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Compressive and Tensile Strength Characteristics of Bamboo Leaf Ash Blended Cement Concrete

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Abstract

One of the most serious problems of the world today is related to removal of waste and to find solution of reusing it. Large volumes of waste are generated worldwide during the production of bamboo. The study determined the effect of calcination temperatures on the chemical and physical properties of bamboo leaf ash (BLA), effects of partial replacement of cement with bamboo leaf ash (BLA) on the compressive and tensile strength of concrete.

A nominal mix of 1:2:4 with water-cement ratio of 0.65 was used as reference, The cement content of the reference was replaced with varying percentages of BLA by weight up to 20 %. A total of 240 cubes were cast, cured in water and tested at ages up to 210 days. The properties investigated were compressive and tensile strengths. The results revealed that the most amorphous BLA that met the minimum requirements for class C pozzolans as specified by ASTMC618-08 was obtained at temperature of 600^0C.

The compressive strength of the BLA blended cement concrete increased significantly (at $p = 0.05$, $R^2 = 0.998$) with increase in curing age but decreased as the BLA contents increased. The optimum compressive strength was attained with 10 % BLA. Similar trend was observed for tensile splitting strength. The tensile splitting strength with 5 % to 20 % BLA was observed to be lower than the control at all curing ages.

Keywords: Bamboo leaf ash, Blended cement, Calcination temperature, Curing age, Compressive strength, Tensile Strength

Introduction

The overall relevance of concrete in virtually all civil and building construction works cannot be overemphasized. This is because construction works depend to a very large extent on concrete. It is one of the major construction materials that can be delivered to the job site in a plastic state and it can be molded insitu or precast to virtually any form or shape. Its basic constituents are cement, fine aggregates (sand), coarse aggregates and water, while its quality is influenced by that of its constituent materials. It is expected that the concrete produced at any given instance should among other qualities have satisfactory compressive strength requirements as well as durability in the environment in which the structure is placed (Umoh, 2012). The compressive strength of concrete is considered as one of the most important properties in the hardened state; and the design of concrete structures is based primarily to resist compressive stresses. (Beshr et *al.*, 2003)

Concrete is of the most important element of building structure. A well designed concrete can be a durable construction material; however, the environmental impact of Portland cement production is a growing concern, as cement manufacturing is responsible for about 2.5% of total worldwide emission from industrial sources. (Binici, et *al.*, 2009) One effective way of reducing the environmental impact of Portland cement is to use natural pozzolans or supplementary cementing materials, as partial replacement for cement a strategy according to (Aldea, *et al.*, 2000) has a potential to reduce costs, conserve energy, and reduce waste volumes. Materials cost, according to Ayangade *et al.* (2004), accounts for two-third of building production cost, It is therefore necessary to look inward and consider how the cost of the widely accepted convectional materials such as cement, sand, granite, and wood can be reduced to affordable level without compromising standards. One of the suggestions in the forefront has been sourcing, development and use of readily available local natural materials suitable for the production of any component of a building as alternatives to more expensive conventional building materials (Morel *et al*., 2001; Kayali *et al*., 2008), one of such alternative natural materials is bamboo leaf ash.

Concrete is not normally designed to resist direct tension, the knowledge of tensile strength is used to estimate the load under which cracking will develop. This is due to its influence on the formation of cracks and its propagation to the tension side of reinforced concrete flexural member. Shear, torsion and other actions also produce tensile stresses to the particular section of concrete member. In most cases member behavior changes upon cracking. So tension strength of concrete is also considered in proportioning concrete member. This strength is of interest in designing of highway and airfield slabs as shear strength and resistance to cracking are very important to sustain such loading.

Bamboo leaf is the common term for members of a particular taxonomic group of large woody grasses (subfamily bambusoideae, family Andropogoneae/Poaceae). Bamboo is one of the most ornamental as well as easy to grow garden and potted plants in Akwa Ibom State. It is natively known as 'Akpo Nyanyanga' in the dialect of the people of the State. Bamboo is particularly adapted to the rainforest belt of Nigeria where it is found in abundance along riverbanks and other relatively marshy areas.

It has been identified that over 1200 bamboo species are available globally (Wang & Shen, 1987), and out of these species, seven are found in Nigeria of which the specie bambusa vulgaris constitutes 80% (Omotoso, 2003) and commonly referred to as the Indian bamboo. Bamboo is being hailed as a new super material with uses ranging from textile to construction. In construction, it is used for the construction of bridges, water transportation facilities, scaffoldings, construction of wattle and daub walls; and widely used in building applications, such as flooring, roof-trusses, rafters and purlin (AbduLatif et al., 1990). It is also used for home utilities such as containers, chopsticks, and woven mats. Massive plantation of bamboo provides an increasingly important source of raw materials for pulp paper industry in China (Hammett et al., 2001). In China and India dried mature bamboo leaves are used to deodorize fish oils while, the foliage has long been used as forage. Ashes obtained by the burning of bamboo leaf under control temperature have been reported to show a very high pozzolanic activity (Dwivedi et al., 2006; Singh et al., 2007; Frias et al., 2012).

Several studies have been conducted on the use of bamboo leaf ash (BLA) as pozzolanic material in construction. Asha et al. (2014) investigated the effect of BLA, as cement replacement, on compressive strength and durability characteristics of concrete with mix ratio 1: 1.5: 3, and found out that the compressive strength of the concrete decreases with increase in percentage of bamboo leaf ash but recorded improvement in acid and chloride resistance at 10% replacement of cement with bamboo leaf ash and therefore concluded that concrete with bamboo leaf ash should be used for civil engineering works where durability is a major concern than high strength.

