*IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
*e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 6 Ver. II (Nov. - Dec. 2015), PP 36-42*
*www.iosrjournals.org*

# Strength of Bamboo Leaf Ash and Pulverized Burnt Clay Waste Blended Cement Concrete

Kolawole John Temitope[ab], Olusola Kolapo Olubunmi[ac], Ata Olugbenga[ad]
[a]*Department of Building, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria*
[b]kolawolej@oauife.edu.ng, [c]kolaolusola@yahoo.co.uk, [d]oata@oauife.edu.ng

***Abstract:*** *This study examines concrete made from ordinary Portland cement (OPC) blended with bamboo leaf ash (BLA) and pulverized burnt clay waste (PBCW).The binders were characterized, their influence on concrete workability examined, and the blended cement concrete compressive strength investigated. 100 mm concrete cubes specimens were cast according to BS EN 12390-3. The specimens were water cured extensively for 3, 7. 14. 28, 56, 90 and 120 days. Incorporation of BLA and PBCW in cement concrete made it sticky, stiffer and less workable, BLA had a greater influence than PBCW. The higher the composition of BLA and PBCW in the blended cement concrete, the lower the compressive strength at early days of curing, however, at later ages of hydration, their strength surpassed that of the control. Binders with 90% OPC and 10% PBCW; 90% OPC and 10% BLA; 80% OPC, 10% PBCW and 10% BLA performed optimally.*

## I. Introduction

Concrete is the most popular building material with high versatility. Though it has been widely used for centuries, its most important ingredient remains cement. This basic material continues to be in high demand all over the world for construction purposes. The global production of cement per annum is estimated at 11 billion tonnes (Mehta and Monteiro, 2006) while the global demand for cement is forecast to grow by 4.7% annually (Hosseini *et al.*, 2011). In Nigeria, cement consumption growth is projected as 8.5% for 2012 to 2015 (Tosin *et al.*, 2013). The annual demand for cement was estimated as 10 million tonnes as at 2006 and projected to 23.2 million tonnes at 2015. As at 2010, cement consumption in Nigeria was estimated as 16 million tonnes, its demand was 17 million tonnes in 2010 while it became 19 million tonnes in 2012 (Bamidele, 2008; LeadCapital Limited, 2013; Tosin *et al.*, 2013). This increasing rate of production necessitates an annual large amount of waste, capital cost, energy expense and conventional raw materials to be needed, generated and used.

The cement industry produces about 5% of the global anthropogenic carbondioxide ($CO_2$) emissions – the main cause of global warming (Worrell *et al.*, 2001). The cement industry emits about 814 kg to 935 kg of $CO_2$ for every1000 kg of cement produced (Metz *et al.*, 2007). The chemical decomposition of limestone accounts for 40% to 50% of $CO_2$ emissions, and fossil fuel combustion is responsible for the remaining $CO_2$ emissions (Worrell *et al.*, 2001; Initiative, 2002; van-Oss and Padovani, 2003). This causes environmental detrimental phenomenon, hence, continuous attempts are being made to reduce the aforementioned problems, leading to an increasing demand for more environmentally friendly buildings constructed with cheap but durable and environmentally friendly building materials (Ata, 2012). One way of achieving this is to use certain low cost waste materials called pozzolans for partial replacement of Portland cement in concrete production (Schmidt *et al.*, 2004; Dipayan, 2007; Goyal *et al.*, 2008). It can be incorporated either as a mineral admixture or as a component of blended Portland cement. So many pozzolans have been investigated for their suitability in the production of blended cement concrete, these include rice husk ash, bamboo leaf ash, burnt clay waste, saw dust ash, corn cob ash, fly ash, silica fume, metakaolin, blast furnace slag, clinoptilolite, periwinkle shell ash.

Burnt clay are readily available in large quantities as wastes at the production factories of clay products (Garba and Kabir, 2007). These clay wastes are manifested as large continuously mounting heaps which pollutes the environment around production factories. These wastes require alternative usage to become a by-product used as pozzolan. Likewise, bamboo leaf is an agricultural waste in abundance in the tropical rainforest region of Nigeria. Waste recycling is one of the solutions to agricultural wastes. When bamboo leaves are burnt into ash, it can be reused in an economical way as a pozzolan.

