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Low-Cost Construction through the Use of Pulverized Bone Foamed Aerated Concrete (PB-FAC)

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Abstract
Provision of affordable housing especially for low-income earners, which forms the majority of the population, continues to be elusive in the nations of world. The major reason given for this is the high cost of building and construction materials. Concrete and concrete products constitute the major building construction materials. However, cement which is the main binder in concrete production has been identified as the major contributor to increasing high cost of construction. This paper presents the results of investigation conducted to assess the structural suitability and adequacy, as well as affordability of using pulverized bone as partial replacement of cement in the production of foamed aerated concrete (PB-FAC) for low-cost building and construction purposes using Nigeria as a case study. The parameters investigated, in accordance with relevant standards, are: workability, density, compressive strength, tensile strength, and water absorption capacity. Cost comparison with equivalent concrete of equal strength was also carried out. The results showed adequate strength and water absorption capacity, as well as cost reduction of up to 36% at 20% cement replacement with pulverized bone. It is concluded that the use of pulverized bone foamed aerated concrete (PB-FAC) can be used as a strong and affordable building and construction material.
Keywords: Cost, Compressive Strength, Density, Pulverized bone, Tensile Strength, Workability.

1. 0 Introduction

The cost of construction continues to rise in every nation of the world (Turner and Townsend, 2012), including Nigeria, where the construction cost is acknowledged to be the highest (Anyim, 2012). The major construction material is concrete with cement as the main binder. In Nigeria, analysis shows that the cost of cement represents a substantial portion of the total construction cost. With the annual consumption of cement put at 19.5million tonnes (Franklin, 2009), Nigeria requires ₦702Billion at the current rate of ₦1800.00 to meet her cement needs alone for concrete production. This is about 14.78% of her annual budget for the 2012 fiscal year. Obviously the cement needs can only be met at the expense of other developmental projects. Thus cost of cement is the major contributor to high cost of construction. This has made it difficult for the low and medium income earners, which constitutes 65% of Nigeria population, and about 85% of the housing demand for the nation (Aletheia, 2012), to build their own houses. Indeed more than 80% of Nigeria population presently live in a rented houses (Alitheia, 2012). The failure of government to meet the housing needs of her population has been attributed to escalating cost of building materials (Pepple, 2012). The cost of building materials now account for between 60 – 80 percent of the entire cost of housing construction (Njoku, 2012, Taffese, 2012). Thus there is a compelling need , either to develop and find a low cost materials, or to find a suitable replacement to cement, or to develop a concrete that minimizes overall material usage, for construction purposes. Hitherto, Day (1990) postulated that inflated construction costs arises because materials are often chosen, usually for small-scale construction, whose properties far exceed that which is necessary for such construction. As a result materials costs are much greater than they need be.

Many research findings have thus identified low cost materials that could be used as a part of the strategy to bring down the cost of construction. For example, compressed stabilized laterite bricks (CSLBs) was investigated into by Alagbe (2011). He found out that it has a low cost advantage over the sandcrete blocks, and thus concluded that its use in building construction will help bring down cost of construction. Nwoke and Ugwuishiwu, (2011) conducted research on the possibility of using bamboo fibres as replacement to reinforcement in concrete for low cost construction. They found out that the use of bamboo fibres to replacement reinforcement can result in materials suitable for low cost construction purposes.

Raheem et al; (2012) conducted investigations on laterite interlocking blocks. Their results showed 28-day higher strength and lower cost, when compared with conventional sandcrete hollow blocks. They thus concluded that laterite interlocking blocks can be used for economic construction.

This paper evaluates the prospect of using pulverized bone foamed aerated concrete (PB-FAC), a lightweight concrete as an alternative, but affordable construction material. PB-FAC by definition is foamed aerated concrete in which the cement constituent has been partially replaced by pulverized bone. Pulverized bone is obtained from cow bones generated as waste from abattoirs. Falade et al. (2012) have recently investigated the effects of pulverized bone on some properties of cement paste and mortar. They concluded that up to 20% replacement of cement with pulverized bone did not result in significant difference in 28-day compressive strength when compared with specimens without pulverized bone. Development of foamed aerated concrete having industrial and agricultural wastes as components, with structural capability for low cost construction, has engaged the attention of researchers in recent times. But none has investigated into the possible use of pulverized bone in the production of affordable foamed aerated concrete with structural adequacy.

