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Influence of curing methods on the mechanical performance of bamboo stem ash cement blended bricks

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Abstract

The influence of different curing methods on the strength and durability of bamboo stem ash (BSA) cement blended bricks was investigated. BSA was introduced into the mixture by direct substitution with cement in proportions of 0%, 5% and 10%. The materials were batched by volume using a binder/sand mix ratio of 1:6. Four curing conditions were examined; water immersion, intermittent water sprinkling, wet rug covering and open-air exposure. The hardened brick specimens were tested for their compressive strength and abrasive resistance. Specimens cured by water immersion were found to possess the highest compressive strength and abrasive resistance. An increase in BSA content was associated with a corresponding decrease in compressive strength and abrasive resistance, however, the 28-day strength activity index (SAI) of all modified specimens satisfied the physical requirements of ASTM C618 (SAI ≥ 75%) across all curing conditions. The compressive strength of all specimens at 28 days satisfied the requirements of the Nigerian Industrial Standard (NIS 978) for non-load bearing bricks (1.5 – 3.5 N/mm2). The differences in 28-day strength for specimens cured by water immersion and those cured by wet covering, sprinkling and open-air, were 3.45%, 21.38% and 29.31%, respectively, for the control specimens (0% BSA content); while for the modified brick specimens, these differences were 5.6%, 19.2% and 31.6%, respectively, for 5% BSA content; and 9.48%, 23.28% and 32.33%, respectively, for 10% BSA content. Curing by complete submersion in water was observed to be the most reliable in promoting adequate strength gain and wear resistance in the brick specimens.

Keywords: Abrasive Resistance; Bamboo Stem Ash (BSA); Compressive Strength; Curing Methods; Modified Bricks; Pozzolanic Material

1. Introduction

Bricks are among the most extensively used construction materials available for housing development in Nigeria. They could be used as load bearing or non-load bearing structural wall elements. They could be made by subjecting natural clay rich in silica and alumina to high temperatures, or they could be made by a combination of cement, sand and water. Cement bricks are produced from the combination of cement (binder), sand (fine aggregate) and water in precise proportioning (mix ratio). The combination of cement and water activates the binding process and ensures that sufficient hardening is achieved through a chemical reaction called hydration. The effectiveness of the hydration process is dependent on the provision of adequate temperature and moisture levels to ensure that the hydration reaction is not prematurely halted by a rapid drying out of the cement paste, which could result in the production of a weaker and less dense material. The performance of cement bricks does not rely only on its constituent materials, but also on the curing methods applied post production. Curing enables the complete hydration of cement by ensuring adequate temperature and moisture are maintained throughout the curing duration, it is critical in ensuring that the produced bricks develop their optimal mechanical characteristics like; load bearing, wear and crack resistance. Different curing methods are commonly practiced in construction and the choice of the method used, is dependent on the prevailing environmental

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condition, availability of water and type of structure. Some of these curing methods include, ponding (water immersion), periodic water sprinkling, steam curing, plastic sheet covering, membrane curing, sawdust curing and open-air curing. Each method yields distinct outcomes for mechanical properties like strength, durability and density. The impact of different curing methods on the mechanical properties of composite cement materials have been studied, valuable insights into the cement hydration process documented. Nevertheless, with new materials discovered to possess cementitious properties post calcination, more investigations into their potential uses are required. The influence of different curing methods on the strength characteristic of palm kernel shell (PKS) modified concrete was investigated by Odeyemi et al. [1], it was discovered that the strength of the hardened PKS modified concrete was greatly influenced by the curing methods used. The 28-day compressive strength of the modified concrete ranged between 13.11N/mm^2 and 17.07N/mm^2, depending on the curing method applied. The water immersion curing technique was reported to be the most effective in aiding the cement hydration process. Letsosa et al. [2] examined the influence of different curing methods on the strength of polypropylene fibre reinforced concrete. It was discovered that specimens cured under temperature-controlled water of 22^{0}c possessed the highest compressive strength, however, the maximum split tensile strength was achieved under the extreme cold (-4^{0}c) curing condition. Extreme heat (165^{0}c) was reported to have no enhancing effect on the strength of concrete over time when compared with the other curing conditions. Alsadik et al. [3] examined the mechanical effectiveness of cement mortar cured under different curing conditions and temperature. It was observed that mortar specimens cured by water immersion exhibited the highest 28-day compressive strength, followed sequentially by wax-based, saturated cover and open-air. Samples made of ordinary portland cement (OPC) and sulphate resisting portland cement (SRPC) attained their highest strength when cured by water immersion at 25^{0}c and 45^{0}c, respectively. Orogbade et al. [4] and Ani et al. [5] evaluated the strength performance of conventional concrete cured under different curing methods. Ani et al. identified water immersion has being the most reliable in sustaining proper concrete hydration. Nevertheless, Orogbade et al. discovered that sand curing was the more effective curing method, the recorded strength of specimens cured by sand curing exceeded those cured by water immersion, sawdust curing, polythene sheet covering and sprinkling. Nwa-David [6] studied the mechanical behavior of concrete modified with nanosized periwinkle shell ash (NPSA) under different curing conditions. It was reported that the replacement of cement with 10 – 20% NPSA content recorded higher 90-day compressive strength values relative to the control concrete (0% NPSA) for specimens cured by water immersion. In general, specimens cured by water immersion exhibited the highest compressive strength, followed sequentially by those cured by sprinkling and plastic sheeting.

