

Characteristics of Bamboo Leaf Ash Blended Cement Paste and Mortar

Umoh, A.A.^{1*} and Odesola, I.¹

Abstract: The use of bamboo leaf ash as cement supplement can contribute to reduction in cost and environmental hazard associated with cement production as well as waste pollution caused by the littered bamboo leaves. Therefore, the characteristics of cement paste and mortar incorporating bamboo leaf ash were investigated. The results of the physical properties of the pastes were within the requirements stipulated by relevant standards while that of the mortar cubes indicated that the compressive strength generally increased with curing age, and that the mix containing 15% Bamboo Leaf Ash (BLA) by mass competes favorably with that of the reference mix at 28 days and above. The water absorption and apparent porosity were observed to increase with increase in BLA content, while the bulk density decreases as the percentage of BLA increases from 5% to 25% by mass. The study concluded that 15% BLA replacing cement is adequate for the production of masonry mortar.

Keywords: Bamboo leaf ash; blended cement mortar; bulk density; compressive strength; porosity.

Introduction

Mortar is material made from the intimate mixture of sand grains, a binder (lime, cement, etc.) and water. The properties and characteristics of the mortars mainly depend on the nature of the binder component. Even though mortar makes up as little as 7% of the total volume of a masonry wall, it plays a crucial role in the performance of the structure. It does not only bond the individual units together, but it also seals the building against moisture and air penetration. Mortar is literally the glue that holds the wall system together.

The compressive strength of mortar is sometimes used as a principal criterion for selecting mortar type, since compressive strength is relatively easy to measure, and it commonly relates to some other properties, such as tensile strength and absorption of the mortar; it is considered as a basis for assessing the compatibility of mortar ingredients. Compressive strength of mortar increases with an increase in cement content and decreases with an increase in lime, sand, water or air content. Flexural strength is also important because it measures the ability of a mortar to resist cracking.

In order to modify and/or to improve some of the properties of the mortars, different products or additional constituents are mixed together with the basic components. At the earlier time, commonly used products were composed of natural substances such as blood, egg yolk, fig juice, animal glue, and vegetable juices [1]. But today, admixtures generally of industrial or agricultural by-products, like fly ash or blast furnace slag, silica fume, metakaolin, rice husk ash, and periwinkle shell ash, are being used in mortar and concrete [2-5]. It is also established that Bamboo Leaf Ash (BLA), which is obtained by the burning of dried bamboo leaves, has the potential of a pozzolan for use as cement replacement in concrete.

A study on the pozzolanic reactivity of BLA by firing the leaves in an open atmosphere and then heated at 600°C for 2 hours in a furnace was conducted [6]. Reactions of the ash with calcium hydroxide showed that the ash is pozzolanic in nature. It was also reported that the pozzolanic reactivity increased with time and temperature. When 20% BLA was mixed with Portland cement, the compressive strength at 28 days hydration was comparable to that without ash.

The amorphousness of Brazilian bamboo leaf ash calcined at 600 °C was investigated [7] using different techniques such as X – Ray Fluorescence (XRF), X – Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Energy Dispersive X – Rays (EDX), Fourier Transform Infrared Spectroscopy (FT-IR), Thermogravimetry (TG), and Derivative Thermogravimetry (DTG). They reported that the ash has a

¹ Building Department, Faculty of Environmental Studies, University of Uyo, Uyo, Akwa Ibom State, NIGERIA

*Corresponding author; e-mail: umohaa@yahoo.co.uk

Note: Discussion is expected before June, 1st 2015, and will be published in the "Civil Engineering Dimension" volume 17, number 2, September 2015.

Received 10 November 2014; revised 30 January 2015; accepted 12 February 2015.

very high pozzolanic activity, with a reaction rate constant K of the order of $10^{-1}/h$ and type 1 Calcium Silicate Hydrate (CSH) gel was the main hydrated phase obtained from pozzolanic reaction; and that when the ash was blended with cements (10% and 20%) it complied with the physical and mechanical requirements of the existing European standards.

