

## Environmental Benefits of the Structural Use of Pulverised Bone in the Production of Foamed Aerated Concrete

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### Abstract

Disposal of wastes resulting from myriads of human activities continues to be a problem especially in developing nations, where effective and efficient wastes disposal system is lacking. This paper presents the result of the study conducted to investigate the environmental benefits of using pulverized bone - obtained from bones generated as waste from abattoirs and slaughter slabs - in the production of structural foamed aerated concrete. Some of the properties investigated into are consistency, workability, compressive strength, tensile strength, and water absorption capacity. The results showed that foamed aerated concrete containing up to 20% cement replacement with pulverized bone developed adequate strength acceptable to standards, for use for construction purposes. It is thus concluded that the use of pulverized bone in concrete production will help clean the environment of potentially hazardous wastes and bring about a significant reduction in use of non-renewable resources. This finding highlights the opportunity that the foamed aerated concrete production provides a mean of efficient and innovative waste management strategy.

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**Keywords:** compressive strength, environment, tensile strength, pulverized bone, workability.

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### INTRODUCTION

One material that is produced with a degradation effects on the environmental is cement, which is the binding material in concrete. Concrete is the major material for the construction of all civil engineering infrastructure in the built environment. Its demand is estimated to double within the next 30years (EcoSmart, 2012). According to Mehta (1999), cement manufacturing is the largest producer of carbon dioxide (CO<sub>2</sub>), accounting for over 50% percent of all industrial CO<sub>2</sub> emissions. In addition, huge amount of natural resources (sand, granite, etc.) which are not renewable are required in the production of cement. This bothers on consumption and depletion of non-renewable resources which raises a serious environmental concern as the usage of cement continues unabated. Researchers (Salau and Olonade, 201; Yilmak, 2010) have however found out that some industrial waste like fly-ash, and agricultural wastes like cassava peel ash, can be processed and later used as a partial replacement of cement in the production of concrete. This has not only helped to cleanse the environment, but also help to gradually reduce the volume of cement being consumed thus leading to lower usage of natural resources that are needed in the manufacture of cement, reduce CO<sub>2</sub> emissions, and lessening its negative environmental impact.

These industrial and agricultural wastes are also becoming a health and environmental problem especially in the developing nations where technology for efficient waste disposal is lacking. One of such waste, whose generation runs to millions of tonnes in Nigeria, is cow bones from which pulverized bone is obtained (Falade et al; 2012). The present disposal system of burning in open sites and indiscriminate dumping on any site does not augur well for the health of human beings and it also constitutes environmental hazard.

According to Ecosmart (2012), about 30% of cement used globally is needed to be replaced with supplementing cementitious materials to achieve, a zero percent increase in CO<sub>2</sub> emission from cement manufacturing. Such wastes that have been found suitable for the production of concrete are: silica fume, granulated blast furnace slag, fly ash, rice husk ash, palm oil fuel ash, etc. For example, Hussin and Abdullah (2009) worked on palm oil fuel ash (POFA), and concluded that it has a beneficial effect on concrete provided the percentage replacement does not exceed 30%. Givi et al. (2010) researched on rice husk ash (RHA). They showed that rice husk ash increased the setting times, improved workability, and increase the compressive and flexural strengths of concrete. Wilson and Ding (2007) investigated the performance of fly ash in mortar and concrete. Their work indicated that the use of fly ash enhanced the

workability and increased the setting times of cement mortar and concrete. Yilmak (2010) worked on silica fume and observed delayed setting times, increase in water demand and reduction in permeability with the use of silica fume. Salau and Olonade (2011) conducted a research into the pozzolanic potentials of cassava peel ash (CPA) on cement paste and mortar cube specimens. The results showed that CPA retarded the rate of hydration reaction and setting times of cement paste; and at up to 15% replacement of cement with CPA, there were no significant difference in the 90-day flexural and compressive strengths when compared with those of the control samples (specimens without CPA).

Falade et al. (2012) investigated the effects of pulverised 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. A result of study of compressive strength and tensile of foamed aerated concrete containing pulverized bone as a partial replacement of cement was reported by Falade et al. (2013). However, in order to determine the environmental benefits of the structural use of pulverized bone in the production of foamed aerated concrete, further properties need to be investigated, and thereafter take a holistic view of the results of all the properties investigated. This will help determine whether such properties collectively are of a quantum that meets minimum structural requirement established by relevant national standards for foamed concrete application, which will thus serve as an innovative and constructive means to rid the environment of wastes.

The objectives of this work are:

- i) to investigate the workability, density, stability, compressive strength, tensile strength, and absorption capacity properties of foamed aerated concrete containing pulverised bone as a partial replacement of cement.
- ii) to determine whether the properties observed in (i) are structurally sufficient for its application according to relevant standard as a construction material.
- iii) to assess the implication of its usage as a construction material in the built environment

## RESEARCH METHOD

### Materials

The binder used for this work is ordinary Portland cement and the pulverized bone. The 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 was obtained from cow bones, 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 150 $\mu$ m 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). The fine aggregate was sand dredged from River Ogun at Ibafo town in Ogun State of Nigeria with particles passing through sieve size 3.35mm but retained on sieve size 0.150mm in accordance with BS 882:1992 and BS 1200:1976.