Researchers have successfully shown that the utilization of bamboo leaf ash or pulverized burnt clay or lateritic waste can successfully serve as a partial replacement of cement in concrete production but none has dealt with a ternary combination of Portland cement, bamboo leaf ash and pulverized burnt clay waste, hence, this study.

## II. Materials and Methods

All the materials used for this research were sourced from Ile-Ife, Osun state. These materials include cement, sand, granite chippings, bamboo leaf and burnt clay waste. The ordinary Portland cement used was the

Elephant product produced to the requirements of BS EN 197-1. The bamboo leaves were got at Obafemi Awolowo University Campus, Ile Ife, while burnt clay brick waste was sourced from a collapsed St. David Grammar School Building, Ile-Ife.

The bamboo leaves (BL) used for this work were sun dried to reduce moisture content. The dried leaves were openly burnt and allowed to cool on a clean surface. The resulting mass was calcinated at a temperature of 1000$^o$C and sifted to 150 µm. The pulverized burnt clay waste (PBCW) used was grinded/pulverized by milling to powder and sifted to 150 µm size. Chemical composition of the ordinary Portland cement (OPC), BLA and PBCW using X-ray fluorescence was done. Likewise, some physical properties were determined.

The mix proportion adopted in this study was 1:2:4 (cement:sand:granite) which is the ordinary mix used for general reinforced concrete. Ten different mix proportions of cement, bamboo leaf ash and pulverized burnt clay waste were adopted for this work as shown in Table 1. The water/cement ratio (w/c) used was pre-determined through a preliminary investigation. Workability was measured in accordance to the requirements of BS EN 12350-2 for all the blended cement concrete mixes and recorded. A total of 210 concrete cubes of size 100 mm at 3 replicates per level were cast according to BS EN 12390-3 and cured extensively in water for 3, 7, 14, 28, 56, 90 and 120 days. After each curing period, their compressive strength were determined.

**Table 1 Mix proportions of cement, BLA and PBCW**

| S/N | Cement (OPC) | Bamboo Leaf Ash (BLA) | Pulverized Burnt Clay Waste (PBCW) |
|---|---|---|---|
| 1 | 100% | 0% | 0% |
| 2 | 90% | 5% | 5% |
| 3 | 90% | 10% | 0% |
| 4 | 90% | 0% | 10% |
| 5 | 80% | 5% | 15% |
| 6 | 80% | 10% | 10% |
| 7 | 80% | 15% | 5% |
| 8 | 70% | 10% | 20% |
| 9 | 70% | 15% | 15% |
| 10 | 70% | 20% | 10% |

## III. Results and Discussion

### 3.1 Physical and Chemical Properties

Table 2 and 3 depict the chemical composition and physical properties of the materials used for the blended cements. It shows that BLA contains higher silica content than PBCW while PBCW is higher in alumina and ferrite content. As stipulated by BS EN 197-1 (2011), both BLA and PBCW have a silica content higher than 25%. Also, the combined oxide content ($SiO_2$ + $Al_2O_3$ + $Fe_2O_3$) of BLA and PBCW is higher than the minimum of 70% requirement for classes F and N pozzolans stated by ASTM C 618-12a.The specific gravity of OPC is higher than that of BLA, and that of BLA is higher than PBCW (3.14, 2.00 and 1.70 respectively). The bulk density of OPC is higher than that of BLA and PBCW, that of PBCW is higher than that of BLA.

**Table 2 Chemical properties of OPC, BLA and PBCW**

| Elemental oxides (%) | OPC | BLA | PBCW |
|---|---|---|---|
| $SiO_2$ | 16.82 | 72.97 | 52.17 |
| $Al_2O_3$ | 4.35 | 2.85 | 27.86 |
| $Fe_2O_3$ | 2.43 | 2.31 | 13.05 |
| CaO | 60.39 | 4.98 | 0.71 |
| MgO | 1.43 | 1.23 | 0.52 |
| $SO_3$ | 1.64 | 0.55 | 0.00 |
| $K_2O$ | 0.16 | 6.07 | 0.13 |
| $Na_2O$ | 0.02 | 0.00 | 0.00 |
| $Mn_2O_3$ | 0.04 | 0.41 | 0.20 |
| $Cr_2O_3$ | 0.01 | 0.05 | 0.03 |
| $P_2O_5$ | 0.21 | 2.37 | 0.05 |
| $TiO_2$ | 0.24 | 0.41 | 1.40 |
| LOI | 9.84 | 4.20 | 1.68 |
| IR | 1.67 | 80.71 | 88.04 |
| Free Lime | 0.36 | 0.05 | 0.00 |
| $SiO_2$ + $Al_2O_3$ + $Fe_2O_3$ | 23.6 | 78.13 | 93.08 |