Asha *et al* [8] investigated the effect of BLA as cement replacement, on compressive strength and durability characteristics of concrete. They found out that the compressive strength of the concrete decreases with increase in percentage content of BLA but recorded improvement in acid and chloride resistance at 10% replacement of cement with BLA. Therefore they concluded that concrete with BLA should be used for civil engineering works where durability is a major concern than high strength.

The characteristics of BLA stabilization on lateritic soil, and as a complementary material to lime in stabilization on lateritic soil, in highway construction were studied [9,10]. It was reported that BLA has the potential for stabilizing lateritic soils as well as increasing the strength of lime stabilized lateritic soil for highway construction. Iorliam *et al.* [11] examined the effect of BLA on cement stabilization of Markurdi shale for use as flexible pavement construction material and found that the use of the shale treated with 14% cement + 20% BLA is suitable for use as sub-base materials in flexible pavement. The use of only BLA as stabilizing agent was carried out by Amu and Babajide [12]. They investigated the geotechnical properties of Markurdi shale treated with BLA and observed that the strength properties of BLA treated shale were below minimum values specified for road building materials and therefore recommended for use as a modifier, in the stabilization of shale with either cement, lime or other additives for road work.

The mechanical performance of ternary blended cement concrete incorporating periwinkle shell and bamboo leaf ash has been assessed [13,14]. It was discovered that at 28 and 56 days period of hydration, ternary blended cement concrete containing 10% periwinkle shell ash (PSA) combined with 10% BLA, each replacing cement by mass, attained higher compressive and tensile splitting strength than the reference mix and other mixtures with incorporation of combined percentage of PSA and BLA greater or less than 20%. Therefore, it was concluded that 20% of PSA and BLA combined by equal mass of cement replacement is the optimal amount to be used for enhancing concrete mechanical properties. Ademola and Buari [15] characterized the strength behavior of BLA blended cement concrete in sulphates environment and concluded that Portland cement-

bamboo leaf ash blended cement concrete could be used in civil engineering and building works in sulphate environment and where early strength is not a major requirement. Apart from these few findings on the use of BLA in concrete, its use in mortar, which could enhance mortar's strength, workability, and durability performance, is scarce in literature. Therefore, this study seeks to investigate the physical and mechanical properties of cement paste and mortar made from ordinary Portland cement blended with BLA with a view to establishing the suitability of BLA blended cement for masonry work.

Materials and Methods

Materials

Bamboo leaves were obtained from bamboo forest in Mkpato Enin Local Government Area of Akwa Ibom State, Nigeria. The leaves were taken to the Department of Building Laboratory, University of Uyo and spread on the floor for it to be properly dried. In order to obtain a reactive ash rich in silica content, and to reduce cost of energy (gas) for burning, a combination of open air burning and calcination were adopted. The dried leaves were ignited in any open drum at a temperature of 100-150 °C, without any application of external energy like the use of firewood or charcoal. Air burning was stopped as soon as all the leaves were charred (Figure 1) and become black in color. Then, it was taken to a gas furnace and heated to a temperature of 500 °C for two hours at which it becomes grey in color (Figure 2). The combined temperature of 600-650 °C could be equivalent to the temperature employed by Dwivedi *et al.* [6], in which the XRD pattern shows that the ash is amorphous in nature. When cooled, the ash was sieved. Over 90% of the ash passes through 75 µm mesh wire, and up to 68% pass through sieve of 45 µm.