Thus the aim of this work is to determine the suitability of foamed aerated concrete in the production of housing units and lightly-loaded structures by investigating properties such as: workability, density, compressive strength, tensile strength, and water absorption capacity. It also includes cost comparison with normal concrete of the same strength.

2.0 Experimental Procedures

2.1 Materials

2.1.1 Binder

Two types of binder were used: namely cement and pulverized bone.

- Cement

Ordinary Portland cement whose production was in accordance with NIS 444: 2003 Part I and classified as CEM I and /or CEM II of the standard was used as the main binder.

- Pulverized Bone

The cow bones, from which pulverized bone was produced, were obtained from Oko-Oba abattoir in Agege Local government of Lagos State, Nigeria. The bones were dried after they have been separated from all the muscles, flesh, tissues, intestines and fats. The dried bones were then ground or pulverized through a grinder into powder, and the fraction passing through 150μm was later packaged in bags and stored in cool place. It was used as a partial replacement of cement up to 20% as determined Falade et al. (2012)

2.1.2 Sand

Sand dredged from River Ogun at Ibafo town in Ogun State of Nigeria with treated to meet the requirements of BS 882:1992 and BS 1200:1976 were used. In addition, all particles size greater than 2.36mm were sieved out in order to improve the flow and the stability of the foamed concrete (Jones and McCarthy, 2005).

2.1.3 Foaming agent (surfactants)

Having been found by Aldridge (2000) and McGovern (2000) to produce more stable, smaller, and stronger bubble structure which resulted in higher strength foamed concrete compared to synthetic foaming agents, protein-based foaming agent, Lithofoam, sourced from Germany, was used for this project. The dilution ratio for the surfactant consists of one part surfactant to 25 parts of water.

2.1.4 Water

The water used for this work is potable tap water. This is crucial when using a protein-based foaming agent because organic contamination can have an adverse effect on the quality of the foam, and hence the concrete produced.

2.2 *Mix Proportions*

From the literatures (Mindess, et al., 2003 and Litebuilt, 2011), foamed aerated concrete with structural value can be obtained in the density range of 1400 – 1900kg/m^3. A target density 1600kg/m^3 was adopted for which mix proportion was developed. Density being the design criterion in foamed concrete technology. The designed density provided the basis of evaluating the structural behavior of the foamed concrete so produced, with and without supplementing cementing material with pulverized bone. And to achieve desired density and workability with the available local materials, trial mixes are done in this study. It was on the basis of the results from trial mix that the following mix design parameters were adopted: (i) binder (cement and pulverized bone) /sand ratio of 1: 3, (ii) water/Binder (cement and pulverized bone) ratio of 0.5, (iii) foaming agent dilution of 1: 25, (iv) curing methods are by Water and Air (at room temperature) at 7, 14, 21, 28, 60, and 90days. In addition, 125grams of foam concentrate was designed for 50kg of sand. The mix without pulverized bone served as the control. The replacement of cement with pulverized bone in the mix was at interval of 5% up to 20%. The mix constituent proportions are shown in Table (1). The mix proportion of normal concrete of equivalent strength as determined from the trail mix was 1:3:6 (cement: fine aggregate: coarse aggregate) and water/cement ratio of 0.5.

Table 1: Mix Constituent Proportions for the Foam Concrete Mixes

% PB*	Binder (kg)		Sand (kg)	Water for Base Mix (kg)	Foam Concentration	
	Cement	PB*			Mixing Water	Foam (g)
0%	25.00	0.00	75	12.50	4.688	187.5
5%	23.75	1.25	75	12.50	4.688	187.5
10%	22.50	2.50	75	12.50	4.688	187.5
15%	21.25	3.75	75	12.50	4.688	187.5
20%	20.00	5.00	75	12.50	4.688	187.5

*PB – Pulverized bone

2.3 Experimental Investigation

The following tests were conducted on the foamed aerated concrete.

2.3.1 Workability Test

The slump test was carried out in accordance with the provisions of BS EN 12350 Part 2: (2000).

2.3.2 Wet Density Test

The wet density of the foamed concrete was determined according to the BS EN 12350: Part 6 (2000) from the weight of a fresh sample in a container of known volume and weight for each of the batches before it was cast in mould. The density was then calculated by dividing the difference in the weight of concrete-filled container and the weight of the empty container by the volume of the container.

