable water that met [29] standards. The water was pure and devoid of visible contaminants, alkalis, organic matter, suspended particles, and acids, which might reduce concrete strength if present. Reinforcement obtained from the open market was used for this investigation. Tensile testing was conducted to ascertain the reinforcements' material qualities to assess the reinforcement's strength. The test was conducted in line with [30]. Two 10mm and 12mm reinforcement samples were tested for tensile strength; both average yield stresses were 501.68 N/mm^2 and 511.67 N/mm^2, respectively. They were all satisfactory and were more significant than the design yield stress of 460 N/mm^2. The 12mm reinforcement was used for tension and compression reinforcements, and the 10mm reinforcement was used as the shear reinforcement.

Figure 2: Arrangement of reinforcement for typical bending and shear beam

2.2 Mix Design

A trial mix to determine the mix ratio and the water-binder ratio required to produce a concrete grade of 25N/mm^2 following the methods specified by [31] was carried out in this study. For this experiment, concrete cubes were produced for compression strength testing. Before being tested for compressive strength, five (5) samples of each of three (3) specimens were cured for 28 days. A composite specimen containing concrete cubes of the mix ratio Specimen A - 1:1.4:2.7; specimen B - 1:1.6:2.9; specimen C - 1:1.3:2.4 was tested, and the average strength of the concrete cubes was determined.

Based on this, a concrete mix design of 1:1.3:2.4 with a water binder ratio of 0.5 resulted in the desired concrete grade after 28 days of curing. Table 4 shows the mix proportion determined by the mix design.

Table 4: Mix proportions utilised in the study

% SDA in the mix	Binder		Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
	Cement (kg/m^3)	SDA (kg/m^3)			
0	177.000	0.000	228	424.5	88.5
2.5	172.575	4.425	228	424.5	88.5
5.0	168.150	8.850	228	424.5	88.5
7.5	163.725	13.275	228	424.5	88.5
10.0	159.300	17.700	228	424.5	88.5

2.3 Arrangements of Reinforcement in Beams

Reinforcement of beam specimens was arranged with 12mm diameter reinforcement bars at the bottom and top for bending resistance and 10mm diameter reinforcement bars placed at 150mm centre to centre for shear resistance, with a 25 mm thick concrete cover, as seen in Figure 2. The tensile strength test result of the reinforcement is presented below in Table 5.

Table 5: Tensile strength test of reinforcement

Bar Size	Yield			Ultimate		Elongation %
	Sample	Load (kN)	Stress N/mm^2	Load (kN)	Stress N/mm^2	
10mm Tiger TMT	A	39.08	497.90	45.98	585.76	13.79
	B	39.68	505.47	46.68	594.67	14.00
Avg		39.38	501.68 (Satisfactory)	46.33	590.22	13.89
12 mm Tiger TMT	A	57.73	510.46	67.92	600.54	14.43
	B	58.01	512.87	68.24	603.38	14.50
Avg		57.87	511.67 (Satisfactory)	68.08	601.96	14.46

2.4 Concreting Operations

The concrete ingredients for the cube and beam specimens were batched by weight. It was well mixed and placed in their respective moulds, properly compacted and finished. After 24 hours, the specimens were removed from the mould and immersed in a water-filled curing tank. Proper curing is essential for the development of strength in concrete. A total number of 105 cube specimens and 120 RC beam specimens were used for this investigation.

2.5 Experimental Investigation

The following investigations were carried out:

2.5.1 Workability test

The concrete slump/compaction factor test relies on observation and experiment to determine the fresh concrete's workability. It mainly assesses the consistency of the concrete in that particular batch. This technique determines the consistency of freshly mixed concrete. The slump/compaction factor test was conducted for each design mix to describe the workability of the concrete at varied mix proportions. The tests were performed according to [32].

2.5.2 Density test

The densities of the concrete specimens containing sawdust ash and cement were tested using 150 by 150 by 150 mm cube specimens. The densities were determined according to [33].

2.5.3 Compressive strength test

Using the Avery Compression Testing Machine, the compressive strength test was conducted on the concrete cubes for the varying mix proportions adopted for this study. Before crushing, the specimens were taken out at each age of curing, weighed, and assessed following the procedure specified in [34]. An average of 3 readings was taken and noted for the percentage of each replacement. Figure 3 depicts how the compressive strength testing equipment was loaded.