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 Litho Foam, sourced from Germany, was used for this project. The dilution ratio for the surfactant consists of one part surfactant to 25 parts of water. Water that is potable tap water was used for this work. 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.

### Mix Proportions

Available literatures (Jones and McCarthy, 2005 and Litebuilt, 2010) revealed that foamed aerated concrete of structural value can be produced at plastic densities of between 1200 and 1900kg/m<sup>3</sup>. A density of 1600kg/m<sup>3</sup> was adopted as the basis for the production foamed aerated concrete used for this work, and subsequent evaluation of its characteristics. Thus a mix proportion that will produce the target plastic density of 1600kg/m<sup>3</sup> ( $\pm$ 100kg/m<sup>3</sup>) was developed. Unlike the normal concrete, density is the design criterion in foamed concrete. 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)

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

### Experimental Procedure

The following structural investigations were conducted on the foamed aerated concrete.

#### ❖ Workability Test

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

#### ❖ 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.

#### ❖ 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 characteristics of each cube were 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.

#### ❖ Splitting Strength Test

The splitting tensile strength was carried out on the foamed concrete in accordance with the provision of Tex-421-A (2008) for lightweight concrete and 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:

$$T_s = 2P/\pi ld \quad (1)$$

where:  $T_s$  = splitting tensile strength (N/mm<sup>2</sup>), P = maximum applied load (in Newtons) by the testing machine, l = length of the specimen (mm), d = diameter of the specimen (mm)

### 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 ASTM C78-02 (2002) and BS EN 12390-5 (2009). The test specimens were 150 x 150 x 750mm beams, and they were tested under the third point loading test. The Modulus of Rupture ( $M_r$ ) is calculated as:

$$M_r = PL/bd^2 \quad (2)$$

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)

### 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).

## RESULTS AND DISCUSSIONS

The results of investigations into the structural properties of foamed aerated concrete with and without pulverised bone as partial replacement of cement, at the designed density of 1600kg/m<sup>3</sup> are presented in Tables 2 – Table 4. 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-day curing varies from 15.43N/mm<sup>2</sup> to 12.98N/mm<sup>2</sup> at 0% to 20% replacement levels respectively for air-cured specimens.

As shown in Table 2, For water-cured specimens, the compressive strength varies from 13.89N/mm<sup>2</sup> to 11.34 N/mm<sup>2</sup> at 0% and 20% replacement levels respectively. This strength meets the requirement for structural lightweight concrete according to both RILEM (1993) and ACI (2003) classifications. RILEM requires a minimum of 3.50N/mm<sup>2</sup> while ACI requires a compressive strength of 7N/mm<sup>2</sup>. Also the tensile strengths are more than 10% of the compressive strength, which qualifies it to be used as highway and roads material. 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 liquid-based agents of deterioration in the domiciled environmental. Concrete with water absorption capacity of less than 10 is considered good (Neville, 2003). The NIS 444 (2003) 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<sup>2</sup> and above.

Table 2: 28-Day characteristics of foamed concrete at designed density of 1600kg/m<sup>3</sup>

	0% PB	5% PB	10% PB	15% PB	20% PB
Wet Density (kg/m <sup>3</sup> )	1668.28	1627.19	1603.71	1589.69	1563.68
Testing Density (kg/m <sup>3</sup> )					
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 <sup>2</sup> )					
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 <sup>2</sup> )					
• Modulus of Rupture	2.53	2.53	2.11	2.11	1.69
• 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

Table 3: 60-Day characteristics of foam concrete at design density of 1600kg/m<sup>3</sup>

	0% PB	5% PB	10% PB	15% PB	20% PB
Wet Density (kg/m <sup>3</sup> )	1668.28	1627.19	1603.71	1589.69	1563.68
Testing Density (kg/m <sup>3</sup> )					
iii) Air-cured	1669.56	1665.75	1651.11	1640.00	1608.35
iv) Water-cured	1713.75	1680.00	1661.25	1656.89	1650.01
Compressive Strength (N/mm <sup>2</sup> )					
iii) Air-Cured	17.96	16.67	15.78	14.67	14.12
iv) Water-Cured	16.78	15.99	15.01	13.98	12.56
Tensile Strength (N/mm <sup>2</sup> )					
• Modulus of Rupture	<b>2.81</b>	<b>2.53</b>	2.53	2.53	2.53
• Splitting Test	<b>2.26</b>	<b>1.98</b>	1.61	1.41	1.41
Ratio of Modulus of Rupture to Compressive Strength	0.15	0.15	0.15	0.15	0.15
Ratio of Splitting Strength to Compressive Strength	0.13	0.12	0.10	0.10	0.10

At both 60 days and 90 days of curing, the properties of the concrete from Table 3 and Table 4 were better than the properties developed at 28-day curing for all levels of cement replacement with pulverized bone. For example, the increase in compressive strength at 60-day curing for air-cured specimens were 15.75%, 17.15%, 12.63%, 10.63%, and 8.78% higher than 28-day specimens respectively for 0%, 5%, 10%, 15%, and 20% cement replacement with pulverised bone. The compressive strength values for 90-day specimens were higher than the 28-day specimens by

16.40%, 17.22%, 12.64%, 10.56%, and 7.85% respectively for 0%, 5%, 10%, 15%, and 20% cement replacement with pulverised bone. The increase of modulus of rupture of 60-day specimens over 28-day specimens were 11.07%, 0%, 42%, 42%, and 49.7% respectively for 0%, 5%, 10%, 15%, and 20% cement replacement with pulverised bone. The same trend was observed for the splitting tensile strength. The splitting strength for 90-day specimens also follows this trend. The overall picture clearly portrayed from the Tables 3 and 4 was that the structural properties improved with curing ages.