2.3.3 Compressive Strength Test

Compressive strength was measured at measured at 7, 14, 21, 28, 56 and 90 days essentially in accordance with BS EN 12390-3 (2009). Two curing methods were employed: water- and air- curing. The water-cured specimens were tested at saturated state (immediately after removal from curing tank). The strength characteristic of each cube was determined on 600KN Avery Denison Universal Testing Machine at a loading rate of 120KN/min. Three specimens for each of the curing ages were tested to failure by crushing, and the maximum load recorded. The average of the three specimens was then taken and divided by the area of the specimens to obtain the compressive strength. The tests were performed for both the foamed aerated concrete and the normal concrete to ensure that they are of equivalent strength.

2.3.4 Splitting Strength Test

The splitting tensile strength was carried out on the foamed concrete in accordance with the provision BS EN 12390-6 (2009). The specimens were 150 x 150 x 300 cylinders. They were water-cured for 7 days, followed by dry curing until the day of testing (Tex-421-A, 2008). The splitting strengths were determined on 600KN Avery Denison Universal Testing machine at a loading rate of 120KN/min until failure. The splitting tensile strength (T_s) is then calculated as follows:

$$T_s = \frac{2P}{\pi l d} \quad \textbf{(1)}$$

where:

T_s = splitting tensile strength (N/mm^2)
P = maximum applied load (in Newton) by the testing machine
l = length of the specimen (mm)
d = diameter of the specimen (mm)

2.3.5 Modulus Of Rupture.

The flexural strength of foamed concrete was determined by using a simple unreinforced beam subjected to a third point loading. The beam specimens were produced, prepared and tested in accordance with the provisions of BS EN 12390-5 (2009). The text specimens were 150 x 150 x 750mm beams, and they were was tested under the third point loading test. The Modulus of Rupture (M_r) is calculated as:

$$T_s = \frac{PL}{bd^2} \quad \textbf{(2)}$$

where:

M_r = modulus of rupture (MPa)
P = maximum applied load (N)
L = span (mm)
b = average width of the specimen at the failure (mm)
d = average depth of the specimen at the failure (mm)

2.3.6 Water Absorption Capacity

The water absorption capacity tests of foamed aerated concrete with and without pulverized bone were carried out in accordance with provisions of BS 1881 Part 122 (2011).

3.0 Results and Discussions

The discussion is under three headings: Preliminary results, Structural Properties and Cost Analysis.

3.1 Preliminary Results

Because foamed aerated concrete is a free-flowing, self-leveling, and self-compacting material, it is expected to give a collapse slump at lower density. But for the high density that was adopted for this work, it is obvious from visual inspection that the material was of such viscosity, at all the level of replacement that subjecting it to slump test would be appropriate. All the specimens at all cement replacement with pulverized bone displayed true slump, with the slump values varying 25mm and 50mm. This is an indication that the material lost its self-levelling and free-flowing characteristics. It however retained its self compacting properties. However, specimens with pulverized bone had lower slump.

3.2 Structural Properties

The results of investigations into the structural properties of foamed aerated concrete with and without pulverized bone as partial replacement of cement, at the designed density of 1600kg/m^3 are presented in Table (2). The average wet density of the foamed aerated concrete with and without pulverized bone was 1610.51kg/m^3. This is within the tolerance limit of 50kg/m^3 (Jones and McCarthy, 2005) Also the standard deviation of the foamed aerated concrete wet density was 39.65kg/m^3 and the average coefficient of variation was 3.53. These values were considered as acceptable level of repeatability of the specimens (Jones and McCarthy, 2005).

Table 2: 28-Day characteristics of foam concrete at design density of 1600kg/m^3

	0% PB	5% PB	10% PB	15% PB	20% PB
Wet Density (kg/m^3)	1668.28	1627.19	1603.71	1589.69	1563.68
Dry (testing) Density (kg/m^3)					
i) Air-cured	1662.50	1659.23	1648.29	1623.78	1603.24
ii) Water-cured	1689.29	1679.01	1648.29	1631.89	1621.79
Testing Density (kg/m^3)					
i) Air-cured	1662.50	1659.23	1644.23	1623.78	1603.24
ii) Water-cured	1689.29	1679.01	1648.29	1631.89	1621.79
Compressive Strength (N/mm^2)					
i) Air-Cured	15.43	14.23	14.01	13.26	12.98
ii) Water-Cured	13.89	13.24	12.81	12.11	11.34
Tensile Strength (N/mm^2)					
i) Modulus of Rupture	2.53	2.53	2.11	2.11	1.69
ii) Splitting Test	1.63	1.56	1.56	0.99	0.85
Ratio of Modulus of Rupture to Compressive Strength	0.16	0.17	0.15	0.13	0.13
Ratio of Splitting Strength to Compressive Strength	0.11	0.11	0.11	0.08	0.07
Absorption Capacity	1.03	1.69	3.10	3.91	5.01