Iorliam *et al.*, (2012), studied the effect of bamboo leaf ash (BLA) on cement stabilization of Makurdi shale for use as flexible pavement construction material. Compaction, Consistency, California Bearing Ratio (CBR) and unconfined compressive strength (UCS) tests, were conducted on Markurdi shale specimen treated with cement and bamboo leaf ash in combined incremental order of 2% to 14% cement, and 4% up to 20% BLA of dry weight of soil sample respectively. The results of test showed that Makurdi shale can be classified as high swell potential soil by AASHO, USCS and NBRRI classification, systems respectively therefore, recommending BLA for use as sub-base materials in flexible pavement..

Experimental Study

Sample collection

The bamboo leaf, sharp sand, granite chipping used in this research work were sourced from Ile-Ife. Ordinary Portland cement was used and were procured from the open market and ascertained to be in conformity with the requirements of BS EN 197-1:2000. The calcium ($CaSO_4$) and magnesium sulphate ($MgSO_4$) salt were obtained from the Department of Chemistry, Obafemi Awolowo University, Ile-Ife.

Instrumentation

The production of concrete and the determination of compressive strength and tensile strength were conducted in the Building Materials and Construction Laboratory, Obafemi Awolowo University, Ile-Ife. The calcination of the bamboo leaf ash was done at the Federal Institute of Research Oshodi Lagos State while the chemical analysis was carried out at the National Agency for Science and Engineering Infrastructure, Akure. The compressive and splitting tensile strength tests were carried out by using ELE 2000KN compression testing machine conforming to BS EN 12390-4&6 in accordance with BS EN 12390-3. All measurements were taken on a 150kg digital weighing balance available in the Department of Building Material Laboratory, Obafemi Awolowo University, Ile-Ife.

Calcinations and chemical analysis

The bamboo leaves were sun-dried on a concrete platform before subjecting it to heat at different temperatures of 500^{o}C, 600^{o}C, and 700^{o}C in a gas furnace; the heat application was stopped as soon as the required temperature was reached. The ashes obtained were ground and sieved with 45 µm and about 150g each was collected in clean plastic containers and taken to the National Agency for Science and Engineering Infrastructure Akure .for analysis. The samples were analyzed for their oxide composition and other chemical requirements as well as their physical properties. The BLA sample at the observed temperature calcinations level found to produce the most suitable (or amorphous) ash was used for the preparation of BLA blended cement concrete test specimens.

Mix proportions

A mixture of 1:2:4 mix ratio representing cement: fine aggregate: coarse aggregate was used as the reference mix. The cement content was subsequently replaced by weight, the percentage of bamboo leaf ash was varied between 5% and 20%, which gave a total of five mixes. In each mix, water cementitious materials ratio was fixed at 0.65 and the fine and coarse aggregate kept constant.

Proportioning and mixing of constituent materials

The sand and granite were thoroughly mixed, so also the bamboo leaf ash and cement on one side before been loaded into the mixer. Sand and granite were first loaded into the mixer followed by bamboo leaf ash mixed with cement and then water was added. The whole mixture was thoroughly mixed before the additional quantity of water was added. The mixture was then discharged from the mixer and the working process of gradual addition of water to the dry mixture and the continuous stirring/agitation with the trowel or/and shovel continues until a homogeneous mixture is obtained. Batching was done by weight, partial replacement of OPC by BLA by weight was calculated for 0%, 5%, 10 %, 15 %, and 20 %.

Casting of test specimens

Before casting, the moulds were thoroughly cleaned and rubbed with oil before casting in each case to ensure easy demoulding and smooth surface finish. Immediately after mixing, the wet mixture was cast into the moulds, using hand trowel. The moulds were filled in three layers and each layer was compacted using the compaction rod (25 mm diameter steel rod), 35 strokes uniformly distributed was applied over its surface during casting as stipulated by the requirements of BS 1881: Part 116 (1983). The work focused on OPC concrete with varying percentages of BLA up to 20%, replacing OPC. This percentage adopted is in consonance with the limits in literature to which the partial replacement is found adequate to produce a strong concrete. (Umoh *et al.*, 2012 and Prasad *et al.*, 2006) Therefore the level of treatment of BLA content variations was limited to control (0), 5, 10, 15 and 20% by weight of OPC

Curing of test specimens

The specimens were stored in a place free from vibration and not exposed to direct sunlight or other sources of heat. The cubes were demoulded after 24 hours and immersed in curing tanks for 7, 14, 21, 28, 60, 120, 180 and 210.

Testing for compressive strength

Compressive strength was determined for all the samples by using a compression testing machine, ELE 2000, Compressive strength was carried out on 100 mm concrete cubes specimens. A total of 120 cubes were cast and tested for compressive strength using a mix ratio of 1:2:4.and water cement ratio of 0.65. Compressive strength was determined at curing age of 7, 14, 21, 28, 60, 120, 180 and 210

Testing for Tensile splitting strength

The splitting tensile strength of the specimen was determined in accordance with BS EN 12390-6. The test specimen were 100 mm cube conforming to BS EN 12350-1, BS EN 12390-1 and BS EN 12390-2 were used for the preparation of the test specimen for the splitting tensile strength. The moulds were covered with polyethylene sheets and moistened for 24 h. Then the specimens were demoulded and cured in water at a temperature of 20 ◦C in the room condition prior to test days A total of 120 concrete cubes were cast and tested using a mix proportion of 1:2:4 and water cement ratio of 0.65. The specimen were cast in steel moulds by filling each mould in three layers, each layer being compacted manually by evenly distributing 35 strokes of steel tamping rod of 25 mm diameter, across the section of mould. The Tensile splitting strength were determined at curing age of 7, 14, 21, 28, 60, 120, 180 and 210. The tests were carried out triplicately and average split tensile strength values were obtained