Bamboo stem is the main structural component of the bamboo plant, it is typically cylindrical and hollow in the middle. It is commonly utilized in construction as scaffolds or as deck supporting columns in Nigeria due to their strength and durability (see figure 1). However, when it loses its load carrying capacity, it is discarded and considered an agricultural waste product [7]. The challenges associated with proper management of agricultural waste is gradually moving away from simple waste disposal to repurposing these waste into useful resources without substantial processing. Agricultural waste such as sugarcane bagasse, cornhub, rice husk, bamboo leaves and coconut shell, when subjected to calcination have been observed to possess pozzolanic properties [8]. It has been reported in literature that the calcination of bamboo stem at high controlled temperatures results in the production of pozzolanic bamboo stem ash (BSA). Pozzolanic materials are silica or aluminosilicate rich materials which manifest their cementitous properties only after undergoing calcination at high controlled temperatures [9]. Several studies have investigated the use of pozzolanic agricultural waste as a substitute for cement, aimed at reducing the emission of greenhouse gases and carbon dioxide into the atmosphere during the cement manufacturing and concrete production processes. Adewuyi and Umoh [10] examined the mechanical performance of laterite bricks stabilized with bamboo leaf ash (BLA) as a partial substitute for cement. It was observed that a continuous increase in BLA-cement substitution led to a steady reduction in the compressive strength of the modified specimens across all curing ages. However, increment in BLA content aided in the increase of the abrasive resistivity of the brick specimens. Adnan et al. [11] investigated the potentials of bamboo ash (BA) as a partial replacement for cement in sandcrete brick mixtures with emphasis on their compressive strength and water absorption characteristics. The pozzolanic properties of BA were demonstrated through an X-ray fluorescence (XRF) test, with high silica and potassium oxide levels detected. The test of compressive strength revealed a steady drop in strength with increase in BA contents, the water absorption test showed that the permeability of the brick specimens rose with increase in BA contents. The 5% BA-cement substitution was reported as optimal for strength and durability requirements. Ikeagwuani et al. [7] studied the cementitious potential of bamboo stem ash (BSA) as a partial replacement of cement in mortar and concrete specimens. Higher BSA substitution resulted in reduced workability and strength. 10% BSA-cement substitution was found to have compared favorably with the control mixture (0% BSA), with percentage strength reduction obtained as 6.9%. Mydin et al. [12] investigated the suitability of BSA as a partial cement replacement in lightweight foam mortar (LFM) due to its high silica concentration and light weight. The optimal BSA replacement proportion was obtained at 15% substitution with cement, where improved pore structure and stronger interfacial matrix bonding were observed through a microstructural investigation, along with a 7% increment in the 28-day compressive strength of the LFM specimens relative to the control specimens. At 20% BSA-cement substitution, the density of the specimens decreased by 4%, along with a 5.4% increase in porosity, while at 25% BSA substitution there was a 0.07W/mk reduction in thermal conductivity when compared with the control mixture. Rodier et al. [8] investigated the pozzolanic properties of bamboo stem ash gotten from the calcination of bamboo stem at 600^0c. The pozzolanic activity of BSA was determined using the saturated lime method, thermogravimetric analysis and strength activity index (SAI). The X-ray fluorescence test was used to determine the composition of oxides present in BSA, the chemical composition of BSA was found to contain compounds such as SiO_2, CaO, MgO as its main oxides, the sum of Al_2O_3, SiO_2 and Fe_2O_3 was obtained as 69.05%, together with a Chapelle index of 345±6 mg CaO/g. These chemical characteristics enabled its classification as a pozzolanic material according to ASTM C618 [9]. Mortar specimens modified with 10% BSA content showed a reduction in strength when compared to the control mix, nevertheless, a strength activity index (SAI) of 85% and 81% was achieved at 7 and 28 days respectively, these values surpassed the 75% minimum physical requirement for specimens prepared from materials considered as pozzolanic in accordance with the specifications of ASTM C618. Notably, Rodier et al. stated that bamboo stem ashes can be described as a pozzolanic material with partial cement replacement permitted up to 10% by weight. Vagestan et al. [13] explored the potentials of bamboo stem ash and alkali treated bamboo fibers as replacements for ordinary portland cement in mortar. An XRF analysis revealed that a high concentration of silicon dioxide (SiO_2) was present in BSA. The durability of the mortar specimens were enhanced by the introduction of sodium hydroxide (NaOH) treated bamboo fibers into the mixture, and this led to a reduction in the water absorption capability of the modified mortar relative to the control mortar. Light weight mortar specimens were produced due to the lower density of BSA relative to cement. Higher replacement of cement with BSA and bamboo fibers resulted in general strength reductions, however, the optimized mix proportion resulted in considerable increment in compressive and flexural strengths of the modified mortar specimens relative to the control specimens. In contrast to the findings on the oxide composition of bamboo stem ashes reported by Rodier et al. [8], Adnan et al. [11], Mydin et al. [12] and Vagestan et al. [13]. Mendonca et al. [14], in a study into the partial replacement of cement by BSA calcined at different temperatures in mortar specimens, reported that BSA did not meet the requirements of a pozzolanic material based on its chemical composition determined through an X-ray fluorescence test. It was discovered that BSA contained a much lower silica content (SiO_2 = 12.25%) than previously reported and a higher content of potassium oxide (K_2O = 50.42%), the sum of oxides, Al_2O_3, SiO_2 and Fe_2O_3 was obtained as 12.93% and this was significantly lower than the minimum requirement (50%) of NBR 12653 [15] and ASTM C618 [9] standards. Nevertheless, a 28-day performance index (93.51%) that exceeded the minimum physical requirement of NBR 12653 standard was achieved by mortar specimens which had a 25% BSA content calcined at 600^oc. Research into the pozzolanic characterization of bamboo stem ash (BSA) and its potential as a substitute for cement in construction is still incipient and requires further investigations given the promising outcomes reported in literature. Table 1 presents the oxide composition of BSA as reported in available literatures.