Figure 1. Bamboo Leaf Ash Burnt in an Open Atmosphere



Figure 2. Bamboo Leaf Ash after Calcinations in Furnace

Chemical properties of the ash were obtained by XRF analysis, while the physical properties conducted on the ash include specific gravity, strength activity index with Portland cement, and fineness. The Strength Activity Index with Portland cement was conducted on mortar cube specimen of size 50 mm. A mix ratio of 1: 2.75 (cement: sand) by mass with water-cement ratio of 0.48 was used as the control. The BLA was blended with cement in the ratio of 0.2 : 0.8 by mass of the cement as stipulated by ASTM C311 [16]. The cube specimens for the control and for the blended cement were tested for compressive strength (expressed in N/mm²) at 7 and 28 days. The percentage strength attainments of the blended specimens with that of the control at the stated ages were calculated. The fineness of the ash, expressed as the percentage retained on the 45 μ m mesh sieve, was determined in accordance with

ASTM C311 [16]. The fineness of the ash was 32%, which is below the maximum 34%, stipulated by ASTM C618 [17]. The results of the chemical and physical analyses are presented in Tables 1 and 2. The ash satisfied the requirements for Class N pozzolan [17].

The cement used was Portland cement (Dangote Brand) produced to conformity of NIS 444-1 [18] which is equivalent to BS EN 197-1 (2009) [19]. The properties of the cement are as presented in Tables 1 and 2. Fine aggregate used was soft sand satisfying the requirement of ASTM C144 [20] for sand to be used for mortar (Table 3); while water was tap water, which is equally suitable for human consumption, and obtained from the Building Laboratory, University of Uyo, and used for mixing and curing of specimens.

Table 1. Chemical Properties of Cementitious Materials obtained by XRF Analysis

Elemental Oxide	Bamboo Leaf Ash (% by mass)	Portland Cement (% by mass)
CaO	4.23	62.44
SiO ₂	72.25	20.06
Al ₂ O ₃	4.08	5.85
MgO	1.01	1.93
Fe ₂ O ₃	1.97	3.05
K ₂ O	3.15	0.97
MnO ₂	0.22	0.20
P ₂ O ₅	0.74	0.17
SO ₃	0.15	2.71
TiO ₂	0.35	0.28
LOI	2.93	1.09

Table 2. Physical Properties of Binders

Properties	Bamboo Leaf Ash	Portland Cement
Specific gravity	2.64	3.10
Soundness (mm)	-	0.10
Consistency (%)	-	29.01
Initial setting time (Minutes)	-	101
Final setting time (Minutes)	-	204
Strength activity index with Portland cement (N/mm ²):		
7 days (% of control)	75.47	-
28 days (% of control)	79.45	-
Fineness (Material retained on 45 μ m sieve - %)	32.85	-

Table 3. Sieve Analysis of Soft Sand used for BLA Blended Cement Mortar

Sieve sizes (mm)	Material retained		Percentage passing	Cumulative retained (%)	Percentage Passing (ASTM C144, 1991)
	gram	%			
4.75	20	3.05	96.95	3.05	100
2.36	6	0.91	96.04	3.96	95-100
1.18	21	3.2	92.84	7.16	70-100
0.6	191	29.12	63.72	36.28	40-75
0.3	340	51.83	11.89	88.11	10-35
0.15	60	9.15	2.74	97.26	2-15
Pan	18	2.74	0.00	100	
Total	656	100	-	-	

Method

Paste and Specimen Preparation

The cement pastes were prepared with a mixture of cement and water. BLA was used in varying contents of 0%, 5%, 15%, 20%, and 25%, by mass, of cement. Physical tests conducted on the Ordinary Portland Cement (OPC) and BLA/OPC were specific gravity, consistency, setting times and soundness.

Mortar was prepared from a mix proportion of 1 : 3 (cement: sand), by mass, with a water-to-cement (W/C) ratio of 0.4 as the reference. The cement in the mix was replaced by BLA in proportions of 5%, 10%, 15%, 20%, and 25%, by mass of cement. The cement and BLA were manually mixed in dry state and added to the already measured sand where the mixing continues. Thereafter water was measured and added while the mixing operation continues until a homogenous mix was achieved.

The fresh mixture was cast in cube moulds of size 50 mm in two layers and each layer was tamped for 25 times. On completion of casting, the specimens were kept in a flat leveled surface and covered with polyethylene sheets for 24 hours. At the end of 24 hours, the specimens were removed from the moulds and immersed in water until their testing ages.

