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A Study on the Compressive and Tensile Strength of Foamed Concrete Containing Pulverized Bone as a Partial Replacement of Cement

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Abstract

In this study, structural properties of foamed aerated concrete with and without pulverized bone were investigated. These properties are: workability, plastic and testing densities, compressive strength, and tensile strength at the design density of 1600kg/m^3. The tensile strength was evaluated by subjecting 150 x 150 x750mm unreinforced foamed concrete beams to flexural test and 150x300mm cylinder specimens were subjected to splitting test. 150mm cube specimens were used for the determination of both the compressive strength and the testing density of the foamed aerated concrete. The plastic density was investigated using a container of known volume, and its workability determined using the slump test. The pulverized bone content was varied from 0 to 20% at interval of 5%. The specimens without the pulverized bone served as the control. At the designed density of 1600 kg/m^3, the results for the control specimens at 28-day curing age are 15.43 and 13.89N/mm^2 for air- and water-cured specimens respectively. The modulus of rupture and splitting tensile strength are 2.53 and 1.63N/mm^2 respectively. The results for specimens with pulverized bone did not differ significantly from the specimens without pulverized bone. From the results of this investigation, it can be concluded that foamed aerated concrete used for this study has potential for structural applications. Also pulverized bone can be used to reduce (partially replace) the quantity of cement used in aerated concrete production; thus ridding our environment of potentially harmful wastes, as well as reduce the consumption of non-renewable resources.

Key Words: Compressive Strength, Density, Modulus of Rupture, Pulverized bone, Splitting Tensile Strength, Workability

1. Introduction

One of the most important components of concrete production is cement. But cement manufacturing is at a great environmental cost. According to Mehta [1], cement manufacturing is the largest producer of carbon dioxide (CO_2) accounting for over 50% percent of all industrial CO_2 emissions. Also huge amount of natural resources 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. On the other hand, 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.

Recent discovery that these wastes can be processed and later used as a partial replacement of cement in the production of concrete is not only helping to cleanse the environment but also gradually reducing the volume of cement being consumed. According to Ecosmart [2], about 30% of cement used globally is needed to be replaced with supplementing cementitious materials to achieve, a zero percent increase in CO_2 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 [3] 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. [4], 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 [5] 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. Yilmaz [6] 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 [7] 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 different in the 90-day flexural and compressive strengths when compared with those of the control samples (specimens without CPA). Falade et al. [8] 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. But the effects of pulverized bone on structural properties of foamed concrete are yet to be investigated.

The objectives of this work are to investigate the structural properties of foamed aerated concrete with and without pulverized bone. These properties are: workability, density, stability, compressive strength, and tensile strength.

2. Experimental Procedures

2.1 Materials

Ordinary Portland cement whose production was in accordance with BS 12:1996 [9] was used as the main binder. 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 pulverized through a grinder into powder, and the fraction passing through 150µm was later packaged in bags and stored in cool dry place. Sand from River Ogun at Ibafo town in Ogun State of Nigeria was used for this work. Particles passing through sieve size 3.35mm but retained on sieve size with 0.150mm aperture in accordance with BS 882:1992 [10] were used. This is because coarser aggregate might settle in a lightweight mix and lead to collapse of the foam during mixing. Protein-based foaming agent was used for this project. The dilution ratio for the surfactant consists of one part surfactant to 25 parts of 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

A mix proportion that will produce the target plastic density of 1600kg/m^3 (±100kg/m^3) was developed; the density being the design criterion in foamed concrete. To date, proper guidelines for mix proportioning of foamed concrete are non-existent. Therefore, to achieve desired density and workability with the available local materials, trial mixes were carried out in this study. It was on the basis of the results from trial mixes 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

The mix constituent proportions for a concrete mixer batch for 20 numbers of 150 x 150 x 150mm cubes are shown in Table 1. All the cube specimens were demoulded 24hrs after casting.

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 – Pulverised bone

The following tests 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), [11].