Figure 1 Bamboo stems used as supporting columns in Nigeria

Table 1 Oxide composition of bamboo stem ash (BSA) as reported in available literatures

Oxides	Percentage (%) composition				
	Rodier et al. [8]	**Adnan et. al [11]**	**Mendonca et al. [14]**	**Mydin et al. [12]**	**Vagestan et al. [13]**
SiO_2	68.74	37.4	12.25	47.77	68.75
Al_2O_3	0.15	1.43	0.56	6.45	0.15
Fe_2O_3	0.16	9.91	0.12	2.89	0.16
CaO	11.92	4.35	0.92	24.51	11.92
MgO	5.83	2.5	1.90	4.31	5.83
SO_3	----	4.83	----	1.18	----
K_2O	0.54	27	50.42	8.28	----
Na_2O	0.74	----	0.16	1.62	0.74
P_2O_5	----	2.53	5.45	1.07	----
M_nO	----	0.197	0.08	0.08	----
Z_nO	----	0.0758	----	0.23	----
C_uO	----	----	----	0.16	----
T_iO_2	----	----	0.02	----	----
*LOI	0.43	----	27.38	1.45	0.42

*LOI is the loss on ignition

The present study is aimed at examining the effect of different curing methods on the engineering performance of bamboo stem ash cement blended bricks. It highlights how the hardening of BSA modified bricks under different moisture and temperature levels impacts their compressive strength and abrasive resistance. To enhance the relevancy of this study to workers in the local construction and manufacturing industry operating in Calabar, Cross River State, Nigeria, the brick production process was deliberately modeled to reflect prevailing practices observed in these local worksites. The curing methods commonly used at these worksites were chosen for this study.

2. Methodology

2.1. Materials

The study materials include sharp sand, fresh water, bamboo stem ash and cement. All materials were obtained within Calabar South Local Government Area of Cross River State, Nigeria.

2.1.1. Fine aggregate

The Sharp sand is responsible for the cohesiveness of the mixture and was sieved through a 4.75mm sieve in accordance with BS 812-103:1 [16]. It was kept clean and dry.

2.1.2. Cement

The binding agent that holds the mixture together is cement. A UNICEM portland limestone cement (PLC): grade CEM II/B-L 32.5R conforming to BS EN 197-1 [17] and NIS 444-1 [18] standards was used.

2.1.3. Water

Clean water devoid of impurities was used in conformance with BS 17075 [19]. The water activates the hydration process upon contact with the cement and is responsible for the hardening of the mixture.

2.1.4. Bamboo Stem Ash

The bamboo stem ash served has a cementitious additive and was obtained from the calcination of waste bamboo stems found littered around construction worksites within the University of Cross River State, Calabar, Nigeria. The bamboo stems were collected and sun dried for a week to rid them of surface moisture prior to combustion at 600^0c for 2 hours. The ash was collected and sieved through a 600 microns sieve.

Tests on physical and chemical properties were conducted on the materials to assess their suitability in the mixture. These tests include specific gravity, loose bulk density, particle size distribution, water absorption and oxide analysis by wet chemical method.

2.2. Method

The materials were batched by volume and combined in a mix ratio of 1:6 (binder: sand). The cement (PLC) was partially replaced with BSA at replacement levels of 0%, 5% and 10%. The materials were mixed manually using a spade, together with a gradual addition of water until a proper consistency of the mixture was achieved. The mixture was carefully transferred into a mould of 215mm x 100mm x 65mm in size and manually compacted using a tamping rod. Three replicates were prepared for each mix combination, curing method and age. The brick specimens were cured under four conditions; water immersion, periodic water sprinkling, open-air exposure and wet rug covering. A total of 84 specimens were produced. The hardened specimens were cured for 14 and 28 days after which they were tested for their compressive strength and abrasive resistance.