Testing of Specimens

Compressive Strength

The compressive strength was tested on cube (50 mm) mortar specimens after 7, 14, 28, and 90 days in accordance to ASTM C109 [21]. Three specimens were tested for each mixture and curing age, and the mean compressive strength computed.

Water Absorption, Porosity, and Bulk Density

Water absorption, apparent porosity, and bulk density tests were determined at 28 days only. The method adopted was that postulated by Mukherjee *et al.* [22] in which the specimens were dried in an oven at 110°C for 24 hours, and the mass taken as dry mass (Dw). The specimens were then boiled in water for 2 hours and kept for another 24 hours in the same warm water for the water to penetrate the pores. Specimens were then suspended in water with copper wire of 0.5 mm thickness to take the suspended mass (S1W). Soaked mass (S2W) was also recorded by carefully removing the surface water and the copper wire.

Results and Discussion

Physical Properties of BLA Blended Cement Paste

The physical properties of bamboo leaf ash blended cement are presented in Table 4. The fineness, expressed as % retained on 45µm sieve, range from 19.60% for 0% BLA content to 18.10% for 25% BLA content, respectively. It shows that the blended cement is finer in particle sizes than the reference, and that the higher the quantity of BLA in the blend, the lower the residue retained on the sieve. However, the quantity of ash retained at each blended level was below the maximum percentage of 34% as stipulated [17].

Table 4 also reveals that the soundness of the blended cement paste ranges between 0.50mm and 0.80mm for replacement levels of 0% to 25%. These values are less than the 10mm limiting value recommended [19, 23]. Hence, the cements do not show any appreciable change in volume after setting.

The consistency increases from 25.6% to 42% as BLA content increases from 0% to 25%. The water required for a standard consistency was noted to increase as the BLA content increases. This can be attributed to the finer particle sizes of blended cement as much water is required for proper lubrication.

The initial setting time was observed to range from 105 minutes with 5% BLA blended cement paste to 245 minutes with blended cement paste containing 25% BLA. Whereas, the final setting times ranges from 178 minutes to 275 minutes for 0% to 25% BLA content. The initial setting times of 5% and 10% BLA contents have values lower than the reference; while the values of the final setting times of the same 5% and 10% BLA blended cement pastes are not differ much from the value of the reference. However, all the cement pastes satisfy requirements of 45 minutes minimum initial setting time and maximum 10 hours final setting time [19,23]. The maximum 375 minutes final setting time spelt out by ASTM C150 [24] were equally satisfied by all the blended cement pastes.

The variation of setting times with percentage BLA replacement shows that, in each case of initial and final setting time, it increases as the BLA content increases. As a result, the hydration process is slowed down, thereby causing setting times to increase. This finding is in consonance with earlier findings [25,26]. The slow hydration means low rate of heat development which is one of the notable advantages of the incorporation of pozzolans in concrete and its attendant use in mass concrete construction as it reduces thermal stress.

Table 4. Summary of Physical Properties of BLA Blended Cement paste

Physical properties	BLA Replacement (%)					
	0	5	10	15	20	25
Fineness (% residue on 45 μm sieve)	19.60	19.25	19.05	18.90	18.36	18.10
Soundness (mm)	0.5	0.5	0.5	0.7	0.8	0.8
Consistency (%)	25.6	29	30.6	32	38	42
Initial Setting time (min)	130	105	125	180	215	245
Final setting time (min)	178	182	190	210	250	275

Table 5. Compressive Strength of BLA Blended Cement Mortar at Various Curing Ages

Bamboo Leaf Ash Content (%)	Compressive strength (N/mm ²)			
	7 days	14 days	28 days	90 days
0	11.87	12.50	14.92	15.96
5	12.67	16.40	19.10	21.12
10	11.92	14.10	16.80	18.80
15	10.27	12.10	14.20	15.00
20	7.60	8.20	7.00	9.80
25	5.20	6.00	6.90	7.80