Wet Density Test: The wet density of the foamed concrete was determined according to the BS EN 12350: Part 6 (2000), [12].

Compressive Strength Test: Compressive strength was measured at 7, 14, 21, 28, 56 and 90 days essentially in accordance with BS EN 12390-3 (2009), [13]. 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 average failure load was recorded. The average failure load of the three specimens was then 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), [14] for lightweight concrete and BS EN 12390-6 (2009), [15]. The specimens were 150 x 150 x 300 cylinders. They were water-cured for 7 days, followed by air curing under ambient condition until the day of testing. The tests were carried out by compressing the cylinders on their sides. 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:

$$T_s = \frac{2P}{\pi l d} \tag{1}$$

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

Modulus of Rupture Test: The flexural strength of foamed concrete was determined by using a simply supported unreinforced beam subjected to a third point loading. 150 x 150 x 750mm beam specimens were tested in accordance with the provisions of BS EN 12390-5 (2009), [16]. Figure 1 shows the third point loading arrangement on a beam specimen.

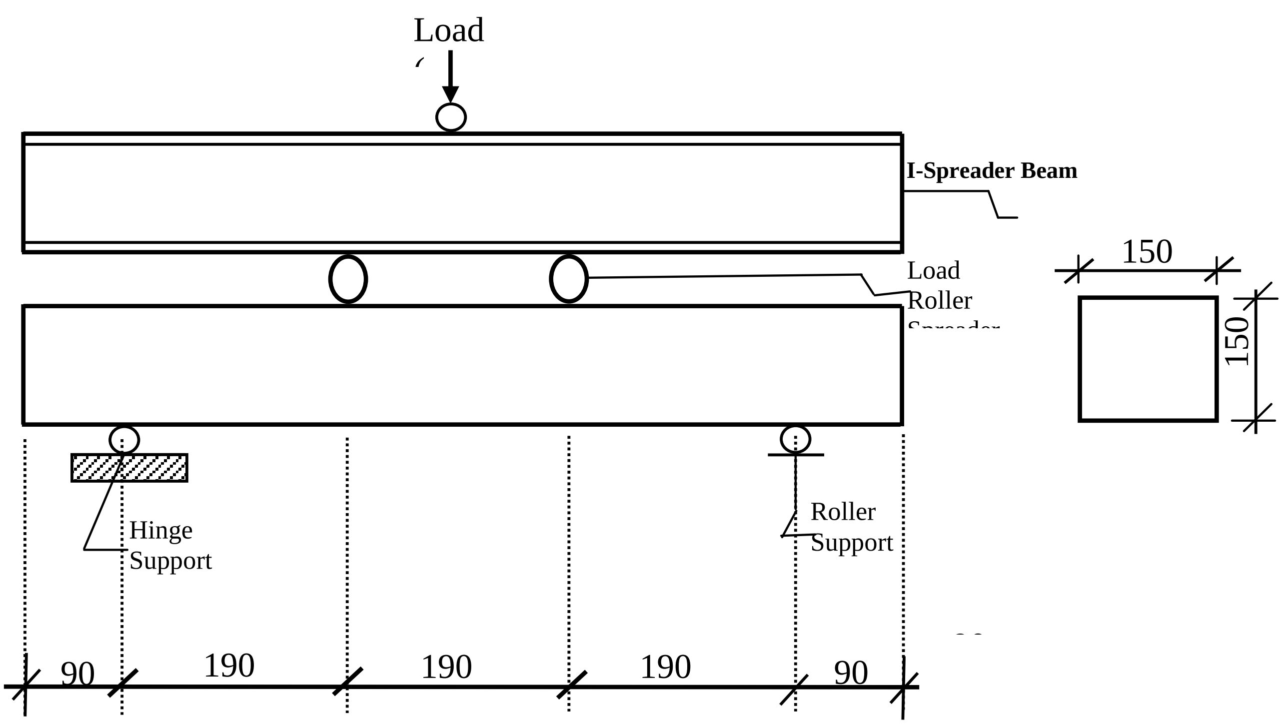

Fig. 1: Typical Beam and Loading Arrangement (Load is in KN, and dimensions in mm)

The specimens were loaded at a constant rate of 120N/min. until failure. The maximum tensile stress (es) reached at the bottom of the fibre of the test beam is known as the modulus of rupture (M_r).