Results and Discussion

Chemical analysis of bamboo leaf ash

Table 1. shows the results of the chemical composition by XRF of samples of bamboo leaf ash used. The activated bsmboo leaf ash analyzed for this study was mainly formed by SiO_2, followed by CaO, K_2O, and MgO. The other oxides (Al_2O_3, Fe_2O_3, Na_2O, TiO_2, P_2O_5 and SO_3) were present in concentrations equal or below 1.01%. The results also indicated that the ash calcined at 600^{o}C attained the highest silica dioxide of (SiO_2) of 83.33 % while ash at 500^{0}C and 700^{0}C had 80.25% and 83.00% respectively. these results show that bamboo leaf ash calcined at 600^{0}C to 700^{0}C had silica content which is greater than BS EN 197-1(2000) minimum requirement of 70 % and a total silicon dioxide, iron oxide and aluminium oxide (SiO_2+Fe_2O_3+Al_2O_3) content of 83.28%, 86.31% and 86.03% for the calcination temperature of 500^{0}C, 600^{0}C and 700^{0}C respectively. Also the values obtained from this study were more than that of ASTMC-618-2008 requirement for class N pozzolans which stipulated a minimum of 75% content. Therefore the ash calcined at 600^{0}C had the combined acidic content of 86.31 % and met the requirement for class N pozzolans. The sulphour trioxide (SO_3) content vary

between 0.10 and 0.15% at all the calcination temperatures. These values are less than the maximum values of 4-5 % specified by ASTMC618-2008. The loss of ignition (LOI) was lower than the ASTMC618-2008 requirement of not greater than 10%. The values recorded were 2.93% 0.40% and 0.41% at 500°C, 600°C and 700°C respectively.

Based on the value of 83.33% silica and a combined acidic oxide contents of 86.31% ash calcined at 600^0C has been taken as the most amorphous.

Table 1: Elemental oxide content of BLA sample calcined at different temperatures

Elemental oxide (%)	Calcination Temperature (^{0}C)		
	500	600	700
SiO_2	80.25	83.33	83.00
Al_2O_3	1.08	1.03	1.02
Fe_2O_3	1.97	1.95	2.01
CaO	4.23	4.44	4.43
MgO	1.01	1.02	1.02
SO_3	0.15	0.10	0.10
K_2O	3.13	3.09	3.09
Na_2O	0.05	0.05	0.06
MnO_2	0.22	0.22	0.23
P_2O_5	0.74	0.72	0.72
TiO_2	0.35	0.34	0.36
Cr_2O_3	0.00	0.00	0.00
LOI	2.93	0.40	0.41
$SiO_2+Al_2O_3+Fe_2O_3$	83.30	86.31	86.03

Physical properties of aggregates

The results of specific gravity and moisture content are presented in Table.2 The values for the specific gravity of the aggregates was 2.65 for both the coarse and fine aggregates. The calculated values of the fineness modulus of the sand sample was 2.09, while that of coarse aggregate was 2.13, a value less than that of cement (3,15) as provided by Neville, (2006). The moisture content of the coarse aggregate varies from 0 to 2 % while that of fine aggregate varies from 0 to 10 %. (ACI EI-07-2007), therefore it can be concluded that the fine and coarse aggregates were uniformly graded and suitable for used in concrete.

Table.2: Physical properties of the aggregates

Material Characteristics	Fine aggregates	Coarse aggregates
Fineness modulus	2.09	2.13
D60	1.18	0.9
D10	0.27	0.3
Cu	4.37	3.00
Specific gravity	2.65	2.65
Moisture content	0.74	2.20

Physical properties of bamboo leaf ash blended cement

The physical properties of the bamboo leaf ash blended cement are presented in Table.3. As observed from Table 3. The result of the fineness test expressed as % retained on sieve 45µm sieve were 34 %, 31.5 %, 30.0 %, 28.5 %, 27.0 % for BLA content of 0 %, 5 %, 10 %, 15 %, and 20 % respectively. Therefore, the parameters decreases from 34.0 % at 0 % to 27.0 % at 20 % BLA replacement. The fineness test shows that the blended cement were finer than the control. This revealed that the higher the BLA content in the blended cement the lower the residue retained on the sieve. All the cement satisfied the BS EN 196:6 (1992).

Table.3: Physical properties of BLA blended cement

Properties	BLA content (%)				
	0	5	10	15	20
Fineness (% retained on 45µm sieve)	34.0	31.5	30.0	28.5	27.0
Soundness (mm)	0.90	1.20	1.60	2.00	2.50
Consistency (%)	26.72	28.70	30.72	32.04	37.56
Initial setting time (minutes)	96	92	104	114	152
Final setting time (minutes)	201	152	225	240	320

The Table also revealed that the soundness of the cement ranged between 0.90 and 2.50mm for replacement levels of 0 % to 20 %. These values are lower than the 10mm limiting value recommended by NIS 439; 2000 and BS EN 197-1:2009. Hence blended cement did not show any appreciable change in volume after setting. The consistency increases from 26.72 % to 37.56 % as BLA content increases from 0% to 20 %. The quantity of water required for a standard consistency was noted to increase as the BLA content increased. This can be attributed to the finer particle sizes of blended cement as much water was required for proper lubrication. Table 5.3 depicts the various percentage replacement. The setting times increased with increase in the amount of bamboo leaf ash. The initial setting time increased from 1 hour 36 minutes at 0 % replacement to 2 hours 32 minutes at 20 % replacement while the final setting time increased form 3 hours 21 minutes at 0 % replacement to 5 hours 20 minutes at 20 % replacement. All the cement satisfy the NIS 439: 2000 and BS EN 197-1: 2000 requirements of 45 minutes minimum initial setting and maximum of 10 hours final setting as spelt out by NIS 439: 2000 and 375 minutes maximum specified for final setting time by ASTM C150. BS EN 197-1:2000.were equally satisfied by all the cement. The variation of setting times with percentage BLA replacement increased. As a result of measured setting time the hydration process was slowed down in consonance with the views of Hossain (2003). The slow hydration means low rate of heat development which is one of the notable characteristics of pozzolanic cements. This is of great importance in mass concrete construction where low heat development is very essential as it reduces thermal stress.