**Table 3 Physical properties of OPC, BLA and PBCW**

| Parameters | OPC | BLA | PBCW |
|---|---|---|---|
| Specific gravity | 3.14 | 2.00 | 1.70 |
| Bulk density ($g/cm^3$) | | | |
| Uncompacted | 1.04 | 0.40 | 0.90 |
| Compacted | 1.30 | 0.60 | 1.11 |

### 3.2 Workability

The slump of every wet concrete mix was measured and their averages with water-to-binder ratio presented in Table 3. The table reveals that as the percentage of OPC replacement increases, the quantity of water required for mixing to achieve a slump between 50 to 100 mm increases. That is, the blended cement concrete becomes stiffer and less workable as the level of replacement increases. This may be due to the presence of high silica content. According to Raheem (2006), the higher the silica content of a cementitious material, the higher the water required for hydration. Also, the silica-lime reaction of a pozzolan cement requires more water in addition to water required during hydration of cement (Raheem, 2006). From Table 1 and 2, the silica ($SiO_2$) content of the blended cement will increase as the BLA and PBCW content increased, hence, more water will be required for hydration and silica-lime reaction.

**Table 3 Slump and water/cement ratio for BLA and PBCW blended cement concrete**

| Mix (OPC:BLA:PBCW) | Slump value (mm) | Actual water to binder ratio | Quantity of water to control (%) | Slump value to control (%) |
|---|---|---|---|---|
| 1 (100:0:0) | 50 | 0.5 | 100 | 100 |
| 2 (90:5:5) | 100 | 0.53 | 106 | 200 |
| 3 (90:10:0) | 60 | 0.66 | 132 | 120 |
| 4 (90:0:10) | 50 | 0.63 | 126 | 100 |
| 5 (80:5:15) | 100 | 0.61 | 122 | 200 |
| 6 (80:10:10) | 80 | 0.71 | 142 | 160 |
| 7 (80:15:5) | 100 | 0.71 | 142 | 200 |
| 8 (70:10:20) | 100 | 0.61 | 122 | 200 |
| 9 (70:15:15) | 80 | 0.67 | 134 | 160 |
| 10 (70:20:10) | 100 | 0.70 | 140 | 200 |

From Table 3, levels of replacement with higher BLA content required more water to achieve stated slump than those with higher PBCW content. This can be attributed to the silica ($SiO_2$) content of BLA (72.97%) which is higher than that of PBCW (52.17%) (Table 2), hence, more water was required for hydration of mixes containing higher content of BLA than for PBCW. Table 4 shows the correlation analysis of the workability parameters and the factors (OPC, BLA, PBCW contents) influencing it. The table corroborates further that BLA has the highest positive correlation coefficient with water/cement ratio while OPC has the highest negative correlation coefficient with the slump. That is, as explained earlier, BLA has the strongest influence on the quantity of water required for mixing the blended cement concrete (water/cement ratio); similarly, OPC has the strongest influence on the slump of the wet blended cement concrete.

**Table 4 Correlation analysis of workability parameters**

| | OPC | BLA | PBCW | w/c | slump |
|---|---|---|---|---|---|
| OPC | 1 | | | | |
| BLA | -0.78446 | 1 | | | |
| PBCW | -0.78446 | 0.230769 | 1 | | |
| w/c | -0.6288 | 0.748016 | 0.238531 | 1 | |
| slump | -0.67054 | 0.565267 | 0.486758 | 0.243923 | 1 |

### 3.3 Compressive strength

The results of the compressive strength for bamboo leaf ash (BLA) and pulverized burnt clay waste (PBCW) blended cement concrete cubes at 28 days of curing are presented in Table 5. Generally, the compressive strength increases with curing age and decreases with increase in bamboo leaf ash and pulverized burnt clay waste content. At 3 days of curing, the control (mix 1) attained 53.5% of the target strength (25 $N/mm^2$), this is closely followed by mix 4 (10% PBCW) with 53.3% of the target strength and the next is mix 3 (10% BLA) with 33.9% of the target strength. According to Domone and Illston (2010), at 3 days of curing, the expected strength of concrete is 40% - 65% of the 28 days target strength. Only mix 1 and 4 satisfied this condition.