The water immersion condition required the complete submersion of the samples in water all through the curing duration. The intermittent water sprinkling condition required spraying water on the specimens for 2-3minutes in every 12±1 hours. The wet rug covering condition involved covering the samples with a wet rug that was regularly moistened to prevent drying out. The open-air exposure condition required that the samples be left out in the open, subject to environmental conditions, whether it be the rainy or dry seasons.

The compressive strength test was done in accordance with BS 1881 – 116 [20]. The specimens were placed in a digital compressive strength machine with load gradually applied until specimen failure occurred. The compressive strength is expressed as:

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{Failure\ load\ (N)}{Surface\ area\ of\ brick\ (mm^2)} \qquad (1)$$

The durability of the specimens was determined through an abrasive resistance test. The test was carried out in accordance with [10]. The bricks were weighed and placed on a horizontal surface; its surface was then brushed with a wire brush for 40 strokes. The wire brush was placed on the brick in a manner that its mass was vertically applied to the brick. The lost mass was removed after brushing and the bricks were weighed again. The abrasion coefficient (Ca) is expressed as:

$$\text{Ca(cm}^2\text{/g)} = \frac{S}{M_1 - M_2} \qquad (2)$$

where M_1 is the mass of the brick before brushing, M_2 is the mass of brick after brushing and S is the brushed surface area.

3. Results and Discussion

The constituent material properties, strength and durability performance of the BSA cement blended brick specimens are presented and discussed.

3.1. Physical properties

The results of the test on the physical properties of the materials are presented in Table 2, Figures 2 and 3. The specific gravity and bulk density of the sand and cement were within acceptable limits of code specification, BS 812 – 2 [21], BS EN 1097-6 [22], BS EN 1097-3 [23] and BS EN 197-1 [17]. The higher water absorption capability of BSA relative to sharp sand and cement indicates that it is porous and required more water to ensure that a consistent and workable mixture was achieved. The BSA possesses lower relative density, hence it could contribute to a reduction in overall weight of the specimens.

The gradation curve shows that the uniformity coefficient (C_u) and coefficient of gradation (C_c) of sand were 3.57 and 1.08, respectively, which indicates that it is uniformly graded since $2 < C_u < 6$, irrespective of C_c falling within the acceptable limit ($1 < C_c < 3$) of a well graded material. The fineness modulus of sharp sand was obtained as 3.9, this revealed that the material is coarse. The curve also revealed that bamboo stem ash (BSA) is uniformly graded since C_u (5.8) < 6, although it is of a relatively finer material.

Table 2 Physical properties of sharp sand, bamboo stem ash (BSA) and cement (PLC)

Properties	**Sharp Sand**	**BSA**	**PLC**
Specific gravity	2.65	2.55	3.15
Bulk density (kg/m^3)	1483.52	1078.57	1163.74
Water absorption (%)	1.73	4.48	0.62
Fineness modulus	3.9	2.3	----
Uniformity coefficient (C_u)	3.57	5.8	----
Coefficient of gradation (C_c)	1.08	1.35	----