Compressive Strength

The results of the compressive strength of BLA blended cement mortar as presented in Table 5 indicated that the strength increases with increased in hydration period for each of the replacement level of cement with BLA. It is equally observed that at the replacement levels of 5-10%, higher strength values were attained when compared to the reference specimens (that is 0% BLA content). For instance, at 28 days hydration, the percentage attainment of compressive strength were 100%, 128%, 113%, 95%, 47%, and 46% for 0% (that is reference mix), 5%, 10%, 15%, 20%, and 25% BLA content, respectively. The compressive strength for the mortar containing 5% BLA has met the minimum strength of 17.2 N/mm² for type "M" (high compressive-strength) mortar, while mortar containing 10-15% BLA have met the minimum strength of 12.4 N/mm² for type "S" (general all-purpose) mortar [27]. At 90 days, the trends were 100%, 132%, 118%, 94%, 61%, and 49% for 0%, 5%, 10%, 15%, 20%, and 25% BLA content, respectively. Based on these results it can be said that 15% BLA, having attained up to 90% strength of the reference could be considered the optimal replacement level for the production of the blended cement mortar as specified [17].

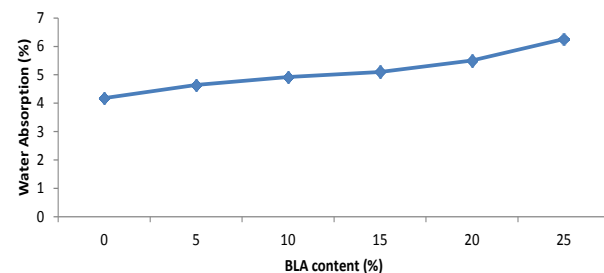
Water Absorption

The water absorption of the BLA blended cement mortar, as presented in Figure 3, indicated that the water absorbed by the specimen increases as the amount of BLA content increases. The least value of 4.18% was recorded with the reference mix while the highest value of 6.26% was recorded for mix containing 25% BLA. A similar trend was obtained [22] using fly ash as partial replacement of cement in mortar. This phenomenon indicates that part of the

BLA in the mix may have not been used up through pozzolanic reaction at the stated age, as the released of calcium hydroxide by cement hydration for this purpose continuously occurred beyond 28 days, and thereby forming weak spots for ingress of water into the specimen. Another possible cause to higher water absorption as the percentage of BLA content increases could be as a result of the reduction of cement content resulting in less quantity for hydration.

Apparent Porosity

The results of the apparent porosity of the mortar specimens as presented in Figure 4 range between 6.52% and 9.12%. The blended mortar specimens were observed to have higher porosity values than that of the reference specimens. This can be attributed to delay in the release of calcium hydroxide, (CaOH)₂, during cement hydration which would have led to secondary formation of Calcium Silicate Hydrate, CSH, through the pozzolanic reaction of the BLA and calcium hydroxide. The fact that pozzolanic reaction is time dependent means that longer period of time is required to ascertain the improvement of the microstructure of the BLA blended cement mortar for serviceability performance.

**Figure 3.** Variation of Absorbed Water with Percentage BLA Content Replacing Cement

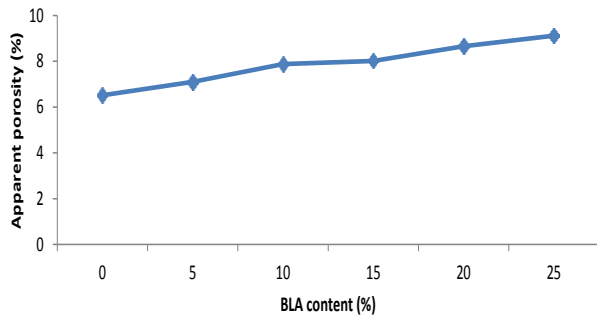


Figure 4. Variation of Apparent Porosity with Percentage BLA Content Replacing Cement