The results at 7 days of curing reveal that the control (0% BLA and 0% PBCW) attained 70.9% of the 28 N/mm$^2$ target strength, it therefore satisfied the requirement of normal concrete strength development of 66% as stipulated by BS 8110-2 for 7 days of curing. Mix 4 (10% PBCW) reached 63.7% of the target strength and closely followed by 10% of BLA that attained 44.5% of the target strength. Mix 2 which has both BLA and PBCW content (5% BLA and 5% PBCW) achieved 42.4% of the target strength at 7 days of curing. Mixes 1 and 4 satisfied 60% - 80% percentage attainment of concrete target strength as specified by Domone and Illston (2010); similar trend as that of 3 and 7 days of curing was observed for 14 days of curing – control (98.7%), level 4 (77.1%), level 3 (56.5) and level 2 (55.7).

At 28 days of curing, the control specimen achieved 116.7% of the target strength while mixes 4, 3 and 6 achieved 100.3%, 73.1% and 72.0% of the target strength respectively. Therefore, blended cement concrete containing 10% of PBCW satisfied the 25 N/mm$^2$ target strength. This is in accordance with Solomon-Ayeh (2009) and Ojo-Olotu (2012) that reported 10% replacement of OPC by calcined ground clay and PBCW respectively as giving satisfactory results for normal strength concrete. Ojo-Olotu (2012) stated a compressive strength of 28 N/mm$^2$ at 28 days of water curing for a blended cement concrete containing 10% PBCW. Vejmelkova *et al.* (2012) and Bektas *et al.* (2009) reported a higher value of 20% fine-ground ceramics and 25% ground clay bricks (GCB), respectively in blended cement concrete producing comparable strength values to that of the control. Nuran and Mevlut (2000) also reported a value of up to 35% replacement as satisfactory, however, the study was on blended cement mortars and not concrete.

As revealed, 56 days of curing improved the strength of BLA and PBCW blended cement concrete. The control attained 121.3% of the target strength while level 3, 4 and 5 attained 100.7%, 118.9% and 99.7% respectively. Level 4 (10% PBCW) of blended cement concrete has similar strength to 116% of target strength (25 N/mm$^2$) attainment by 10% PBCW in blended cement concrete at 60 days of curing reported in Ojo-Olotu (2012). The strength value of 25.2 N/mm$^2$ of level 3 (10% BLA) is higher than that reported by Oni (2012) as 21.73 N/mm$^2$ at 10% of OPC replacement with BLA at 60 days of curing. 90 days of curing improved further the compressive strength of the blended cement concrete. Replacements level 1 to 6 have strength higher than the target strength. In fact, mixes 3 and 4 have strengths higher than that of the OPC concrete (control) while mix 5 has approximately the same strength as that of the control. At 120 days of curing, the same phenomenon occurred with mixes 1 to 6 surpassing the target strength; levels 3 and 4 surpassing the control strength while levels 2 and 5 have approximately the same strength as the control.

All these trends attest to the established fact that pozzolanic blended cement concrete have slow strength development at early ages but out-perform ordinary concrete at later ages (Khatib and Hibbert, 2005; Bui *et al.*, 2005). It can be concluded that ordinary Portland cement can be replaced by 10% PBCW (level 4) to make blended cement concrete with no undesirable reduction in strength (ASTMC 618-12), especially for normal reinforced concrete. For mass concreting, OPC can be replaced by 10% BLA (level 3) or 5% BLA + 10% PBCW (level 5) or 10% BLA + 10% PBCW (level 6). Mix 6 (80% OPC + 10% BLA + 10% PBCW) would be better as ideal replacement for mass concreting. None of the ternary combinations performed favourably to have similar strength as that of the control at 28 curing days probably because BLA and PBCW have no adequate lime content to make them serve as supplementary cementitious material to the used cement. The lesser comprehensive strength recorded for BLA may be due to higher content of less reactive crystalline silica ($SiO_2$) than highly reactive amorphous silica.