Thus the Modulus of Rupture (M_r) is calculated as:

$$M_r = \frac{PL}{bd^2} \qquad (2)$$

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) and d = average depth of the specimen at the failure (mm).

3. Results and Discussion

3.1 Preliminary Investigations

The grading and the physical properties of the sand show that the uniformity coefficient is 2.0 while the coefficient of curvature is 1.2. The sand is well graded. The results of chemical analysis to determine the chemical composition of cement and the pulverized bone used for this study is shown in Table 2. From the table, it is seen that the composition of the pulverized bone is almost similar to that of Portland cement used. Yet pulverized bone on its own was unable to produce any cementious until cement was present [8]. This could be attributed to the fact that, unlike cement, it did not go through high temperature regime in the process of its manufacture, which would have remove impurities of organic source. The presence of residual organic element might have been responsible for its non-cementitious traits.

Table 2: Chemical Composition of Portland Cement and Pulverized Bone

Sr.No.	Compound	Portland Cement	Pulverized Bone
1	Cao	72.26	70.87
2	SiO_2	6.39	7.03
3	Al_2O_3	0.88	0.91
4	Fe_2O_3	0.05	0.15
5	MnO	0.01	0.03
6	MgO	2.60	2.58
7	K_2O	0.39	0.51
8	Na_2O	1.58	1.67
9	SO_2	0.73	1.24
10	H_2O	0.62	0.75
11	CO_2	0.00	0.00
12	Loss on Ignition	0.98	1.14
13	Specific Gravity	2.92	2.22

The loss on ignition, a measure of the extent of carbonation and hydration of free lime and free magnesia due to atmospheric exposure, of pulverised bone is 1.14%. This value is within the limits of 3.0% set by [9]. The alkalis (K_2O and Na_2O), with a combined percentage of 2.18% is low, and thus reduce the possibility of the destructive alkali-aggregate reaction [20]. But it is however free of cyanide which cause corrosion of reinforcement The specific gravity of pulverized bone was lower than that of cement. This means more volume of pulverized bone will be needed for the same unit weight of cement.

3.2 Workability

Foamed concrete is a free-flowing, self-leveling, and self-compacting material and should therefore be expected to give a collapse slump at lower density. Thus neither the slump test (BS EN 12350: Part 2: 2000), [11], for normal weight concrete, nor the flow test (BS EN 12350: Part 6: 2000), [12], for concrete with a high slump are applicable. Therefore, the workability of foamed concrete is evaluated visually and in most cases it would not be difficult to spot when workability was unacceptably low. Thus, for the high density that was adopted for this work, it was obvious from visual inspection that the material was of such viscosity that subjecting it to slump test will be appropriate. Subsequently, slump test was carried out in accordance with BS EN 12350: Part 2 (2000), [11]. The aerated concrete material used in this investigation displayed true slump. The slump values are 50, 40, 30, 30 and 25mm for 0, 5, 10, 15 and 20% replacement level of cement with pulverized bone.

3.3 Wet Density

The effect of pulverized bone on the density of the foamed concrete is shown in Fig. 2.

Figure 2 shows that density decreases with increasing content of pulverized bone. In relation to the control specimens, the decreased in wet density are 2.5%, 4.0%, 4.8%, and 6.3% respectively for 5%, 10%, 15%, and 20% cement replacement with pulverized bone. This trend can be attributed to the fact that the specific gravity of cement of is 2.92 and that of pulverized bone is 2.22. The results of the dry density test on specimens are presented in Appendix A.