Table 4: 90-Day characteristics of foam concrete at design density of 1600kg/m<sup>3</sup>

	0% PB	5% PB	10% PB	15% PB	20% PB
Wet Density (kg/m <sup>3</sup> )	1668.28	1627.19	1603.71	1589.69	1563.68
Testing Density (kg/m <sup>3</sup> )					
v) Air-cured	1671.00	1666.00	1652.00	1641.00	1606.29
vi) Water-cured	1714.00	1690.00	1662.00	1662.01	1655.00
Compressive Strength (N/mm <sup>2</sup> )					
v) Air-Cured	17.96	16.68	15.78	14.66	14.00
vi) Water-Cured	16.90	15.98	15.10	13.00	12.90
Tensile Strength (N/mm <sup>2</sup> )					
• Modulus of Rupture	<b>2.85</b>	<b>2.62</b>	2.63	2.69	2.60
• Splitting Test	<b>2.62</b>	<b>2.33</b>	1.89	1.71	1.73
Ratio of Modulus of Rupture to Compressive Strength	0.15	0.14	0.17	0.18	0.19
Ratio of Splitting Strength to Compressive Strength	0.15	0.14	0.12	0.12	0.12

### Field Applications

On the basis of the results obtained from this work, considering its strength and absorption capacity as measure of its structural adequacy (Wright and Macgregor, 2009), the foamed aerated concrete meets the minimum requirements for the followings applications.

### Block-Walling Applications

With the compressive strength greater than  $3.45\text{N/mm}^2$  and water absorption capacity of less than 12%) set by the Nigerian Industrial Standard NIS 444 (2003) for blocks that are to be used as load-bearing and non-load-bearing purposes, the foamed aerated concrete with partial replacement of cement with pulverised bone up to 20% can be used for applications:

- Low-cost Housing Units and Low-rise Housing Units
- External Skin of Low storey Industrial Buildings and Factory Complex
- Load-bearing and non load-bearing applications in Frame Structure

### For Lightly-Loaded Beam Constructions

For example, for the construction of lintels, tie beams, secondary beams in frame structures and roof beams in low-rise structures.

### For Miscellaneous Civil Engineering Works

Such works include: usage as foundation material in poor soil, bridge repair works, road widening schemes, and ground/soil stabilization works.

## ENVIRONMENTAL BENEFITS OF USING PULVERISED BONE IN FOAMED CONCRETE PRODUCTION

### Removal of Wastes

Cow bones, which are a source of pulverized bone is one of the wastes whose generation is bound to increase especially in developing nations where cow meat is the major source of protein for the population that is projected to increase. The fact that its utilization in the pulverized form, to partially replace cement up to 20% resulted in the production of foamed aerated concrete, with structural characteristics acceptable to relevant standards for construction purposes will result in the following benefits:

- i) An efficient and innovative system of getting rid of waste material that is harmful and hazardous to humans and the environment
- ii) Reduction in the amount of non-renewable resources that goes into the production of cement.
- iii) Reduction in the green house of emission, thus improved environment health
- iv) Turning waste to a productive use in the making of foamed aerated concrete also means economic empowerment. Healthy economic environment for

the human constituent of the built environment result in a sound and healthier environment.

### Reduction in Material Usage

The highest dry density of foamed aerated concrete used for this work is  $1714.00\text{kg/m}^3$  (0% water-cured for 90 days) and lowest was  $1603.24\text{kg/m}^3$  (20% air-cured for 28days). The average is  $1658.62\text{kg/m}^3$ , which in relation to the density of the normal weight concrete of  $2400\text{kg/m}^3$ , is about 30.89% weight reduction. This is a significant reduction in material usage.

## CONCLUSION

From the results of this investigation, the followings are made:

- i) Pulverized bone up to 20% can be used to replace cement in the production of foamed aerated concrete with adequate structural capability.
- ii) The use pulverized bone as a partial replacement of cement in the production of foamed aerated concrete will serve as a means of innovative and constructive disposal of bones generated from our abattoirs, thus riding our environment of potentially harmful wastes.
- iii) The use of pulverized bone as partial replacement of cement in the production of foamed aerated concrete will reduce the amount of cement used, thereby reducing the amount of non-renewable raw materials, energy, and green house emission that are all attendant to the production of cement.
- iv) The use of pulverized bone in the production of foamed aerated concrete wills the economic environment through human empowerment.

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