**Table 5 Compressive strength of BLA and PBCW blended cement concrete cubes**

| Curing age (days) | Mix | Compressive strength (N/mm$^2$) 1 | 2 | 3 | Mean compressive strength (N/mm$^2$) | Percentage of target strength (%) |
|---|---|---|---|---|---|---|
| 3 | 1 | 13.4 | 12.6 | 14.1 | 13.4 | 53.5 |
| | 2 | 8.0 | 7.3 | 14.1 | 7.8 | 31.1 |
| | 3 | 7.4 | 7.4 | 8.6 | 8.5 | 33.9 |
| | 4 | 14.4 | 12.4 | 13.2 | 13.3 | 53.3 |
| | 5 | 6.0 | 5.0 | 7.0 | 6.0 | 24.0 |
| | 6 | 7.8 | 8.2 | 8.0 | 8.0 | 32.0 |
| | 7 | 4.8 | 4.2 | 4.5 | 4.5 | 18.0 |
| | 8 | 4.4 | 3.2 | 3.6 | 3.7 | 14.9 |
| | 9 | 5.6 | 6.1 | 5.0 | 5.6 | 22.3 |
| | 10 | 3.4 | 3.6 | 3.2 | 3.4 | 13.6 |
| 7 | 1 | 17.0 | 17.4 | 18.8 | 17.7 | 70.9 |
| | 2 | 10.6 | 9.8 | 11.4 | 10.6 | 42.4 |
| | 3 | 10.8 | 11.4 | 11.2 | 11.1 | 44.5 |

| Curing age (days) | Mix | Compressive strength ($N/mm^2$) | | | Mean compressive strength ($N/mm^2$) | Percentage of target strength (%) |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| 7 | 4 | 16.2 | 15.0 | 16.6 | 15.9 | 63.7 |
| | 5 | 9.0 | 11.0 | 10.4 | 10.1 | 40.5 |
| | 6 | 10.5 | 9.0 | 10.0 | 9.8 | 39.3 |
| | 7 | 7.0 | 9.4 | 7.6 | 8.0 | 32.0 |
| | 8 | 4.5 | 5.6 | 6.0 | 5.4 | 21.5 |
| | 9 | 7.6 | 7.8 | 8.6 | 8.0 | 32.0 |
| | 10 | 4.5 | 5.6 | 4.0 | 4.7 | 18.8 |
| 14 | 1 | 24.0 | 24.0 | 26.0 | 24.7 | 98.7 |
| | 2 | 13.6 | 12.8 | 15.4 | 13.9 | 55.7 |
| | 3 | 14.8 | 13.6 | 14.0 | 14.1 | 56.5 |
| | 4 | 18.0 | 19.0 | 20.8 | 19.3 | 77.1 |
| | 5 | 13.4 | 12.5 | 12.8 | 12.9 | 51.6 |
| | 6 | 12.8 | 11.0 | 14.0 | 12.6 | 50.4 |
| | 7 | 10.4 | 9.2 | 10.0 | 9.9 | 39.5 |
| | 8 | 9.2 | 10.2 | 10.0 | 9.8 | 39.2 |
| | 9 | 12.0 | 13.2 | 11.8 | 12.3 | 49.3 |
| | 10 | 9.2 | 9.6 | 8.4 | 9.1 | 36.3 |
| 28 | 1 | 29.0 | 30.5 | 28.0 | 29.2 | 116.7 |
| | 2 | 18.4 | 15.0 | 16.0 | 16.5 | 65.9 |
| | 3 | 20.8 | 17.0 | 17.0 | 18.3 | 73.1 |
| | 4 | 26.2 | 25.0 | 24.0 | 25.1 | 100.3 |
| | 5 | 13.0 | 17.4 | 15.8 | 15.4 | 61.6 |
| | 6 | 15.0 | 18.0 | 21.0 | 18.0 | 72.0 |
| | 7 | 13.0 | 14.6 | 13.6 | 13.7 | 54.9 |
| | 8 | 11.0 | 12.0 | 11.5 | 11.5 | 46.0 |
| | 9 | 13.0 | 14.5 | 14.3 | 13.9 | 55.7 |
| | 10 | 10.0 | 11.0 | 12.2 | 11.1 | 44.3 |
| 56 | 1 | 30.5 | 30.0 | 30.5 | 30.3 | 121.3 |
| | 2 | 20.0 | 27.6 | 20.0 | 22.5 | 90.1 |
| | 3 | 26.1 | 24.8 | 24.6 | 25.2 | 100.7 |
| | 4 | 30.0 | 29.2 | 30.0 | 29.7 | 118.9 |
| | 5 | 25.5 | 23.5 | 25.8 | 24.9 | 99.7 |
| | 6 | 21.2 | 23.6 | 20.6 | 21.8 | 87.2 |
| | 7 | 15.8 | 18.2 | 17.4 | 17.1 | 68.5 |
| | 8 | 13.8 | 16.6 | 15.0 | 15.1 | 60.5 |
| | 9 | 16.4 | 17.8 | 16.8 | 16.8 | 67.2 |
| | 10 | 13.6 | 14.8 | 15.2 | 14.5 | 58.1 |
| 90 | 1 | 30.5 | 31.5 | 31.0 | 31.0 | 124.0 |
| | 2 | 29.0 | 28.5 | 30.0 | 29.2 | 116.7 |
| | 3 | 30.0 | 32.5 | 34.5 | 32.3 | 129.3 |
| | 4 | 31.5 | 35.0 | 34.3 | 33.6 | 134.4 |
| | 5 | 32.0 | 30.5 | 34.3 | 30.7 | 122.7 |
| | 6 | 24.6 | 27.7 | 25.1 | 25.8 | 103.2 |
| | 7 | 21.5 | 24.9 | 27.0 | 24.5 | 97.9 |
| | 8 | 20.4 | 26.3 | 18.9 | 21.9 | 87.5 |
| | 9 | 21.2 | 24.0 | 19.0 | 21.4 | 85.6 |
| | 10 | 16.8 | 18.3 | 18.5 | 17.9 | 71.5 |
| 120 | 1 | 30.5 | 31.5 | 33.0 | 31.7 | 126.7 |
| | 2 | 28.5 | 30.5 | 34.5 | 31.2 | 124.7 |
| | 3 | 32.5 | 36.0 | 31.5 | 33.3 | 133.3 |
| | 4 | 32.5 | 35.8 | 36.5 | 34.9 | 139.7 |
| | 5 | 32.0 | 30.5 | 31.5 | 31.3 | 125.3 |
| | 6 | 29.0 | 30.8 | 26.5 | 28.8 | 115.1 |
| | 7 | 23.1 | 25.9 | 25.8 | 24.9 | 99.7 |
| | 8 | 25.9 | 27.3 | 21.6 | 24.9 | 99.7 |
| | 9 | 20.5 | 23.8 | 23.8 | 22.7 | 90.8 |
| | 10 | 17.5 | 21.3 | 20.8 | 19.9 | 79.5 |