Figure 3: Loading the equipment for compressive strength measurement

2.5.4 Bending strength test

Specimens were tested using a four-point loading bending principle in a loading frame. The two loads were placed at a distance of l/3 (150mm) from the supports at both ends. The load-deflection response and how fracture happens for the beams were investigated. This testing machine measures bending strength and bending behaviour by combining the load of the beam that collapsed with the movement of the beam. Bending tests were conducted on the beams following [35]. First, the beams were supported on a rigid steel frame at the ends. Load application was made at a constant rate. Then, the beams were loaded until the beam's ultimate load capacity was attained; these procedures were done again for all the beams. The load was made more significant in stages till the specimen's failure.

At each step of the loading development, the following collected and recorded information was established: (i) ultimate load, (ii) how the crack happens and the mode of failure, and (iii) first crack load. The crack patterns during the test were marked, and all required measurements were taken at each load increment. In addition, the impact of sawdust ash on the bending response of reinforced concrete beams was investigated. 60 RC beams of 150mm by 150mm by 600mm (width × depth × length) were cast to study how the bending crack happens. For each percentage replacement, three reinforced concrete beams were cast. The loading arrangement is shown in Figure 4.

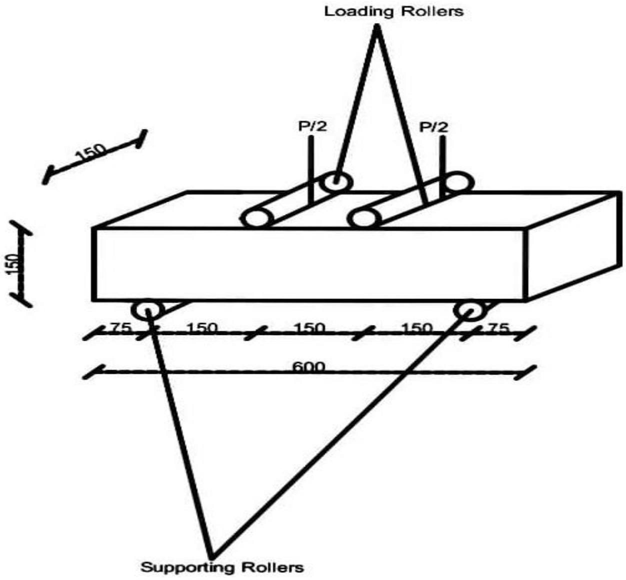


Figure 4: A typical four-point test arrangement for the bending test

2.5.5 Shear strength test

Specimens were tested using a four-point loading bending principle in a loading frame. The two loads were placed at a distance of l/4 (75mm) from the supports at both ends. The load-deflection response and how fracture happens for the beams were investigated. This testing machine measures shear strength and shear behaviour by combining the load of the beam that collapsed with the movement of the beam. The beams were subjected to a shear test following [35]. First, the beams were supported on a rigid steel frame at the ends. Load application was made at a constant rate. Then, the beams were loaded until the beam's ultimate load capacity was attained. These procedures were done again for all the beams. The load was made more significant in stages till the specimen's failure.

At each step of the loading development, the following collected and recorded information was established: (i) ultimate load, (ii) how the crack happens and the mode of failure, and (iii) first crack load. The crack patterns during the test were marked, and all required measurements were taken at each load increment. In addition, the impact of sawdust ash on the shear response of reinforced concrete beams was investigated. 60 RC beams of 150mm x 150mm x 450mm (width × depth × length) were cast to study how the shear crack happens. For each percentage replacement, three reinforced concrete beams were cast. The loading arrangement is shown in Figure 5.