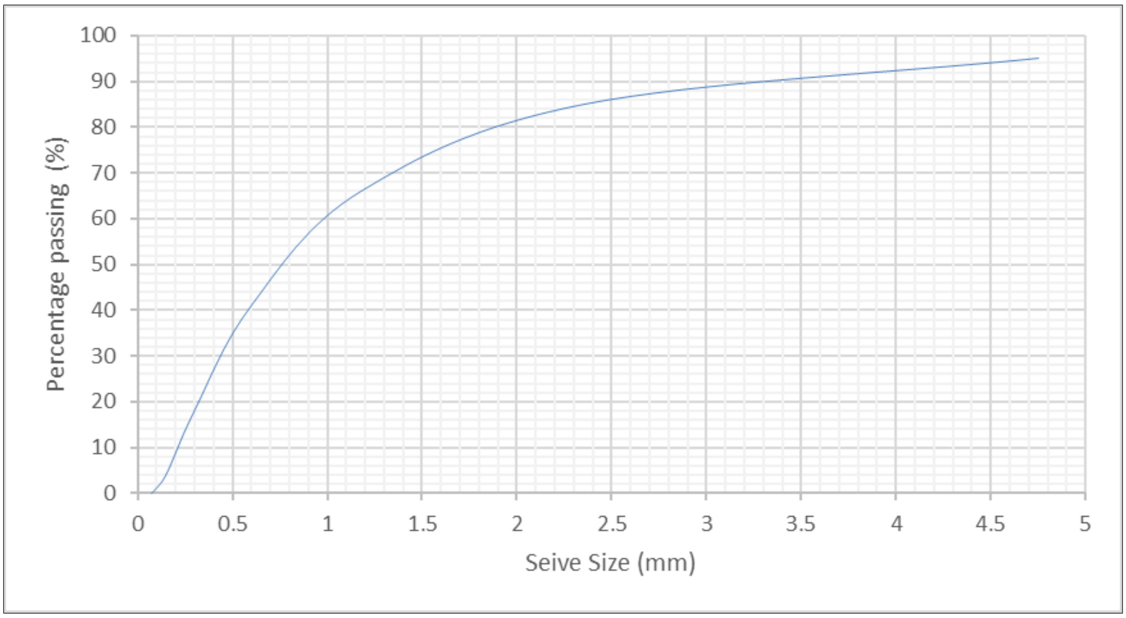

Figure 2 Gradation curve: sharp sand

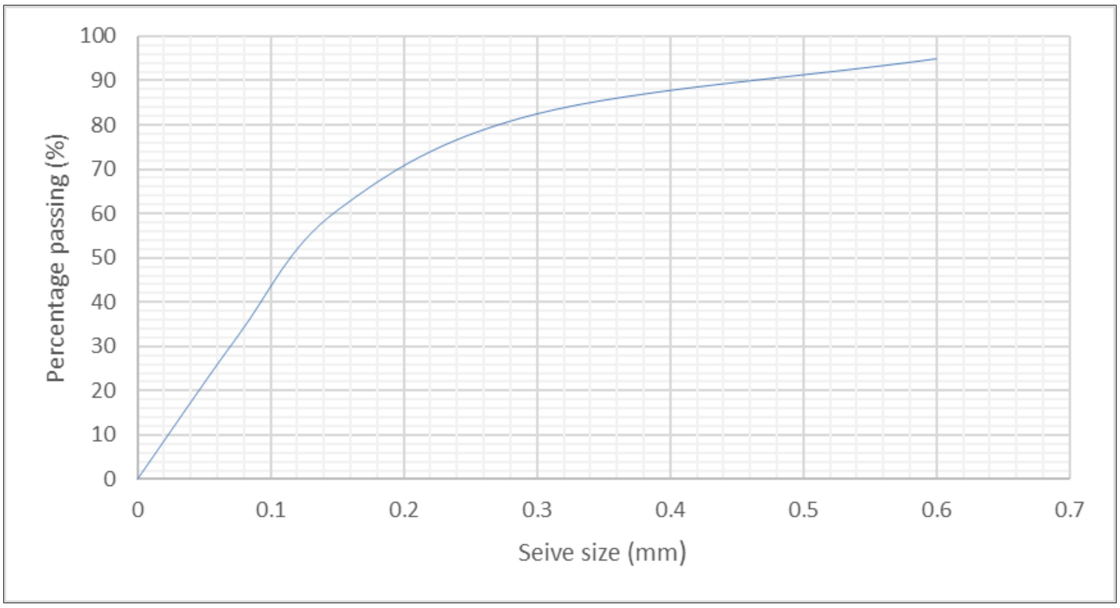

Figure 3 Gradation curve: Bamboo stem ash

3.2. Chemical Composition

The oxide analysis test presented in Table 3 revealed that the main compounds found in cement were calcium oxide (CaO), silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3). The reaction of these compounds when exposed to water (H_2O) activates the hydration process and is responsible for the rapid set, early strength and ultimate strength of cement. The main compounds present in bamboo stem ash were potassium oxide (K_2O) and silicon dioxide (SiO_2). The BSA does not meet most of the requirements of ASTM C618 governing the classification of a material as pozzolanic, only the material's loss on ignition (LOI = 5%) ≤ 10% and sulphur trioxide content (SO_3 = 3.01) ≤ 5% met the requirements of the standard. The sum of Al_2O_3, SiO_2 and Fe_2O_3 obtained as 10.59% fall significantly below the minimum requirement (50%) of a class C pozzolanic material. The high alkali levels (K_2O = 67%, Na_2O = 0.61%) present in BSA promotes early hydration reactions through early ettringite formation, which results in early set and stability of the specimens, however, if left uncontrolled it could lead to long term durability problems for the brick specimens. Hence, it is important to limit the BSA-cement substitution to small proportions to curtail excess alkali oxides contained in the mixture. Notably, the results of the oxide composition of BSA are in close agreement with those reported in Mendonca et al. [14].

Table 3 Oxides composition of bamboo stem ash (BSA) and cement (PLC)

Oxides	BSA (%)	Cement (%)
SiO_2	8.41	19.15
Al_2O_3	1.91	4.91
Fe_2O_3	0.27	3.32
CaO	2.83	62.46
MgO	3.70	1.25
SO_3	3.01	1.37
K_2O	67.00	0.18
Na_2O	0.61	0.15
Loss on ignition (LOI)	5.00	6.34