Figure 1 shows the effect of replacement of OPC with BLA and PBCW on the compressive strength of the blended cement concrete cured in water. Generally, the strength decreases as the level of replacement increases. It decreases from the control and then increase from level 2 up to level 4 where it begins to decrease up to level 10 for all curing ages. However, mixes 4 and 6 have higher compressive strength than other levels for 28 days of curing, hence, they may serve as optimal replacements. In Figure 2, as the curing age increases, the compressive strength increases. Mixes of 2, 3, 4, 5 and 6 have their compressive strengths almost equal to or higher than the control at later days of curing.

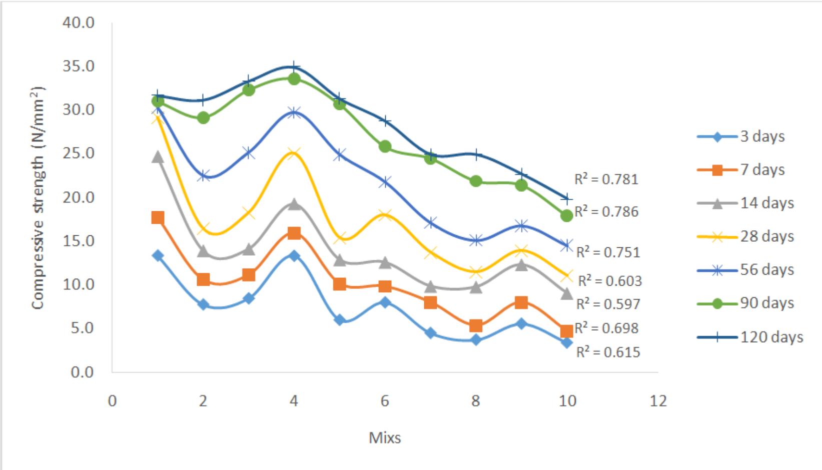


Figure 1 Variation of compressive strength with binder mixes at different curing days