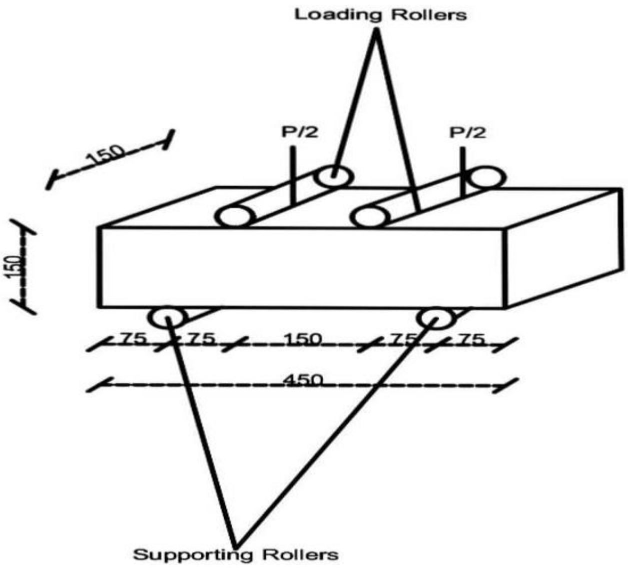


Figure 5: A typical four-point test arrangement for the shear test

3.0 RESULTS AND DISCUSSIONS

3.1 Workability

The impact of SDA replacement on the workability characteristics of concrete samples was investigated, as shown in Table 6. All specimens displayed true slump and medium compaction factors; this trend implies homogeneity and consistency in the concrete matrix, making the concrete suitable for placement and relatively easy to compact. That is, the internal cohesion of the specimens is not affected by the sawdust ash content. Since a constant water/binder ratio was utilised, the workability of the mix tended to reduce. The higher water demand in SDA mixes might be attributed to SDA's high fineness, which meant a better specific surface to be lubricated and wetted. This is consistent with the recent result of the influence of RHA in concrete by [36].

Table 6: Workability test results (mm)

SDA in the Mix (%)	Initial Height (mm)	Final Height (mm)	Slump Value (mm)	Slump Type	Compaction Factor Value	Compaction Factor Type
0.00	300.00	180.90	119	TRUE	0.93	MEDIUM
2.50	300.00	197.60	102	TRUE	0.91	MEDIUM
5.00	300.00	205.10	95	TRUE	0.88	MEDIUM
7.50	300.00	226.70	73	TRUE	0.86	MEDIUM
10.00	300.00	235.60	64	TRUE	0.84	MEDIUM

3.2 Density

The results of the density tests (kg/m^3) for all the sawdust ash replacements are shown in Table 7. Table 7 shows that the densities of concrete with SDA in the mix are comparable to those of control concrete, resulting from the close values of their specific gravities. The samples' average density values, the control mixes (0% SDA) with an average density of 2424.29 kg/m^3, were the least dense compared to other percentage replacements of sawdust ash. All the concrete mixes are within the density of standard-weight concrete (2200–2550 kg/m^3) [37]; this indicates that the composite matrix's SDA content does not reduce the use of the concrete.

The pozzolanic activity of sawdust ash contributed to denser concrete, enhancing inter-particle bonding and potentially mitigating the adverse effects of unburned organic matter.

Table 7: Density of concrete cube specimens

SDA in the Mix (%)	Curing Age (Days)							Average Density (kg/m^3)
	7	14	21	28	60	90	180	
0.00	2390	2440	2420	2440	2440	2430	2410	2424.29
2.50	2430	2440	2430	2440	2449	2440	2430	2437.00
5.00	2420	2440	2440	2449	2430	2430	2400	2429.86
7.50	2410	2440	2449	2430	2449	2440	2420	2434.00
10.00	2420	2430	2449	2440	2449	2440	2410	2434.00

3.3 Compressive Strength

Figure 6 shows the results of the specimens' compressive strengths (in N/mm^2). It was discovered that the compressive strength of the specimens improved with curing time for all replacement levels. However, the results at 14, 21 and 28 days showed that 2.5% SDA and 5% SDA have higher compressive strength than the regular concrete 0% SDA. The seven-day result showed that 7.5% SDA had better compressive strength than regular concrete 0% SDA. After 28 days of curing, it was observed that the optimum replacement that met the design mix (25N/mm^2) for concrete was 5% SDA.