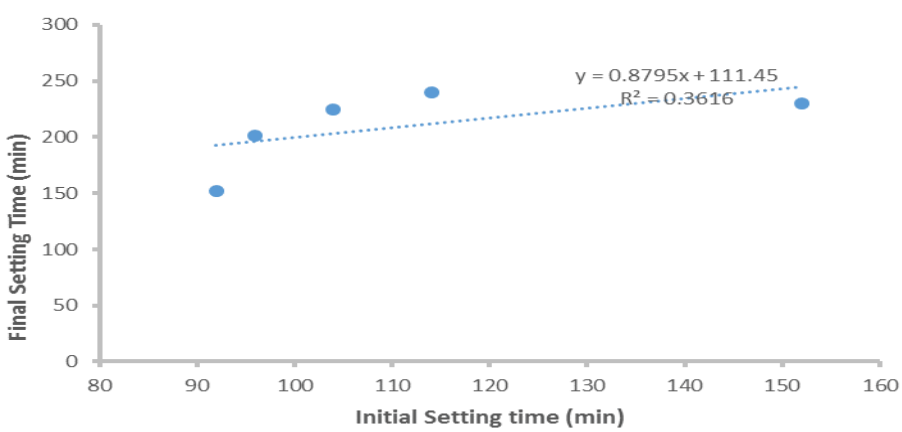

Fig. 1. Relationship between Initial and Final Setting Times of BLA Blended Cement

A plot of initial setting time against the final setting time as shown in fig, 1.indicate a strong relationship between the parameters as the coefficient of correlation was calculated to be R^2 = 0.3616 with an equation of final setting time being y = 0.8795x + 111.45

From where the estimate of the final setting time can be deduced when an initial setting time is known, where y = final setting time, x = initial setting time

Chemical composition of BLA blended cement

Table 4 shows the chemical composition of BLA blended cement.. The cement satisfied the chemical composition as spelt out by NIS 441-1:2003 and BS EN 197-1: 2009. From table 4. The percentages of the silica content increased from 62.38 % for 5 % BLA replacement to 63.58 for 20 % BLA content representing about 1.89 % increase in the percentage of silica content of BLA blended cement. It was also observed that alumina and ferric oxide increased from 3.23 % to 3.45 % and 1.00 % to 1.07 % for 5 % and 20 % BLA contents respectively. Similar trends were observed with magnesium oxide MgO which increased from 0.56 % at 5 % BLA content to 0.83 % at 20 % BLA content. The calcium oxide CaO content decreases from 27.13 % for 5 % BLA to 26.61 % for 20 % BLA replacement. The minor compounds of Na_2O and K_2O, known as alkalis, ranges from 0.20 % to 0.19 % for Na_2O and 0.43 to 0.40 for K_2O for 5 % and 20 % of BLA content.. These values are lower than those for the control, which are 0.21 for Na_2O and 0.97 for K_2O respectively. However, the limiting value of 0.4 % to 1.3 % of the combined alkalis content was satisfied for both the Portland cement and the blended cements.

The loss on ignition (LOI) of the BLA blended cement was higher than that of the control. There was an increase in the LOI of the blended cement from 0.11 % at 5 % BLA content to 0.18 % at 20 % BLA content as against 0.09 % content for the control. The increase in the LOI depicts the presence of much carbon in the blended cement which could adversely affect the binding properties of the cement. However, the LOI content in all the cements was within the limit of 5 % recommended by BS EN 197-1: 2009.

Table 4: Chemical composition of BLA-blended cements

Elemental Oxide (%)	BLA Content (%)				
	0	5	10	15	20
SiO_2	62.03	62.38	63.40	64.07	68.58
Al_2O_3	3.23	3.37	3.40	3.92	3.45
Fe_2O_3	1.00	1.02	1.04	1.06	1.07
CaO	27.41	27.13	26.71	27.01	26.61

MgO	0.54	0.56	0.60	0.81	0.83
SO_3	2.81	2.71	2.74	2.71	1.52
K_2O	0.97	0.43	0.60	0.50	0.40
Na_2O	0.21	0.20	0.18	0.19	0.19
MnO_2	0.20	0.10	0.10	0.05	0.05
P_2O_5	0.16	0.17	0.12	0.10	0.08
TiO_2	0.28	0.19	0.12	0.16	0.14
Cr_2O_3	0.20	0.24	0.25	0.26	0.25
LOI	0.09	0.11	0.14	0.17	0.18

Compressive strength

The percentage of 28-day strength are shown in Table 5 while Figures 2 and 3 show the variation of the compressive strength, with curing age and percentage replacement of BLA blended cement concrete. The compressive strength generally increased with curing age and decreased with increased percentage of BLA in the mixes.

The compressive strength at 7days of curing as presented in Table 5 showed that at all the replacement levels of BLA, the percentage with respect to the 28 day strength ranges between 62.29 % and 76.59 % for the control specimen. Representing about 62.29 % for 0 % replacement and 20 % BLA content having the highest value of 75.63 %. These values satisfied the requirement of normal concrete strength development which is stipulated to be between 50-66 % (Ilston, 1994, BS 8110 part 2, 1985). The results of the experiment showed that a minimum of 68.39 % of the 28-day strength was developed at 5 % BLA replacement level. The compressive strength of the control (0 % BLA replacement) has the highest value at this level. It was observed that the strength factor with respect to ordinary Portland cement decreases with increase in the amount of BLA content. The values of the percentage strength factor with respect to OPC at 7 days curing age were 100 %, 97.31 %, 93.04 %, 85.88 %, 80.79 % for 0 %, 5 %, 10 %, 15 % and 20 % respectively.