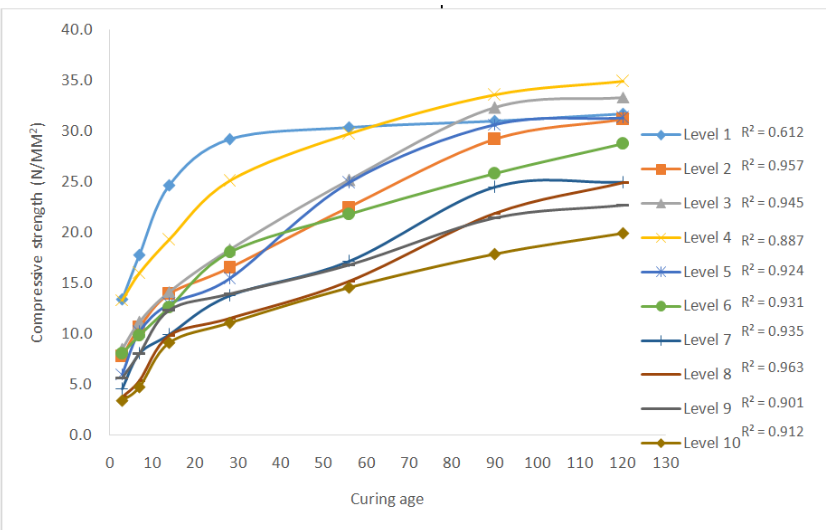


Figure 2 Variation of compressive strength with curing days at different binder mixes

## IV. Conclusion

BLA and PBCW are suitable materials as pozzolan. They met the minimum requirements stipulated by relevant standards and codes. The addition of BLA and PBCW in blended cement concrete reduced its workability, hence, more water was required to make a workable mix. BLA required more water than PBCW. BLA and PBCW blended cement concrete had low compressive strength relative to conventional concrete at early ages of hydration but had higher strength at later ages. However, 10% of PBCW attained the targeted strength of 25 N/mm$^2$ at 28 days of curing, hence, it is regarded as optimum replacement for structural concrete. For concreting when early strength is not paramount, a replacement of 10% PBCW and 5% BLA is regarded as good while for mass concreting, a replacement of 10% PBCW and 10% BLA is adjudged as best For medium performance concrete (e.g. 35 N/mm$^2$) designed for later days of hydration, 10% of PBCW as replacement can be utilized.