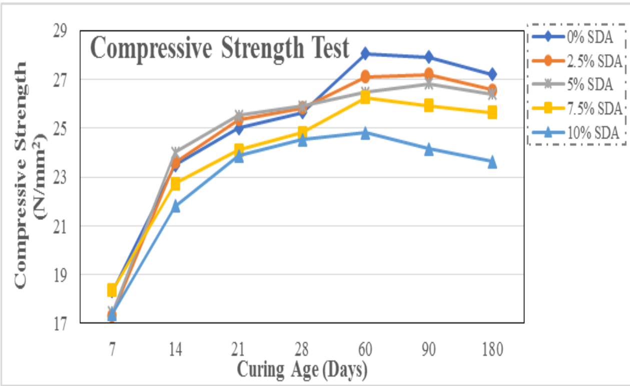


Figure 6: Compressive strength development of cube specimen with curing age

The improvement in compressive strength at an early age (7 days, 14 days, 21 days, and 28 days) and lower SDA (2.5% and 5% content) replacement levels could be related to the initial filling of voids by the SDA. At higher levels of SDA (i.e., 7.5% and 10%)

https://doi.org/10.4314/njt.v43i1.2

replacement, the holes must have been filled while the excess causes a reduction in strength. This finding was reported by [38], who stated that the initial filling of voids by silica fume significantly improves compressive strength. Still, at higher levels, improvement decreases.

3.4 Bending Strength

The effect of sawdust ash on the bending performance of the concrete samples was presented in Figure 7; findings revealed a nuanced relationship between sawdust ash content and bending performance. At 28 days, while slight reductions in bending strength were observed for higher replacement ratios (>5.0%), incorporating lower percentages (2.5-5.0%) displayed slightly improved bending behaviour, with a 5% replacement of SDA as the optimum replacement level for concrete cube and reinforced concrete beam production because the strength of concrete gradually reduces beyond this replacement level. However, exceeding the optimum (5% SDA) replacement level had detrimental effects on bending performance, highlighting the importance of staying within this optimum replacement level. SDA-RC beams at up to 5% replacement exhibited sufficient strength to meet the strength class (25 N/mm^2) standard designed for the mix, which is adequate for normal-weight concrete, while 7.5% - 10% SDA can be utilised as lightweight concrete as it met the strength class 17 N/mm^2. The study also revealed that sawdust ash reduced the cracking of the concrete beams.

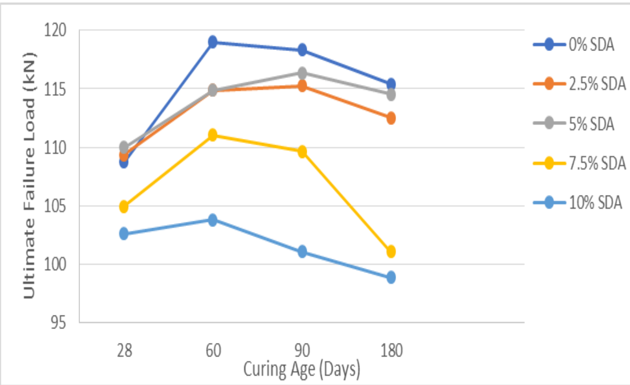


Figure 7: Graph of flexural strength versus curing age

It was observed that there was a considerable increase in the cracking load of the test specimens at 28 days, with the inclusion of sawdust ash at up to 5% replacement. This means that at the 28-day hydration period, the effect of SDA replacement up to 5% makes the reinforced concrete beam denser and stiffer. Figure 8 depicts the crack patterns in the beams – bending fractures formed during the loading phases in the pure bending area. As the stress rose, diagonal fractures occurred within the beams' mid-height within the beams' clear span. While the diagonal fractures grew throughout the length, their breadth spread inside the shear span area. The failure mechanism discovered was a typical compression failure. This is because the connection between the aggregate and the binder was consistent, and the shear reinforcement was in place to resist shear failure. The crack width is an average of 4mm.

8a: 0%SDA(600mm Beam) 2.5%SDA(600mm Beam)

8b: 5.0%SDA(600mm Beam) 7.5%SDA(600mm Beam)

8c: 10.0%SDA(600mm Beam)

Figure 8: Reinforced concrete beams showing diagonal and bending cracks

It is noted that the formation and propagation patterns of the crack are similar for all the reinforced concrete beams with and without SDA. While being tested, a virtual inspection of samples showed that the cracking width is similar across all percentage replacement levels. These results show that tension, compression and shear reinforcement in concrete beams contributed to the carrying capacity of test specimens.