Table 5 shows the results of the compressive strength test at 14 days curing age. Figures 2 and 3 are the graphs for the compressive strength based on the average data on the Table 5. The 14 days results showed similar trend to that of 7 the day. The control specimen has strength of 16.67 N/mm^2 which is the highest compared to other specimens. The results of the strength factor for the 14 days hydration were 95.08 %, 88.06 %, 85.90 %, and 73.67 % for, 5 %, 10 %, 15 % and 20 % respectively. These results indicated that BLA blended cement concrete gain strength slowly at early curing age. This is in consonance with the previous findings by Moises *et al* (2012). Also, this is followed by 5 %, BLA with 76.72 % of the 28-day strength. While 10 %, 15 % and 20 % BLA had compressive strength of 14.68 N/mm^2, 14.32 N/mm^2 and 12.28 N/mm^2 representing 83.22 %, 86.11 % and 79.18 % of the 28-day strength respectively.

At 21 days BLA blended cement concrete showed a slight decrease in compressive strength value with respect to the control. The compressive strength for the control and the blended cement ranged between 85.11 % and 87.88 % with the control having 85.11 % of 28-day strength and 20 % BLA content having the least value of 87.88 % of the 28-day strength, this values were higher than the value obtained by (Olofintuyi *et. al.*, 2015).

Table 5 showed the variation of the compressive strength with curing age and percentage replacement of BLA at 28 days hydration. The compressive strengths at this age were 23.31 N/mm^2 and 20.66 N/mm^2 at 0 % and 5 % BLA, while that at 10 %, 15 % and 20 % were 17.64 N/mm^2, 16.63 N/mm^2 and 15.51 N/mm^2 respectively. The values of percentage strength factors with respect to 28 days were 88.63 %, 75.68 %, 71.34 % and 66.54 % at 5 %, 10 %, 15 % and 20 % respectively. These values of the compressive strength at 28 days are higher than the results obtained from previous studies (Utudio, et al. 2015, Ernesto et al. 2011). Which involved characterization and study of pozzolanic behavior between calcium hydroxide and bamboo leaf ash. There was a slight decrease in compressive strength between 10 % and 15 % BLA replacement. For the 28 days strength. This could be attributed to the fact that pozzolanic reaction depends on the release of calcium hydroxide from cement hydration. With compressive strength up to 17.64 N/mm^2 obtained at 10 % replacement. Therefore BLA can be used effectively up to 10 % replacement level in BLA/OPC for medium grade concrete

At 60 days of curing, the control specimen achieved 108.84 %, of the 28 days strength for the control while 109.18 %, 105.78 %, 106.13 % and 106.38 % was achieved at 0 %, 5 %, 10 %, 15 % and 20 % BLA respectively. This is in accordance with (Solomon-Ayeh 2009).and (Umoh, and Ujene 2014) that reported 10 % replacement of OPC by calcining BLA gives a satisfactory results for normal concrete.

The results at 120 days indicated that for all the mixes there was continuous increase in strength, indicating that there was both hydration and pozzolanic reactions. The 5 % BLA had higher rate of development than the control. Nuran and Mevlut (2000) also reported a value of up to 20 % replacement as satisfactory for a blended cement concrete.

180 days of curing improved the strength of BLA blended cement concrete. The control attained 112.40 % of 28 days strength while 5 %, 10 %, 15 % and 20 % attained 118.44 %, 120.58 %, 118.34 % and 123.81 % of 28 days strength representing 24.47 N/mm^2, 21.27 N/mm^2, 19.68 N/mm^2, and 20.59 N/mm^2, respectively. 15 % of BLA blended cement concrete had similar strength up to 118.34 % of 28 days strength (19.68 N/mm^2) attainment by 15 % BLA in

blended cement concrete at 180 days curing It means that where later age strength is required at 180 days hydration period. 15 % replacement of cement with BLA is adequate.

At 210 days there was a continuous and significant increase in the rate of strength development. The strength of BLA blended cement concrete was higher than that of control, indicating long term strength development as the strength of BLA blended cement at 5 % was 26.47 N/mm^2, in which there was no significant difference from the strength of the control which had a strength of 27.31 N/mm^2. This can be attributed to the fact that quantity of calcium hydroxide liberated from cement is adequate to be consumed by the pozzolanic reaction

The result of the compressive strength reflects that the rate of strength development of BLA blended cement concrete was slow at early curing ages but faster at later ages, unlike the strength development of the control (i.e. 0 % BLA normal concrete) which accelerates at the initial stage and then decelerates after 28 days. These results corroborate earlier findings on pozzolan cement concrete (Raheem 2006, Hassan 2006, Antiohos *et al*., 2005, and Kim *et al.*, 2003). This implies that BLA blended cement concrete is not advisable for use when early strength is required, rather it is mostly applicable for structures requiring long term strength development. This could be inferred that the strength development of BLA blended cement concrete is a function of curing age and percentage of BLA content.