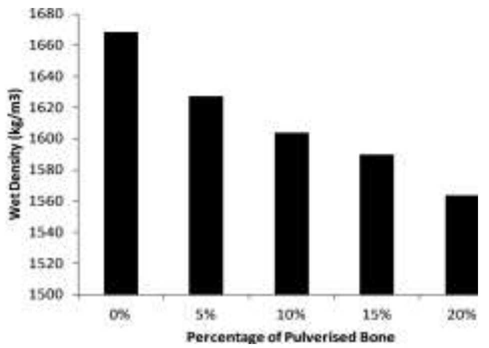

Fig. 2 Effect of pulverized bone on density of foamed concrete

3.4 Stability

Stability indicates the ability of the foam to go through the whole production process without collapse. It is the ratio of wet density to design density. For stability, this value must tend to unity. The ratios obtained for different percentages of pulverized bone are presented in Table 3 where the results show that stability is achieved at all levels of cement replacement with pulverized bone with the ratio revolving around unity. Thus the inclusion of pulverized bone up to 20% of cement did not reduce the stability of the mix.

Table 3: Effect of Pulverised Bone on Stability of foamed Concrete

%age of PB	Wet Density (kg/m^3)	Design Density (kg/m^3)	Wet/Design Density
0%	1668.28	1600	1.04
5%	1627.19	1600	1.02
10%	1603.71	1600	1.00
15%	1589.69	1600	0.99
20%	1563.68	1600	0.98

3.5 Testing Density

The effects of pulverized bone on dry density of the foamed concrete are shown in Figures 3 (a and b). It can be seen that increase in the pulverized bone content in the mix resulted in decrease in the dry density at all the curing ages both for water- and air-cured specimens. For example, at 7-day curing age, for water-cured specimens, there was decrease in the dry density with increase in the replacement of pulverized bone in the mix (Table 4). This trend was also observed for all curing ages for both water-cured and air-cured specimens. For example in Figure 3(a), the densities are 1689.29kg/m^3, 1679.01 kg/m^3, 1648.29 kg/m^3, 1631.89kg/m^3, and 1621.79kg/m^3 for 0%, 5%, 10%, 15%, and 20% cement replacement with pulverized bone respectively at 28-day for water-cured specimens; while from figure 3(b), the densities are 1662.50kg/m^3, 1659.23kg/m^3, 1644.23kg/m^3, 1623.78kg/m^3, and 1603.24kg/m^3 for 0%, 5%, 10%, 15%, and 20% cement replacement with pulverized bone respectively at 28-day for air-cured specimens.