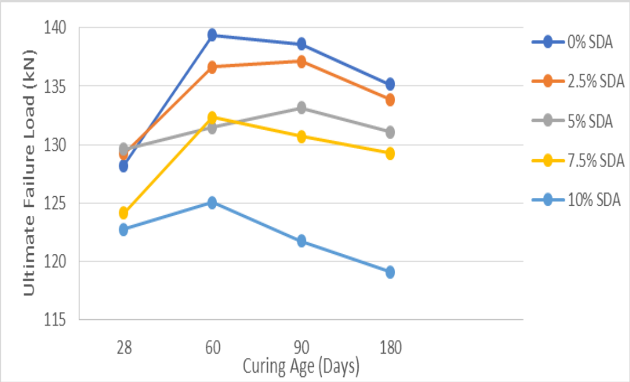


Figure 9: Graph of shear strength versus curing age

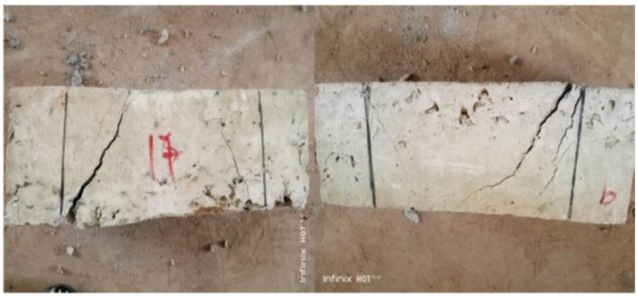
3.5 Shear Strength

The effect of SDA on the maximum applied load was presented in Figure 9; shear behaviour results exhibited similar trends with the results of the bending at 28 days, with optimal sawdust ash incorporation leading to slight increases in shear strength and improved crack resistance. This is related to the matrix's improved pore structure and densification. However, exceeding the optimal replacement threshold had detrimental effects on shear performance, highlighting the importance of careful dosage calibration. There is also an improvement in the shear performance. The pozzolanic reaction between sawdust ash and calcium hydroxide, which creates extra C-S-H gel, is responsible for the enhanced shear performance. This gel contributes to increased interlocking and improved shear transfer mechanisms within the concrete matrix, enhancing the overall shear strength of the beams.

It was noted that the cracking load of the test specimens increased considerably at 28 days with the inclusion of sawdust ash up to 5% replacement. This means that at the 28-day hydration period, the effect of SDA replacement up to 5% makes the reinforced concrete beam denser and stiffer.

Figure 10 depicts the crack patterns in the beams. Diagonal fractures developed over the length of the beams' clear span length in the loading phases, and their breadth progressed inside the shear span zone. The failure mechanism discovered was a typical deep beam failure. The connection between the aggregate and the binder was consistent, and the shear reinforcement resisted the shear failure. The crack width is an average of 4mm.

It is noted that the formation and propagation patterns of the crack are similar for all the reinforced concrete beams with and without SDA. While being tested, a virtual inspection of samples showed that the cracking width is similar across all percentage replacement levels. These results show that tension, compression, and shear reinforcement in concrete beams contributed to the carrying capacity of test specimens.



10a: 0%SDA(450mm Beam) 2.5%SDA(450mm Beam)

10b: 5.0%SDA(450mm Beam) 7.5%SDA(450mm Beam

10c: 10.0%SDA(450mm Beam)

Figure 10: Reinforced concrete beams showing diagonal cracks

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Summary of Findings

From this investigation, the following can be findings can be summarised:

i. A concrete mix ratio of 1:1.3:2.4 and a constant water/binder ratio of 0.50 at 5% SDA replacement is adequate for producing normal-weight reinforced SDA blended concrete of 25 N/mm^2.
ii. Including SDA in concrete reduced workabilities at all levels of replacement considered. With increased SDA content, the concrete becomes stiffer.

iii. The developed densities of concrete specimens with SDA are in the range of values for normal-weight application, which is between 2200–2550 kg/m^3.
iv. Concrete specimens with up to 5% SDA replacement levels showed enhanced compressive strength.
v. Incorporating SDA in reinforced concrete (RC) up to 5% by weight of cement resulted in improved beam bending strength and crack resistance.
vi. Sawdust ash incorporation in reinforced concrete to up to 5% SDA content improves shear strength and crack resistance.

4.2 Conclusion
The research on the bending and shear behaviour of RC beams containing SDA, a partial substitute for cement, was an essential step towards developing more sustainable and environmentally friendly construction practices. The experimental result has demonstrated the feasibility and effectiveness of using sawdust ash in plain and reinforced concrete production. By reducing the construction industry's carbon footprint, this research contributed significantly to sustainable development, which is crucial for the future of our planet.