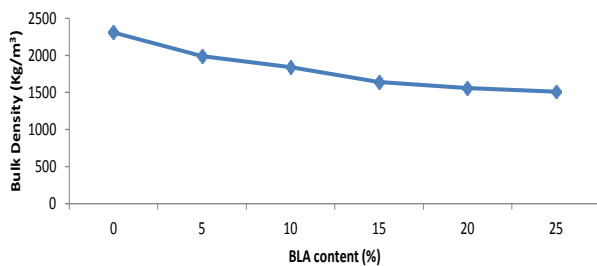


Figure 5. Variation of Bulk Density with Percentage BLA Content Replacing Cement

Bulk Density

The values of the bulk density of the BLA blended cement mortar are presented in Figure 5. It indicates that the bulk density decreases as the percentage of BLA content replacing cement increases. This characteristic could be ascribed to the fact that BLA is lighter than cement in the mix, hence there is a decrease in the mass of the specimen without a change in the volume leading to a decrease in the density of the specimen. This confirms a similar assertion [28] that increasing natural fiber (which is lighter than cement) content in composite materials, decreases the density of the composite. On the other hand, it was noted that the variation in the bulk density of the blended specimens, especially that of 25% BLA content, with that of the control was exceedingly high. This high variation recorded could be attributed to higher amount of water required to attain standard consistency, which after drying must have created much pores in the specimen which later on had to be filled by water and thereby increasing the bulk density of the specimen.

Conclusions

From the results of the study, the following conclusions can be drawn: The bamboo leaf ash had a combined silica, alumina and ferric oxides content of 78.30%, thereby satisfying the requirement of Class N Pozzolan suitable for mortar and concrete

production. The BLA, which is lighter than cement, and which occupies a greater volume for the same mass of cement, therefore requires additional water in the mix as the amount of BLA content increases in order to attain to a paste of standard consistency. The initial and final setting times of the pastes range between 130–245 minutes and 178–275 minutes, respectively, and falls within the range recommended by most standards. The compressive strength of the BLA blended cement mortar increases with increase in curing age in all the mixes. Furthermore, mortar with 10% BLA content performed better than the reference mix; while the one with 15% BLA blended cement mortar compete favorably with the reference in term of strength. The water absorption and apparent porosity of the blended cement mortar increase as the BLA content increased, whereas, the bulk density decreases with increase in BLA content. It is recommended that 15% BLA content by mass of cement is optimally adequate for the production of masonry mortar for building works.

References

1. Thirumalini, P. and Sekar, S.K., Review on Herbs used as Admixture in Lime Mortar used in Ancient Structures, *Indian Journal of Applied Research*, 3(8), 2013, pp. 295-298.
2. Khatib, J.M. and Hibbert, J.J., Selected Engineering Properties of Concrete Incorporating Slag and Metakaolin, *Construction and Building Materials*, 19, 2005, pp. 460-472.
3. Ramezani-pour, A.A., Khani, M.M., and Ahmadibeni, G., The Effect of Rice Husk Ash on Mechanical Properties and Durability of Sustainable Concrete, *International Journal of Civil Engineering*, 7(2), 2009, pp. 83-91.
4. Lee, S.T., Moon, H.Y. and Swamy, R.W., Sulfate Attack and Role of Silica Fume in Resisting Strength Loss, *Cement and Concrete Composites*, 27, 2005, pp. 65-76.
5. Umoh, A.A. and Olusola, K.O., Performance of Periwinkle Shell Ash Blended Cement Concrete Exposed to Magnesium Sulphate, *Civil Engineering Dimension*, 15(2), 2013, pp. 96-101.
6. Dwivedi, V.N., Singh, N.P., Das, S.S., and Singh, N.B., A New Pozzolan Material for Cement Industry: Bamboo Leaf Ash, *International Journal of Physical Sciences*, 1(3), 2006, pp. 106-111.
7. Frias, M., Savastano, H., Villar, E., Sanchez de Rojas, M.I., and Santos, S., Characterization and Properties of Blended Cement Matrices Containing Activated Bamboo Leaf Wastes, *Cement and Concrete Composites*, 34, 2012, pp. 1019-1023.
8. Asha, P., Salman, A., and Arun Kumar, R., Experimental Study on Concrete with Bamboo