Table 5.5: Compressive strength of BLA blended cement concrete specimens

Curing age (days)	BLA content (%)	mean compressive strength	strength factor (%)	percentage wrt 28 day strength (%)
7	0	14.52	100.00	62.29
	5	14.13	97.31	68.39
	10	13.51	93.04	76.59
	15	12.47	85.88	74.98
	20	11.73	80.79	75.63
14	0	16.67	100.00	71.51
	5	15.85	95.08	76.72
	10	14.68	88.06	83.22
	15	14.32	85.90	86.11
	20	12.28	73.67	79.18

21	0	19.84	100.00	85.11
	5	18.21	91.87	88.14
	10	16.84	84.88	95.47
	15	15.50	78.13	93.21
	20	13.63	68.70	87.88
28	0	23.31	100.00	100.00
	5	20.66	88.63	100.00
	10	17.64	75.68	100.00
	15	16.63	71.34	100.00
	20	15.51	66.54	100.00
60	0	24.24	100.00	103.99
	5	21.73	89.65	105.18
	10	18.66	76.98	105.78
	15	17.65	72.81	106.13
	20	16.53	68.19	106.58
120	0	25.37	100.00	108.84
	5	21.90	86.32	106.00
	10	19.36	76.31	109.75
	15	18.64	73.47	112.09
	20	17.51	69.02	112.90

Table 5: Contd Compressive strength of BLA blended cement concrete specimens

Curing age (days)	BLA content (%)	mean compressive strength	strength Factor (%)	percentage wrt 28 day strength (%)
180	0	26.20	100.00	112.40
	5	24.47	93.40	118.44
	10	21.27	81.18	120.58
	15	19.68	75.15	118.34
	20	18.52	70.68	119.41
210	0	27.31	100.00	117.16
	5	26.47	96.92	128.12

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10	22.33	81.77	125.59
15	20.59	75.39	123.81
20	19.61	71.81	126.44

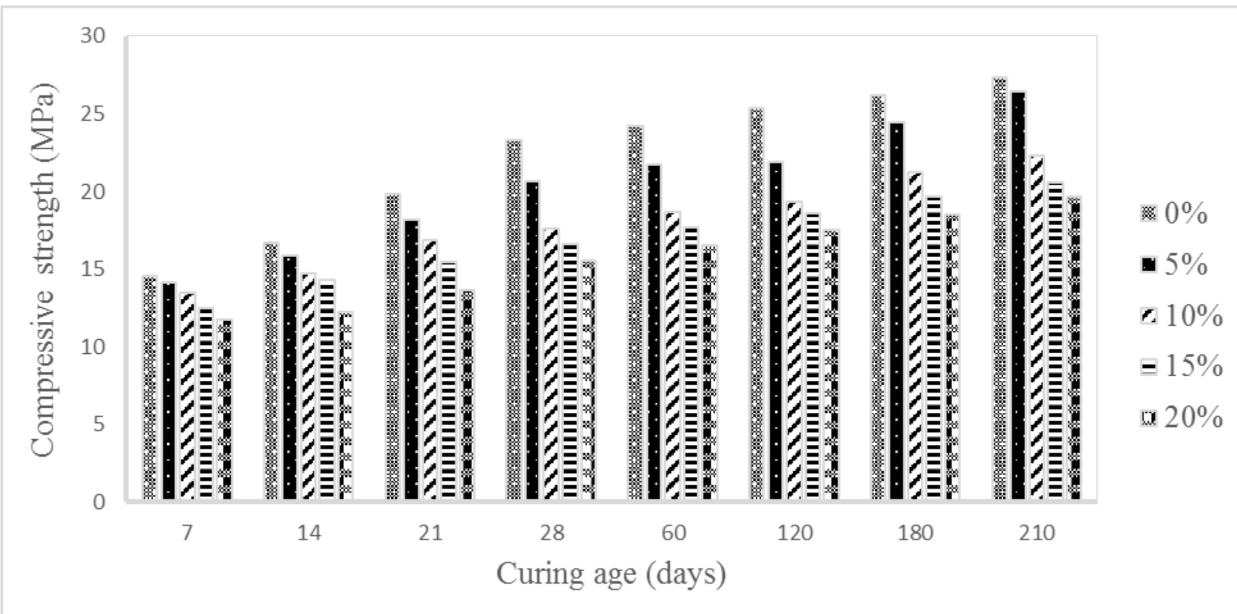

Fig. 2: Compressive strength of BLA blended cement concrete for different curing ages

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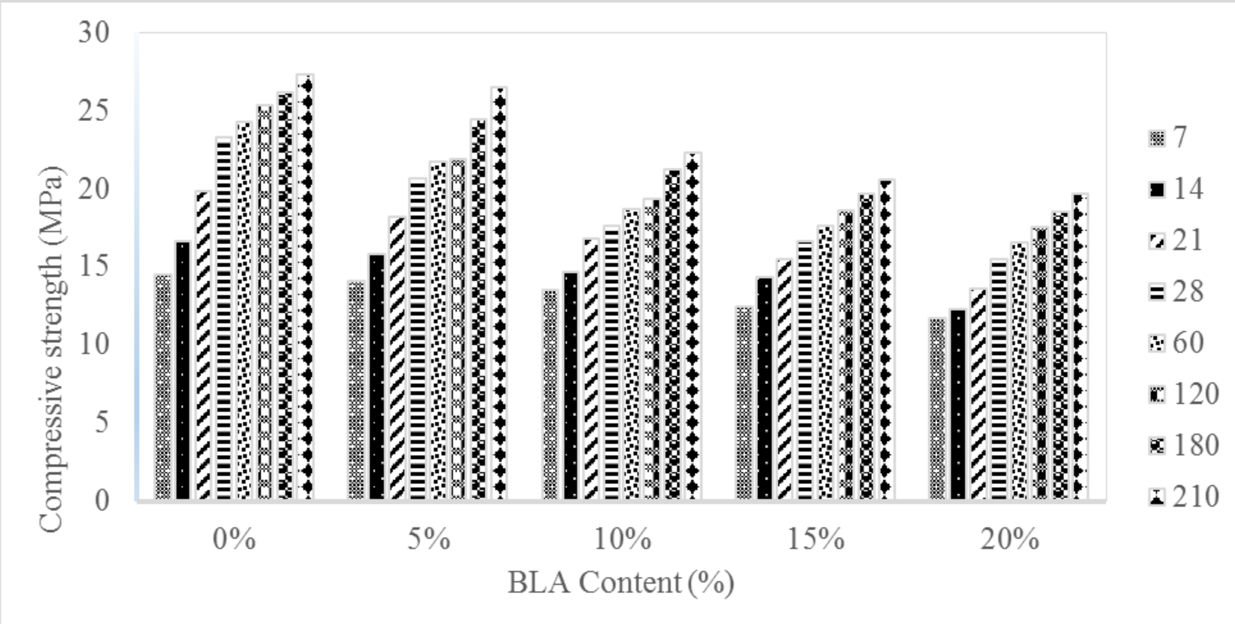