Table 4: Variation of Dry Density with Pulverized Bone at 7-Day of Water-Curing

%PB	Density (kg/m^3)
0%	1603. 19
5%	1601. 20
10%	1600.29
15%	1598.65
20%	1589.26

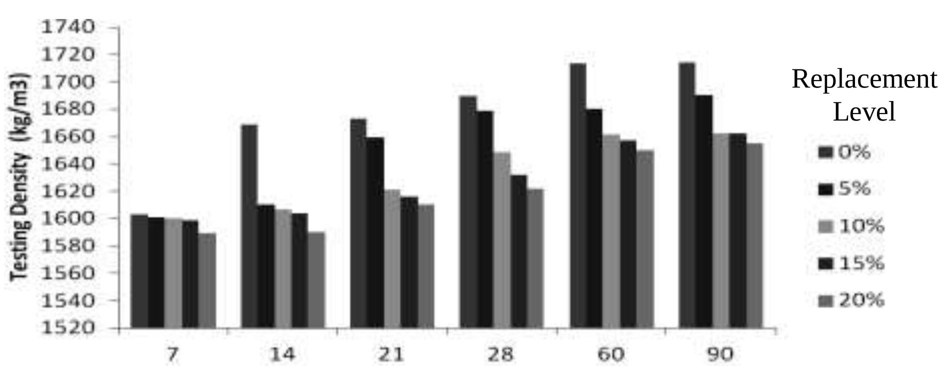

Fig.3a Curing Age (Days) for Water-Cured Specimens

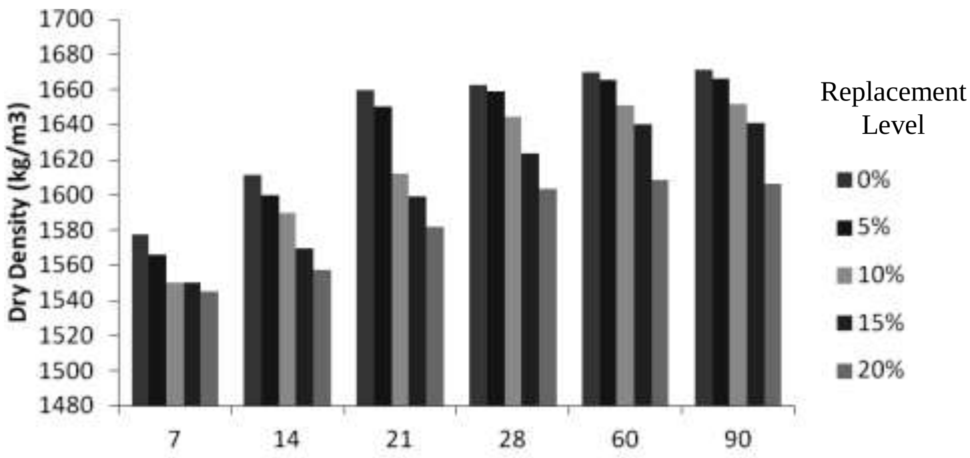

Fig.3b Curing Age (Days) for Air-Cured Specimens

This behaviour can be explained from the fact that the pulverized bone has lower specific gravity value than cement. Lower specific gravity has been found to result in lower density (Terzagi et al.), [17]. Thus, increasing the replacement levels has the effect of making the resulting concrete lighter.

Also for each of the percentage replacement of cement with pulverized bone, the dry density increased with curing age, but in a non-linear manner. A typical curve is shown in Fig. 4 for 5% cement replacement with pulverized bone for air-cured specimens.

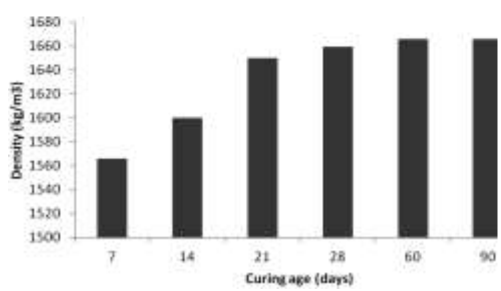

Fig. 4 Variation of Dry Density with Curing Age for 5% cement replacement with pulverized bone

Furthermore, specimens that were water-cured developed higher density than the specimens that were air-cured at room temperature at all the replacement levels. A typical curve is shown in Fig. 5 for 5% cement replacement with pulverized bone. The increased density in water-cured specimens may be due to the presence of water in the pores which have the effect of making the specimens to be heavier than the specimens that are air-cured.

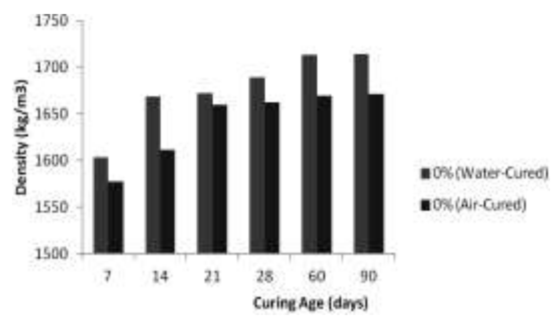

Fig. 5 Variation of Density with Curing Methods for Specmens with 5% Cement Replacement with pulverized Bone.

3.6 Compressive Strength

The effects of pulverized bone on the compressive strength are shown in Figures 6 – 8.