- Leaf Ash, *International Journal of Engineering and Advanced Technology*, 3(6), 2014, pp. 2249-8958.
9. Amu, O.O. and Adetuberu, A.A., Characteristics of Bamboo Leaf Ash Stabilization on Lateritic Soil in Highway Construction, *International Journal of Engineering and Technology*, 2(4), 2010, pp. 212-219.
 10. Amu, O.O and Babajide, S.S., Effects of Bamboo Leaf Ash on Lime Stabilized Lateritic Soil for Highway Construction, *Research Journal of Applied Sciences, Engineering and Technology*, 3(4), 2011, pp. 278-283.
 11. Iorliam, A.Y., Agbede, I.O., and Joel, M., Effect of Bamboo Leaf Ash on Cement Stabilization of Markudi Shale for use as Flexible Pavement Construction Material, *American Journal of Scientific and Industrial Research*, 3(3), 2012, pp. 166-174.
 12. Iorliam, A.Y., Okwu, P., and Ukya, T.J., Geotechnical Properties of Markurdi Shale Treated with Bamboo Leaf Ash, *AUJ.T.*, 16(3), 2013, pp. 174-180.
 13. Umoh, A.A. and Femi, O.O., Comparative Evaluation of Concrete Properties with Varying Proportions of Periwinkle Shell and Bamboo Leaf Ashes Replacing Cement, *Ethiopia Journal of Environmental Studies and Management*, 6(5), 2013, pp. 570-580.
 14. Umoh, A.A., Alake, O., Babafemi, A.J., and Olasunkanmi, O.F., Assessing the Mechanical Performance of Ternary Blended Cement Incorporating Periwinkle Shell and Bamboo Leaf Ashes, *Journal of Civil and Environmental Research*, 3(1), 2013, pp. 26-35.
 15. Ademola, S.A. and Buari, T.A., Behaviour of Bamboo Leaf Ash Blended Cement Concrete in Sulphate Environment, *IOSR Journal of Engineering*, 4(6), 2014, pp. 1-8.
 16. ASTM C311, *Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for use in Portland-Cement Concrete*, American Society for Testing and Materials, 2007.
 17. ASTM C618, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for use in Concrete*, American Society for Testing and Materials, 2008.
 18. NIS 444-1, *Cement- part 1: Composition, Specification and Conformity Criteria for Common Cements*, Nigeria Industrial Standard, 2003.
 19. BS EN 197–1, *Cement Composition, Specification and Conformity Criteria for Common Cements*, British Standard Institution, 2009.
 20. ASTM C144, *Standard Specification for Aggregate for Masonry Mortar*, American Society for Testing and Materials, 1991.
 21. ASTM C109, *Standard Test Methods for Compressive Strength of Hydraulic Cement Mortars*, American Society for Testing and Materials, 2001.
 22. Mukherjee, S., Mandal, S., and Adhikari, U.B., Study on the Physical and Mechanical Property of Ordinary Portland Cement and Fly Ash Paste, *International Journal of Civil and Structural Engineering*, 2(3), 2012, pp. 731-736.
 23. NIS 447, *Methods of Testing Cement: Determination of Setting Time and Soundness*, Nigeria Industrial Standard, 2003.
 24. ASTM C150, *Specification for Portland Cement*, American Society for Testing and Materials, 1994.
 25. Hossain, K.M.A., Blended Cement using Volcanic Ash and Pumice, *Cement and Concrete Research*, 33, 2003, pp. 1601-1605.
 26. Mehta, P.K. and Monteiro, P.J.M., *Concrete: Microstructure, Properties, and Materials*, Third edition, McGraw-Hill publishing company Ltd., New Delhi, 2006.
 27. ASTM C270, *Standard Specification for Mortar for Unit Masonry*. Annual Book of Standards, American Society for Testing and Materials, 2006.
 28. Aggarwal, L.K., Studies on Cement-bonded Coir Fibre Boards, *Cement and Concrete Composites*, 14, 1995, pp. 63-69.