Fig. 3: Compressive strength of BLA blended cement concrete for different percentage of BLA content

Tensile splitting strength

The variation of tensile strength with respect to concrete age for concrete containing 0%, 5%, 10%, 15% and 20% BLA content are presented in Table 6. The rate of strength gained as shown in Table 6. indicates that Tensile splitting strength of the conventional concrete (i.e. Control; concrete without bamboo leaf ash substitution) is higher than that of bamboo leaf ash concrete. It was also observed that Tensile splitting strength decreases with increase with bamboo leaf ash content from 0% to 20%. Figures. 4 and 5 indicates a systematic decrease in tensile strength with increase in BLA content. It was observed that the presence of BLA was not significance at 15 % and 20 % with the strength of the control exceeding that of BLA. The values of the splitting tensile strength at 7, 14, 21, 28, 60, 120, 180 and 210 days were 2.06 N/mm^2, 2.27 N/mm^2 , 2.46 N/mm^2, 2.86 N/mm^2, 2.98 N/mm^2, 3.00 N/mm^2, 3.24 N/mm^2, 3.90 N/mm^2, respectively representing 72.03 %, 79.37 %, 86.01 %, 100.00 %, 104.20 %, 108.04 %, 113.29 % and 136.36 % of the strength at 28 days respectively while the values of 20 % BLA were 1.89 N/mm^2, 2.00 N/mm^2, 2.26 N/mm^2, 2.79 N/mm^2, 2.83 N/mm^2, 2.99 N/mm^2, 3.13 N/mm^2, and 3.70 N/mm^2, representing 66.31 %, 71.68 %, 81.00 %, 100.00 %, 101.43 %, 107.17 %, 112.19 %, 132.62 % of the 28 days strength. Whereas that of the control (i.e. 0 % BLA) were

2.49 N/mm^2, 2.70 N/mm^2, 2.95 N/mm^2, 3.24 N/mm^2, 3.39 N/mm^2, 3.65 N/mm^2, 3.86 N/mm^2, 4.27 N/mm^2, representing 76.85 %, 83.33 %, 91.05 %, 100.00 %, 104.63 %, 112.65 %, 119.14 %, 131.79 % for 7, 14, 21, 28, 60, 120, 180 and 210 days respectively. This trend agrees with the result reported by (Tasdemirr, *et el.* 1997); (Khatip and Hibbert, 2005). The trend indicates a general increase in tensile splitting strength as the curing age increases and decreases as the BLA content increases.

Also it was observed that the rate of increase in strength is relatively low as compared with the rate before 28 days. This is in line with expectation for concrete and those containing pozzolanic material in general. It can be concluded from the above result that the improvement of tensile splitting strength of concrete with the incorporation of BLA is effective with 5 % replacement of the cement with BLA. The improvement in tensile splitting strength at early age and lower BLA (5 % content) replacement could be attributed to the initial filling of the voids by BLA at higher levels of BLA (i.e. > 5 %) substitution, the voids must have been filled while the excess cause reduction in strength. This finding was reported by Bhanja and Sngupta (2002), which stated that initial filling of voids by silica fume significantly improves the tensile strength, but at higher levels, the improvement decreases as shown in Figures 6.and 7.

Table 7. Tensile strength of BLA blended cement concrete at various curing ages

Curing age (days)	BLA content (%)	mean tensile strength	strength factor (%)	percentage wrt 28 day strength (%)
7	0	2.49	100.00	76.85
	5	2.38	95.58	76.28
	10	2.31	92.77	74.52
	15	2.06	82.73	72.03
	20	1.85	74.30	66.31
14	0	2.70	100.00	83.33
	5	2.47	91.48	79.17
	10	2.42	89.63	78.06
	15	2.27	84.07	79.37
	20	2.00	74.07	71.68
21	0	2.95	100.00	91.05

	5	2.74	92.88	87.82
	10	2.51	85.05	80.97
	15	2.46	83.39	86.01
	20	2.26	76.61	81.00
28	0	3.24	100.00	100.00
	5	3.12	96.30	100.00
	10	3.10	95.70	100.00
	15	2.86	88.27	100.00
	20	2.79	86.11	100.00
60	0	3.39	100.00	104.63
	5	3.32	97.94	106.41
	10	3.13	92.33	100.97
	15	2.98	87.91	104.20
	20	2.83	83.48	101.43
120	0	3.65	100.00	112.65
	5	3.67	90.55	117.63
	10	3.16	86.58	101.94
	15	3.09	84.66	108.04
	20	2.99	81.92	107.17
180	0	3.86	100.00	119.14
	5	3.94	92.07	126.28
	10	3.36	87.05	108.39
	15	3.24	83.94	113.29
	20	3.13	81.09	112.19
210	0	4.27	100.00	131.79
	5	3.90	91.34	125.00
	10	3.83	89.70	123.55
	15	3.90	91.33	136.36
	20	3.70	86.65	132.62