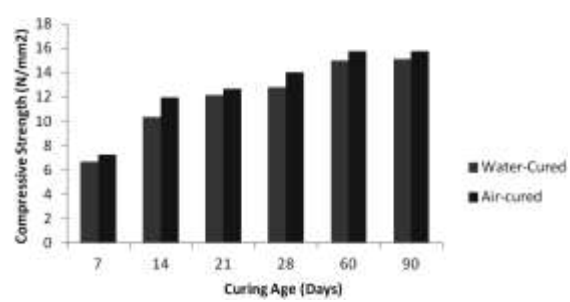

Fig. 6 Effects of Curing Method of Strength Development (10% pulverized Bone Content

3.6.1 *Effect of Curing Methods on Compressive Strength*

At all the replacement levels of cement with pulverized bone, the air-cured specimens developed higher strength than water-cured specimens. Figure 6 shows a typical trend for 10% cement replacement with pulverized bone. This behaviour agreed with Kearsley [18], who concluded that testing of water-cured foamed concrete specimens gave low strengths due to the build-up of pore water pressure in the saturated microstructure of the foamed concrete. Subsequent works by Falade et al. [19] agreed with this trend. Neville [20] explained that the lower strength exhibited by water-cured specimens may be due to dilation of cement gel by the adsorbed water which has the effect of reducing the forces of cohesion of the solid particles. The 28-day strength was 15.43N/mm^2 and 13.89N/mm^2 for the air-cured and water-cured specimens respectively.

At the 60-day curing the compressive strengths were 17.96N/mm^3 and 15.89 N/mm^3 for dry-cured and water-cured specimens respectively. There was no difference between the 60-day and 90-day compressive strength for air-cured specimens, but for water-cured specimens, the strengths were 16.78mm^2 and 16.90N/mm^2 for both 60-day and 90-day curing ages respectively.

3.6.1 Effect of Curing Age on Compressive Strength Development

Figures 7(a) and 7(b) present variation of the compressive strength with curing age for water- and air-cured specimens respectively. The figures show that compressive strength of foamed concrete at the designed density of 1600kg/m^3 used for this study increased with curing age for both water- and air-cured specimens at all the replacement levels.

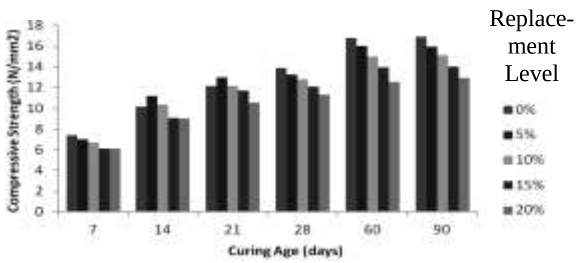

Fig.7a Effect of Curing Age on Strength Development (Water-Cured Specimens)

This is an indication of the production of the strength-forming C-S-H gel as a result of cement hydration with curing age. For the control specimens (0% pulverized bone) the 28-day strengths are 13.89N/mm^2 and 15.43N/m^2 for both water- and air-cured specimens; and the 60-day strength are 16.78N/mm^2 and 17.96N/mm^2 for both water- and air-cured specimens respectively. These represent increases in strengths after 28 days of 20% and 16% for both water- and air-cured respectively. After 60 days of curing, there is a strength increase for water cured specimens, but strength of air-cured specimens remained the same.

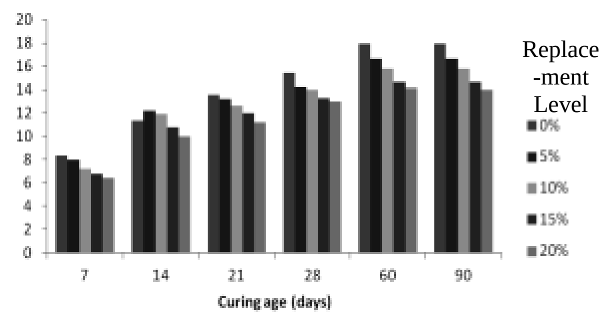

Fig.7b Effect of Curing Age on Strength Development (Ai-Cured Specimens)