3.3. Compressive strength

Table 4, Figures 4 and 5 shows the strength performance of the hardened brick specimens modified with different proportions of bamboo stem ash subjected to different curing ages and methods. It is apparent that the compressive strength improves over time, regardless of the BSA contents or curing methods used, an increase in BSA content led to a drop in strength of specimens across all curing ages and methods. These observations were consistent with those reported in Adewuyi and Umoh [10], Rodier et al. [8] and Ikeagwuani et al. [7]. Notably, at 28 days, all specimens modified with BSA satisfied the minimum strength activity index (SAI ≥ 75%) specified in ASTM C618, across all curing conditions. The SAI measures the effectiveness of a pozzolanic material, with higher SAI values indicating better performances in compressive strength development. Among the specimens cured by water immersion, wet covering, sprinkling and open-air for 28 days, a 5% BSA content led to a drop in strength by 13.79%, 15.71%, 11.4% and 16.59%, respectively, when compared with their corresponding control specimens; while a 10% BSA content resulted in strength reduction of 20%, 25%, 21.93% and 23.41%, respectively. The loss in strength with continual increase in BSA content could be attributed to the dilution effect, which means with an increase in BSA content more water is required to maintain consistency and workability of the mixture, due to the porous structure and higher water absorption capability of BSA relative to cement. Additionally, a continual substitution of cement with BSA would result in a decrease in the quantity of the highly reactive calcium oxide (CaO) present in cement, which is responsible for facilitating the hydration reaction [8].

Table 4 Strength performance of BSA blended cement bricks

Specimen age (days)	Curing method	% (PLC + BSA)	Compressive strength (N/mm²)	Strength activity index (SAI)	Strength reduction (%)
14	Water immersion	100 PLC + 0 BSA	2.72	----	----
		95 PLC + 5 BSA	2.40	88.24	11.76
		90 PLC + 10 BSA	2.14	78.68	21.32
	Wet rug covering	100 PLC + 0 BSA	2.37	----	----
		95 PLC + 5 BSA	2.10	88.61	11.39
		90 PLC + 10 BSA	1.89	79.75	20.25
	Intermittent sprinkling	100 PLC + 0 BSA	2.08	----	----
		95 PLC + 5 BSA	1.82	87.50	12.5
		90 PLC + 10 BSA	1.73	83.17	16.83
	Open-air	100 PLC + 0 BSA	1.82	----	----
		95 PLC + 5 BSA	1.28	70.33	29.67
		90 PLC + 10 BSA	1.24	68.13	31.87
28	Water immersion	100 PLC + 0 BSA	2.90	----	----
		95 PLC + 5 BSA	2.50	86.21	13.79
		90 PLC + 10 BSA	2.32	80.00	20.00
	Wet rug covering	100 PLC + 0 BSA	2.80	----	----
		95 PLC + 5 BSA	2.36	84.29	15.71

		90 PLC + 10 BSA	2.10	75.00	25.00
	Intermittent sprinkling	100 PLC + 0 BSA	2.28	----	----
		95 PLC + 5 BSA	2.02	88.60	11.40
		90 PLC + 10 BSA	1.78	78.07	21.93
	Open-air	100 PLC + 0 BSA	2.05	----	----
		95 PLC + 5 BSA	1.71	83.41	16.59
		90 PLC + 10 BSA	1.57	76.59	23.41

The highest strength performances were obtained from the control (0% BSA content) specimens cured by the water immersion, followed sequentially by wet rug covering, intermittent sprinkling and open-air as 2.90 N/mm^2, 2.8 N/mm^2, 2.28 N/mm^2 and 2.05 N/mm^2, respectively. These values were in good agreement with those reported in Ogbanu and Ani [24] and Ukpata et al. [25]. The strength recorded for the modified specimens were 2.5 N/mm^2, 2.36 N/mm^2, 2.02 N/mm^2 and 1.71 N/mm^2, respectively, for 5% BSA content; and 2.32 N/mm^2, 2.1 N/mm^2, 1.78 N/mm^2 and 1.57 N/mm^2, respectively, for 10% BSA content. Notably, all cured brick specimens were observed to have met the requirements of the Nigerian Industrial Standard NIS 978 [26] for non-load bearing bricks (1.5 – 3.5N/mm^2) at the age of 28 days.