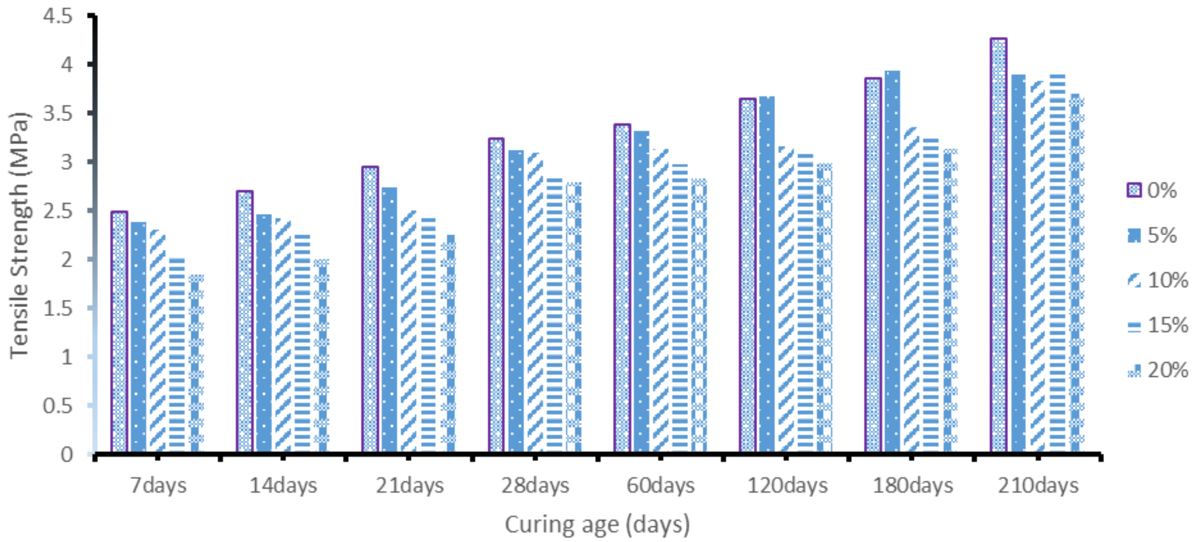

Fig. 6: Tensile strength of BLA blended cement concrete at different curing age

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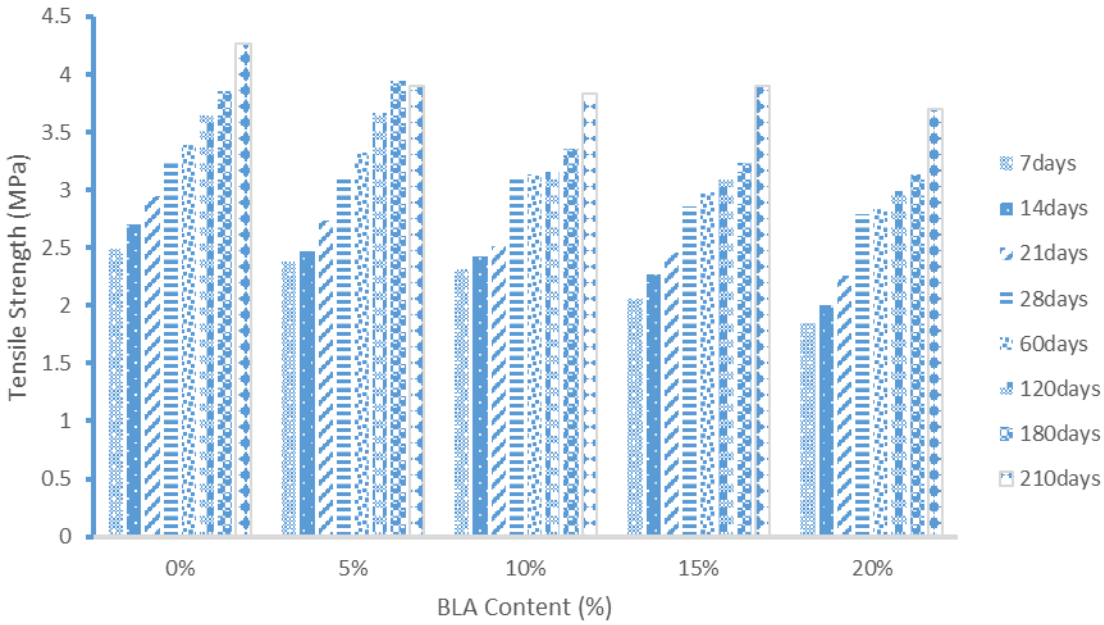

Fig. 7: Tensile strength of BLA blended cement concrete for different percentage of BLA content

Conclusion

From the test carried out to determine the compressive and tensile splitting test of bamboo leaf ash blended cement concrete the following conclusions were drawn

1. BLA of the calcination temperature of 500-700^{o}C investigated had silica content higher than 25 % minimum specified by BS EN 197-1. It was also observed that BLA calcined at 600^{0}C had the highest combined acidic content of 86.31 % and met the requirement of class C pozzolans as stipulated by ASTMC 618.

2. Chemical composition by XRF shows that bamboo leaf ash has a high content of silica of (about 80.33 %). and low content of lime (about 4.4 %). at the calcination temperature of 600^{0}C. The rest oxides are present in low concentrations.

3. The compressive strength of BLA blended cement increases with age but decrease with increase in percentage replacement of cement with BLA. Therefore 10% BLA met the requirement of class C pozzolans at 28days hydration period. While the tensile splitting

strength reached the optimum with 5% BLA. Therefore, the compressive and tensile splitting strengths of BLA blended cement concrete were significantly affected by BLA replacement and curing age.

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