The use of sawdust ash as a partial cement replacement in reinforced concrete beams has potential environmental and performance benefits. However, carefully considering an optimum replacement level of 5% SDA, proper incineration at 600℃ for 60 minutes and sieved with 600 µm-sieve and sieving of sawdust ash and a mix ratio of 1:1.3:2.4, constant water/binder ratio of 0.50; are crucial for ensuring positive outcomes. The optimum replacement ratio is crucial to maximise environmental benefits and mechanical performance. Excessively high replacement, above the optimum replacement level, can negatively impact strength.

4.3 Recommendation
For future research, existing design codes like BS 8110-1 [39] should be used to analyse and design sawdust ash-reinforced concrete to fully unlock this sustainable material's potential and establish its reliable application in the construction industry. By embracing such innovative approaches, the construction industry can move towards a greener future while ensuring built structures' continued performance and safety. This will help promote SDA usage and enhance its sustainability in reinforced concrete production.

REFERENCES

[1] Fapohunda, C. A., Osanyinlokun, O. E., and Abioye, A. O. "A Review of Structures and Performance of Ternary Blends of Rice Husk Ash and Some Wastes in Concrete", 2023, June 10–13. https://doi.org/10.56748/ejse.234 73.

[2] Ikponmwosa, E. E., Fapohunda C. A., and Osanyinlokun, O. E. "Effects of Palm Kernel Shell Ash on Some Structural Properties of Concrete with Recycled Coarse Aggregates", *ANNALS of Faculty of Engineering Hunedoara – International Journal of Engineering.*, 2015, 13(3), 191–196.

[3] Hossain, M. U., and Poon, C. S. "Comparative LCA of wood waste management strategies generated from building construction activities", *J. Clean. Prod.*, 2018; 177, 387–397.

[4] Meyer, C. "The greening of the concrete industry", *Cem. Concr. Compos.*, 2009; 31, 601–605.

[5] Sandanayake, M., Gunasekara, C., Law, D., Zhang, G., Setunge, S., and Wanijuru, D. "Sustainable criterion selection framework for green building materials – An optimisation-based study of fly-ash Geopolymer concrete", *Sustain. Mater. Technol.*, 2020; 25(e00178).

[6] Saha, A. K. "Effect of class F fly ash on the durability properties of concrete. Sustainable environment research", 2018; 28(1): 25 – 31.

[7] Alex, J., Dhanalakshmi, J., and Ambedkar, B. "Experimental investigation on rice husk ash as cement replacement in concrete production", *Constr Build Mater*, 2016; 127: 353–362.

[8] Siddika, A., Amin, M. R., Rayhan, M. A., Islam, M. S., Al Mamun, M. A., Alyousef, R., and Amran, Y. H. M. "Performance of Sustainable Green Concrete incorporated with Fly ash, Rice husk ash, and Stone dust", 2021; 61(1), 279–291. https://doi.org/10.14311/ap.2021.61.0279.

[9] Fapohunda, C., Kilani, A., Adigo, B., Ajayi, L., Famodimu, B., Oladipupo, O., and Jeje, A. "A review of some agricultural wastes in Nigeria for sustainability in the production of structural concrete", *Nigerian Journal of Technological Development*, 2021; 18(2), 76–87. https://doi.org/10.4314/njtd.v18i2.1.

[10] Mangi, S. A., Jamaluddin, N., Wan Ibrahim, M. H., Mohamad, N., and Sohu, S. "Utilization of Sawdust Ash as Cement Replacement for the Concrete Production: A Review", *Engineering Science and Technology International Research Journal*, 2017; 1(3): 11-15. September, 2017.