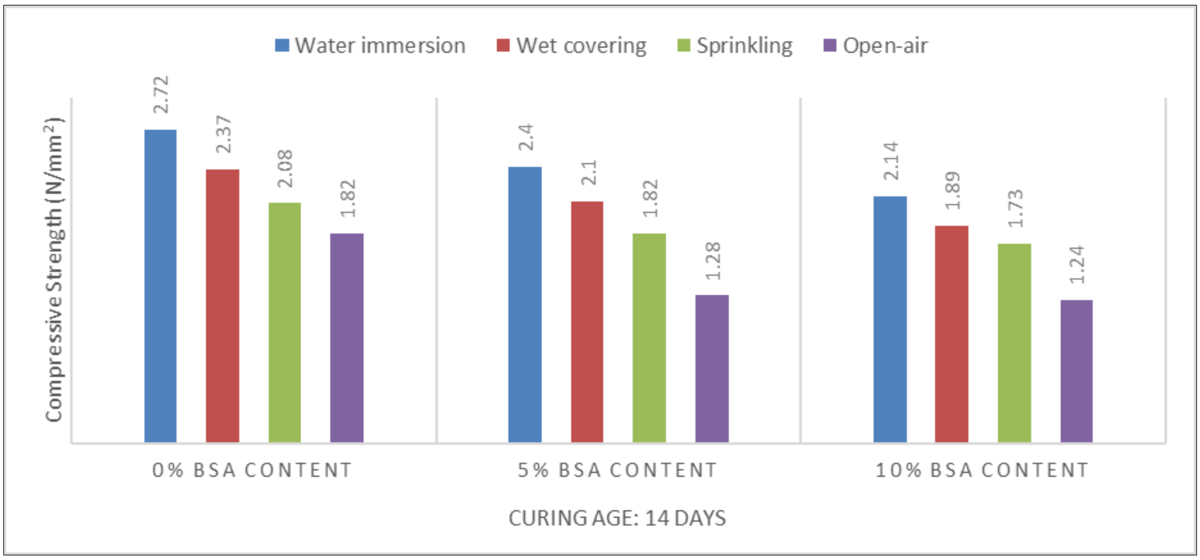

Figure 4 14-day compressive strength of BSA blended cement bricks

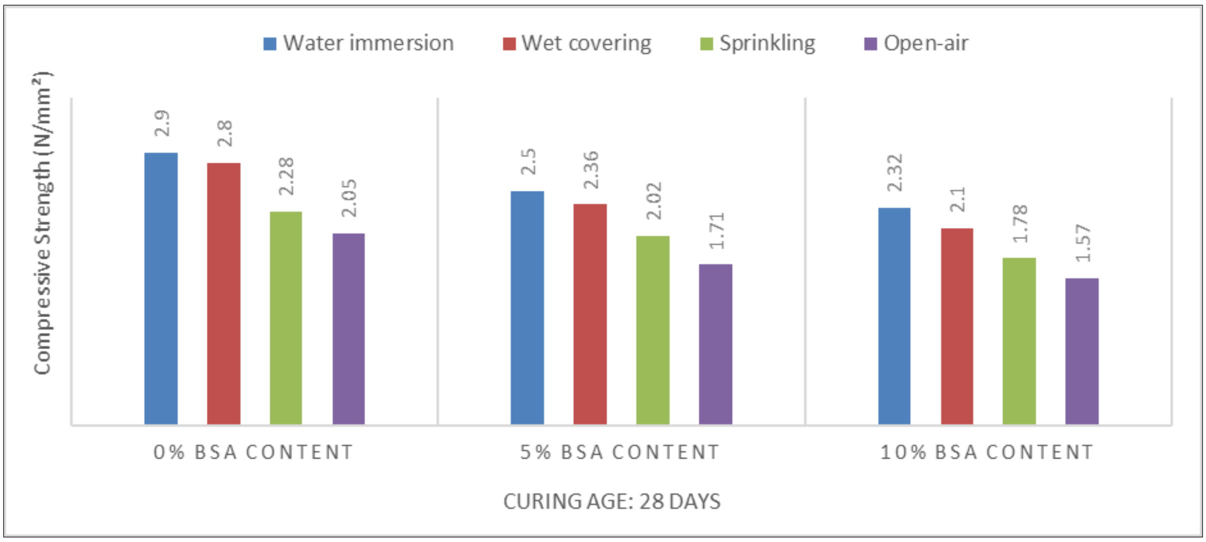

Figure 5 28-day compressive strength of BSA blended cement bricks

Table 5 Differences in compressive strength among the curing methods

S/N	**Curing methods**	**Compressive strength (N/mm^2)**					
		0% BSA content		**5% BSA content**		**10% BSA content**	
		14 days	**28 days**	**14 days**	**28days**	**14 days**	**28days**
1	Water immersion	2.72	2.90	2.40	2.50	2.14	2.32
	Wet rug covering	2.37	2.80	2.10	2.36	1.89	2.10
	Diff. in comp. strength	0.35	0.10	0.30	0.14	0.25	0.22
	% Difference	12.87	3.45	12.50	5.60	11.68	9.48
2	Water immersion	2.72	2.90	2.40	2.50	2.14	2.32
	Sprinkling	2.08	2.28	1.82	2.02	1.73	1.78
	Diff. in comp. strength	0.64	0.62	0.58	0.48	0.41	0.54
	% Difference	23.53	21.38	24.17	19.20	19.16	23.28
3	Water immersion	2.72	2.90	2.40	2.50	2.14	2.32
	Open-air	1.82	2.05	1.28	1.71	1.24	1.57
	Diff. in comp. strength	0.90	0.85	1.12	0.79	0.90	0.75
	% Difference	33.09	29.31	46.67	31.60	42.06	32.33
4	Wet rug covering	2.37	2.80	2.10	2.36	1.89	2.10
	Sprinkling	2.08	2.28	1.82	2.02	1.73	1.78
	Diff. in comp. strength	0.29	0.52	0.28	0.34	0.16	0.32
	% Difference	12.24	18.57	13.33	14.41	8.47	15.24