The average density of the normal concrete of equivalent strength used for this investigation was 2376.60kg/m^3, which is an acceptable value for normal concrete. From the standpoint of structural applications, compressive strength at 28 days of curing is considered to be the index of concrete quality (Wright and Macgregor, 2009). From Table (2), the compressive strength at 28 days curing varies from 15.43N/mm^2 to 12.98N/mm^2 at 0% to 20% replacement levels respectively for air-cured specimens.

These strengths meet the requirement for moderate structural lightweight concrete according to both RILEM (1993) and ACI (2003) classifications. Also the tensile strengths are more than 10% of the compressive strength. The water absorption capacity varies from 1.03% to 5.01% for zero and 20% cement replacement with pulverized bone. This is a measure of its ability to withstand water-based agents of deterioration in the service environmental. Concrete with water absorption capacity of less than 10 is considered good (Neville, 2003). The NIS 87 (2004) requires a water absorption capacity of less than 12 for materials that is to be used for blocks both for load-bearing and non-load-bearing purposes in addition to a compressive strength of 3.45N/mm^2 and above.

3.3 Cost Analysis and Comparison

Having determined from section (3.1) that the foamed aerated concrete with cement replacement with pulverized bone up to 20% is structurally adequate according to the NIS 87 (2004), the next stage is to determine whether there is cost advantage in its usage. In order to carry out the cost analysis, the mix ratio presented in Table (1) was used. The proportion of each constituent by weight of the total weight is calculated as follows:

$$\text{Cement} = \frac{25}{117.38} = 0.21$$

Sand $= \frac{75}{117.38} = 0.63$

Foam $= \frac{0.19}{117.38} = 0.0002$

Water $= \frac{17.19}{117.38} = 0.15$

Now, let us recall that the:

$$\text{Volume of solid} = \frac{\text{Weight of solid}}{\text{specific gravity of solid x 1000}} \quad (3)$$

Thus for the foamed aerated concrete with specific gravity of 1.6, the total weight of 1m^3 foamed aerated concrete from the above relations is 1600kg. And the weight of each constituent in 1m^3 of foamed aerated concrete is calculated as follows:

Weight of cement= 0.21 x 1600 = 336kg
Weight of sand = 0.63 x 1600 = 1008kg
Weight of foam = 0.0002 x 1600 = 0.32kg
Weight of water = 0.15 x 1600 = 240kg

The production cost of foamed aerated concrete used in this work is calculated from the cost of each of the constituents for foamed aerated concrete containing up to 20% cement replacement with pulverized bone, and presented in Tables (3) to (7).

Table 3: Production Cost for the Control Specimens

s/no	Material	Quantity (Kg)	Unit Cost (₦)	Total Cost (₦)
1	Cement	336	1,800/50kg	12096.00
2	Sand	1008	10,000/5000kg	2016.00
3	Foam	0.32	1,230/kg	393.60
4	Water	240	1,200/1000kg	288.00
Labour				1500.000
Production Cost				16293.60

Table 4: Production Cost for 5% cement replacement with pulverized bone

s/no	Material	Quantity (Kg)	Unit Cost (₦)	Total Cost (₦)
1	Cement	319.20	1,800/50kg	11491.20
2	Pulverized Bone	16.80	15/kg	252.00
3	Sand	1008	10,000/5000kg	2016.00
4	Foam	0.32	1,230/kg	393.60
5	Water	240	1,200/1000kg	288.00
Labour				1500.00
Production Cost				15940.20

Table 5: Production Cost for 10% cement replacement with pulverized bone

s/no	Material	Quantity (Kg)	Unit Cost (₦)	Total Cost (₦)
1	Cement	302.4	1,800/50kg	10951.20
2	Pulverized Bone	33.60	15/kg	504.00
3	Sand	1008	10,000/5000kg	2016.00
4	Foam	0.32	1,230/kg	393.60
5	Water	240	1,200/1000kg	288.00
Labour				1500.00
Production Cost				15652.80