## References

[1]. American Society of Testing and Materials (2012). Standard Specification for coal fly ash and raw or calcined natural pozzolan for use in concrete, ASTM C 618-12a.
[2]. Ata, O. (2012). Durability characteristics of laterized concrete exposed to sulphate environments. An unpublished Ph.D thesis, Department of Building, Obafemi Awolowo University, Ile Ife.
[3]. Bamidele, A. (2008). Nigeria's cement manufacturing industry report. LeadCapital Equity Research, LeadCapital Limited, Victoria Island, Lagos, Nigeria.
[4]. Bektas, F., Wang, K. and Ceylan, H. (2008). Use of ground clay brick as a pozzolanic material in concrete. ASTM International Journal, **5**(10).
[5]. British Standard Institution (2009). Testing fresh concrete: slump test, BS EN 12350-2, BSI, London.
[6]. British Standard Institution (2009). Testing hardened concrete: Compressive strength of test specimens, BS EN 12390-3, BSI, London.
[7]. British Standard Institution (2011). Cement composition, specification and conformity criteria for common cements, BS EN 197, Part 1, BSI, London.
[8]. Bui, D.D., Hu, J. and Stroeven, P. (2005). Particle size effect on strength of rice husk ash blended gap-graded Portland cement concrete. Cement and Concrete Composite, **27**, 357-66.
[9]. Dipayan, J. (2007). A new look to an old pozzolan: clinoptilolite-a promising pozzolan in concrete. Paper presented at the 29th annual conference of cement microscopy, Quebec City, Canada.
[10]. Domone, P.L.J. and Illston, J.M. (2010). Construction materials, their nature and behaviour, 4th edn, Spon Press, New York.
[11]. Garba, M.M. and Sa'ad, M.M. (2007). Comparative pozzolanic activity of selected pulverized Nigerian burnt bricks. ATBU Journal of Environmental Technology, **3**(1).
[12]. Goyal S., Kumar, M. and Bhattacharjee, B. (2008). Effect of relative proportion of pozzolana on compressive strength of concrete under different curing conditions. International Journal of Engineering, **2**(1).
[13]. Hosseini, M.M., Yixin, S. and Whalen, J.K. (2011). Biocement production from silicon-rich plant residues: perspectives and future potential in Canada. Biosystems Engineering, **110**(4).
[14]. Initiative, C. S. (2002). The cement sustainability initiative: Our agenda for action. World Business Council for Sustainable Development, Geneva.
[15]. Khatib, J.M. and Hibbert, J.J. (2005). Selected engineering properties of concrete incorporating slag and metakaolin. Construction and Building Materials, **19**, 460-72.
[16]. LeadCapital (2013). Cement manufacturing industry report. LeadCapital Equity Research, LeadCapital Limited, Victoria Island, Lagos, Nigeria.
[17]. Mehta, P.K. and Monteiro, P.J.M. (2006). Concrete: microstructure, properties and materials, 3rd edn, McGraw-Hill, New Delhi.
[18]. Metz, B., Davidson, O., Bosch, P., Dave, R., & Meyer, L. (2007). Climate change 2007 Mitigation of climate change, Intergovernmental Panel on Climate Change, Geneva (Switzerland), (Working Group III).
[19]. Nuran, A. and Mevlut, U. (2000). The use of waste ceramic tile in cement production. Cement and Concrete Research, **30**, 497-9.
[20]. Ojo-Olotu, F. (2012). Durability Performance of Pulverized Burnt Clay Waste blended cement concrete. An unpublished MSc thesis. Department of Building, Obafemi Awolowo University, Ile Ife.
[21]. Oni, Y.O. (2012). Strength and water absorption characteristics of bamboo leaf ash blended cement concrete. An unpublished MSc thesis, Department of Building, Obafemi Awolowo University, Ile-Ife.
[22]. Raheem, A.A. (2006). An investigation of corn cob ash blended cement concrete production. An unpublished PhD thesis. Department of Building, Obafemi Awolowo University, Ile Ife.
[23]. Sathawane, S.H., Vairagade, V.S., and Kene, K.S. (2013). Combined effect of rice husk ash and fly ash on concrete by 30% cement replacement. Procedia Engineering, **51**, 35-44.
[24]. Schmidt, M, Middendof, B, Velmer, C, Geisenhanslueke, C (2004). Blended Cements in Bhatti, J.I., MacGregor, F. and Kosmatka, S.H. (Eds) Innovations in Portland cement manufacturing, Portland Cement Association, Skokie, Illinois. pp. 1107-1148.
[25]. Shannag, M.J. (2000). High strength concrete containing natural pozzolan and silica fume. Cement & Concrete Composites, **22**, 399-406.
[26]. Solomon-Ayeh, K.A. (2009). Opportunity for the increased use of clay pozzolana – the BRRI experience. Building and Road Research Institute (BRRI), Kumasi, Ghana.
[27]. Tosin O., Lawal, D., Obilomo, F. and Ezeoke T. (2013). Nigeria cement sector report, emerging prominence from a deficit past. Equity Research, CardinalStone Partners, 29 October, 2013.
[28]. Umoh, A.A., Alake, O., Babafemi, A.J., Olasunkanmi, O.F. (2013). Assessing the performance of ternary blended cement concrete incorporating periwinkle shell and bamboo leaf ashes. Civil and Environmental Research, **3**(1), 26-35.
[29]. van-Oss, H. G., &Padovani, A. C. (2003). Cement manufacture and the environment Part II: environmental challenges and opportunities. Journal of Industrial Ecology, **7**(1), 93-126.
[30]. Vejmelkova, E., Kulovana, T., Keppert, M., Konvalinka, P., Ondracek, M., Sedlmajer, M. and Konvalinka, P. (2012). Application of waste ceramics as active pozzolana in concrete production. IACSIT Coimbatore Conference, IPCSIT, **28**, 132-6.
[31]. Worrell, E., Price, L., Martin, N., Hendriks, C., and Meida, L.O. (2001). Carbon dioxide emissions from the global cement industry 1. Annual Review of Energy and the Environment, **26**(1), 303-29.