[11] Marthong, C. "Effect of rice husk ash (RHA) as partial replacement of cement on concrete properties", *Int J Eng Res Technol.*, 2012; 1(6), 1–8.
[12] Obilade, I. O. "Use of Sawdust Ash as Partial Replacement for Cement in Concrete", *International Journal of Engineering Science Invention.*, 2014; 3(8), 36–40.
[13] Owoyemi, J. M., Zakariya, H. O., and Elegbede, I. O. "Environmental and Socio-economic Studies Sustainable wood waste management in Nigeria", 2016; 1–9. https://doi.org/10.1515/environ-2016-0012.
[14] Dwivedi, S. S., Manoharan, S., and Dodagoudar, G. R. "Effect of Sawdust Ash on Properties of Concrete", *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, 2013; 7(6).
[15] Jadhav, H. P., Bairagi, N. K., and Kadam, K. N. "Study on Flexural Behaviour of Reinforced Concrete Beams Containing Sawdust Ash as Partial Replacement of Cement", *International Journal of Advanced Engineering and Research Development*, 2017; 4(2).
[16] Patil, A. S., and Kadam, A. B. "Experimental Study on Shear Strength of Reinforced Concrete Beams Using Sawdust Ash as Partial Replacement of Cement", *International Journal of Civil Engineering and Technology*, 2017; 8(1).
[17] Udoeyo, F. F. "Sawdust ash as concrete materials", *Journal of Materials in Civil Engineering*, 2002; 14(2), 173–176.
[18] Shetty, M. S. "Concrete technology theory and practice", *S. Chand and Company*., 2001.
[19] Cheah, C. B., and Ramli, M. "The implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar: An overview", *Resources, Conservation, and Recycling*, 2011; 55 (2011) 669–685.
[20] Elinwa, A. U., Ejeh, S. P., and Mamuda, A. M. "Assessing the fresh concrete properties of self-compacting concrete containing sawdust ash", *Constr Build Mater*, 2008; 22:1178–82.
[21] Elinwa, A. U., and Mahmood, Y. A. "Ash from timber waste as cement replacement material", *Cement Concrete Composites*, 2002; 24:219–222.
[22] Auta, S. M., Uthman, A., Sadiku, S., Tsado, T. Y., and Shiwua, A. J. "Flexural strength of a reinforced revibrated concrete beam with sawdust ash as a partial replacement for cement", 2016; 5(44), 31–45.
[23] NIS 444-1. "Cement – Part I: Composition and Conformity Criteria for Common Cements", 2014.
[24] BS EN 197-1. "Cement. Part 1: Composition, Specifications, and Conformity Criteria", 2011.
[25] ASTM Standard C618. "Standard specification for fly ash and raw or calcined natural pozzolan for use as mineral admixtures in Portland cement concrete", *Annual Book of ASTM Standards*, 1994.
[26] ASTM C150. "*Standard Specification for Portland Cement (ASTM C150–05)"*, 2005.
[27] BS EN 12620. "Aggregates for Concrete", 2013.
[28] ASTM D6913-04. "Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis", *Annual Book of ASTM Standards*, 2009; e1.
[29] BS EN 1008. "Mixing Water for Concrete", *Specification for Sampling, Testing and Assessing the Suitability of Water, Including Water Recovered from Processes in the Concrete Industry, as Mixing Water for Concrete*, 2002. http://shop.bsigroup.com/en/ProductDetail/?pid=000000000019990036.
[30] BS 4449:2005+A2:2009. "Steel for the reinforcement of concrete – Weldable reinforcing Publication steel – Bar, coil, and decoiled Product – Specification", 2009.
[31] COREN. "Council for the Regulation of Engineering in Nigeria", *CONCRETE MIX DESIGN MANUAL*, 2017.
[32] BS EN 12350: Part 2. "Method for Determination of Slump", 2009.
[33] BS EN 12390: Part 7. "Testing hardened concrete – Density of hardened concrete", 2019.
[34] BS EN 12390: Part 3. "Testing hardened concrete – Compressive strength of test specimens", 2019.
[35] BS EN 12390: Part 5. "Testing hardened concrete – Flexural Strength of test specimens", 2019.
[36] Bhanja, S., and Senguptab, B. "Investigation of the compressive strength of silica fume concrete using statistical methods", *Cement and Concrete Research.*, 2002; 32(9), 1391–1394.
[37] Zhang, M. H., and Malhotra, M. H. "High-performance concrete incorporating rice husk ash as a supplementary cementing material", *ACI Materials Journal*, 1996; 93(6), 629–636.
[38] BS EN 206 – 1. "Concrete – Specification, Performance, production and conformity", 2000, Vol. 1.

[39] BS 8110. “Structural use of concrete - Part 1. Code of practice for design and construction”, 1997; Vol. Part 1.

https://doi.org/10.4314/njt.v43i1.2