Table 6: Production Cost for 15% cement replacement with pulverized bone

s/no	Material	Quantity (Kg)	Unit Cost (₦)	Total Cost (₦)
1	Cement	285.60	1,800/50kg	10281.60
2	Pulverized Bone	50.40	15/kg	756.00
3	Sand	1008	10,000/5000kg	2016.00
4	Foam	0.32	1,230/kg	393.60
5	Water	240	1,200/1000kg	288.00
Labour				1500.00
Production Cost				15235.2

Table 7: Production Cost for 20% cement replacement with pulverized bone

s/no	Material	Quantity (Kg)	Unit Cost (₦)	Total Cost (₦)
1	Cement	268.80	1,800/50kg	9676.80
2	Pulverized Bone	67.20	15/kg	1008
3	Sand	1008	10,000/5000kg	2016.00
4	Foam	0.32	1,230/kg	393.60
5	Water	240	1,200/1000kg	288.00
Labour				1500.00
Production Cost				14882.40

The production cost for normal concrete of equivalent strength used in this investigation is showed in Table 8

Table 8: Production Cost for concrete with mix ratio of 1: 3: 6

s/no	Material	Quantity (Kg)	Unit Cost (₦)	Total Cost (₦)
1	Cement	237.70	1,800/50kg	8557.20
2	Sand	712.98	10,000/5000kg	1425.96
3	Gravel	1425.96	41500/5000kg	11835.47
4	Water	118.85kg	1,200/1000kg	142.62
Labour				1500.00
Production Cost				23461.25

A cost-comparison and weight-comparison between the foamed aerated concrete produced in this work and a normal concrete with a comparable strength (1:3:6) was made, and the result presented in Table (9).

Table 9: Cost Analysis for the Utilization of Foamed Aerated Concrete

Costs	Concrete (1:3:6)	Foamed Aerated Concrete				
		0%PB	5%	10%	15%	20%PB
Total Production Costs (₦)/m^3	23461.25	16293.60	15940.20	15652.8	15235.2	14882.40
Percent Cost Reduction		30.67%	32.17%	33.39%	35.17%	36.67%

From the Table (9), it can be seen that there are benefits to be derived by the use of foamed aerated concrete either alone or with 20% cement substitution by pulverized bone. The cost reduction is about 29.61% and 36.67% respectively for 0% and 20% cement replacement with pulverized bone. In monetarily terms, this can be seen in Table (10).

Table 10: Monetary Benefits from the Use of Pulverized Bone

		Tones (million)	Rate (₦)	Cost (B₦)
1	National Cement Consumption	19.50	1800.00	702.00
2	Consumption assuming 20% substitution with Pulverized bone	15.60	1800.00	561.60
	Potential Annual Savings			140.40

From the above Table (10), Nigeria needs ₦702B (seven hundred and two billion naira) to satisfy her cement needs. But if 20% of her cement needs is replaced with pulverized bone, the cost reduced to ₦561.60 billion (five hundred and sixty one billion and six hundred million naira). The cost reduction is ₦140.40 billion (one hundred and forty billion and four hundred million naira). It can be seen that the use of pulverized bone up to 20% to replace cement in the production of foamed concrete will result in savings in the hundreds of billions naira. Thus the adoption of pulverized bone in the production of foamed aerated concrete is a worthwhile course of action that must be embraced and encouraged and nurtured continuously. Also the use of foamed aerated concrete produced in this study will result in about 30.67% in cost savings per m^3 when compared with normal concrete of equivalent strength. In addition, there is significant reduction material utilization that is between 29.61% and 32.43% respectively for 0% and 20% cement replacement with pulverized bone in relation to the normal concrete.

4.0 Conclusions

From the results of this investigation, the following conclusions can be drawn:

1) The foamed aerated concrete with and without pulverized bone up to 20% as a partial substitute for cement produced in this work satisfied the minimum structural requirements, by all available codes governing lightweight concrete.
2) From the cost analysis, foamed aerated concrete is cheaper than the normal concrete of equivalent

strength.

3) The use of pulverized bone as a partial replacement of cement in the production of foamed aerated concrete will result in significant savings.
4) The foamed aerate concrete produced in this work is structurally adequate and cost effective, and thus recommended for building affordable houses and low-cost construction infrastructure.

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