5	Wet rug covering	2.37	2.80	2.10	2.36	1.89	2.10
	Open-air	1.82	2.05	1.28	1.71	1.24	1.57
	Diff. in comp. strength	0.55	0.75	0.82	0.65	0.65	0.53
	% Difference	23.21	26.79	39.05	27.54	34.39	25.24
6	Sprinkling	2.08	2.28	1.82	2.02	1.73	1.78
	Open-air	1.82	2.05	1.28	1.71	1.24	1.57
	Diff. in comp. strength	0.26	0.23	0.54	0.31	0.49	0.21
	% Difference	12.50	10.09	29.67	15.35	28.32	11.80

Table 5 reveals the extent to which the strength performance of the brick specimens are influenced by their curing conditions. The differences in 28-day strength for specimens cured by water immersion and those cured by wet rug covering, intermittent water sprinkling and open-air exposure were 3.45%, 21.38% and 29.31%, respectively for the control specimens; while for the modified brick specimens, these differences were obtained as 5.6%, 19.2% and 31.6%, respectively, for 5% BSA content; and 9.48%, 23.28% and 32.33%, respectively, for 10% BSA content. The influence of the methods of curing used, as it impacts the strength performance of the hardened BSA cement blended bricks, is quite significant, with variations in strength ranging between 3% and 47% across the four different curing conditions examined. Water immersion curing has been shown to be the most reliable in promoting strength increase through complete cement hydration. This is because it ensures continuous moisture availability and surface temperature regulation, thereby mitigating the risks associated with rapid temperature changes. These findings are in agreement with [1], [3], [5] and [6].

3.4. Abrasive resistance

The abrasive coefficients of the brick specimens are presented in Table 6, notably, across all curing methods, the abrasive resistance is shown to diminish with corresponding increase in BSA content. The modified specimens with 10% BSA replacement possessed the least abrasive resistance, while the control specimens (0% BSA content) recorded the highest abrasive resistance across all the curing methods. Specimens cured by water immersion was observed to have the greatest resistance to abrasion when compared to specimens cured by wet covering, sprinkling and open-air, the difference in abrasive resistivity was obtained as 27.4%, 28.69% and 45.29%, respectively, for the control specimens; while for the modified brick specimens, these differences were obtained as 28.56%, 33.77% and 38.65%, respectively, for 5% BSA content; and 8.6%, 14.74% and 19.2%, respectively, for 10% BSA content. A direct relationship was observed between the abrasive resistance of the brick specimens and their corresponding compressive strength, specimens with higher load-carrying capacity exhibited greater resistance to wear.

Table 6 Abrasive resistance of BSA blended cement bricks

S/N	Curing method	% (PLC + BSA)	M_1(g)	M_2(g)	$M_1 - M_2$ (g)	S(cm^2)	Abrasive coefficient, Ca (cm^2/g)
1	Water immersion	100 PLC + 0 BSA	2670	2583	87	215	2.471
		95 PLC + 5 BSA	2550	2450	100		2.150
		90 PLC + 10 BSA	2580	2441	139		1.547
2	Wet covering	100 PLC + 0 BSA	2490	2370	120	215	1.792
		95 PLC + 5 BSA	2420	2280	140		1.536
		90 PLC + 10 BSA	2400	2248	152		1.414
3	Sprinkling	100 PLC + 0 BSA	2573	2451	122	215	1.762

		95 PLC + 5 BSA	2460	2309	151		1.424
		90 PLC + 10 BSA	2528	2365	163		1.319
4	Open-air	100 PLC + 0 BSA	2347	2188	159	215	1.352
		95 PLC + 5 BSA	2312	2149	163		1.319
		90 PLC + 10 BSA	2247	2075	172		1.250

4. Conclusion

This research evaluated the influence of different curing methods on the strength and durability of bamboo stem ash (BSA) cement blended bricks. BSA was introduced into the mixture by a direct substitution with cement in proportions of 0%, 5% and 10%. The chemical composition of BSA showed that it doesn't meet most of the chemical requirements of ASTM C618 to be regarded as a pozzolanic material, however, all specimens blended with BSA met the physical requirements of ASTM C618 by attaining a 28-day strength activity index of ≥ 75%. An increase in BSA content was associated with a corresponding decrease in compressive strength and abrasive resistance. Specimens cured by water immersion were found to possess the highest compressive strength and abrasive resistance, followed sequentially by wet rug covering, intermittent water sprinkling and open-air exposure. All samples tested across the different curing methods satisfied the requirement of the Nigerian Industrial Standard for non-load bearing bricks (1.5 – 3.5 N/mm^2) at 28 days. Under the water immersion curing technique, a 5% BSA-cement replacement achieved a sufficient strength activity index of 88.24% and 86.21% at 14 and 28days, respectively, while also limiting the high alkali content associated with higher BSA quantities introduced into the brick mixture. This could support agricultural waste recycling and reduce the emission of greenhouse gases and carbon dioxide by lowering cement usage. Water immersion curing method was observed to be the most reliable in promoting adequate strength gain and wear resistance through the provision of an appropriate environment for complete hydration reaction.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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