3.6.3 Effect of Pulverized Bone on Foamed Concrete on Compressive Strength

In this study, all the specimens containing partial replacement of cement with pulverized bone developed lower strengths when compared with the control specimens at all the curing ages for both water- and air-cured specimens. From Figure 7(a and b), at 7-day curing age, the strengths are 7.41N/mm^2, 7.01N/mm^2, 6.68N/mm^2, 6.09N/mm^2, and 6.09N/mm^2 for 0%, 5%, 10%, 15%, and 20% cement replacement with pulverized bone respectively. This represent 5%, 10%, 18%, and 18% reduction in strength from the control; for 5%, 10%, 15% and 20% cement replacement with pulverized bone respectively. The trend was also observed for air-cured specimens. Typical 28-day strengths for air- and water-cured specimens are presented in Fig. 8. The results of the compressive strength test on specimens are presented in Appendix B.

Table 5 shows the trends in compressive strength reduction. It is noted that the strength reduction is insignificant up to 10% replacement of

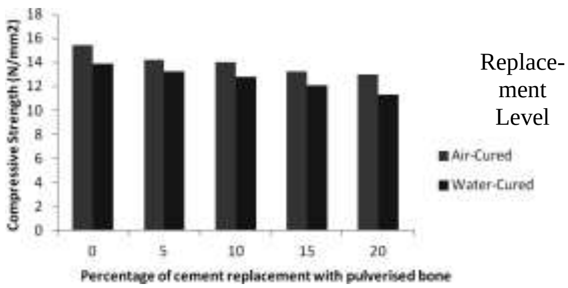

Fig.8 Variation of Compressive Strength with Pulverized Bone

Table 5 Compressive Strengths at Different Content of Pulverized Bone

% PB	Compressive Strength (N/mm^2)					
	Water Cured			Air Cured		
	Curing Age (Days					
	28	60	90	28	60	90
0.0 (Control)	13.89	16.78	16.90	15.43	17.96	17.95
5.0	13.24	15.99	15.98	14.49	16.67	16.68
10.0	12.61	15.01	15.10	14.01	15.78	15.78
15.0	12.11	13.89	13.99	13.26	14.67	14.66
20.0	11.34	12.56	12.90	12.98	14.12	14.00

cement with pulverized bone. However, the strength development up to 20% pulverized bone content levels still qualified the foamed aerated concrete used for this investigation to be classified as structural lightweight concrete (ACI 213R-03, 2003), [21].

3.6.4 Tensile Strength

The effect of cement replacement with pulverized bone on the tensile characteristics of foamed concrete with a designed density of $1600kg/m^3$ was evaluated using two indirect test procedures: Splitting tensile strength and Modulus of Rupture (Flexural tensile strength). It is difficult to determine tensile strength by direct tension because of the difficulty in maintaining applied load truly axial and the associated wide scatter of test results.

a) Splitting Strength

The results of the investigation into the splitting strength of foamed aerated concrete with pulverized bone are presented in Table 6 and figures 9 and 10. It is observed that the splitting tensile strength increased with curing age at all the replacement levels. But there was decrease in splitting tensile strength as the pulverized bone content increased. The 28-day splitting tensile strength of the foamed concrete at the design density of $1600kg/m^3$ was $1.63N/mm^2$. This value was comparable to $1.8N/mm^2$ for the same density that was earlier obtained by Jones [22]. The lowest splitting strength was $0.85N/mm^2$ for 20% cement replacement with pulverized bone at 28-day curing. The reduction in splitting strength in relation to the control may be due to weak bond between the paste and the sand grains. This value was still greater than $0.17N/mm^2$ recommended by ASTM C869-91, [23] for lightweight concrete.

Table 6:Variation of Splitting Tensile Strength with Pulverised Bone

% PB	Splitting Tensile Strength (N/mm^2)		
	28-day	60-day	90-day
0	1.63	2.26	2.62
5	1.56	1.98	2.33
10	1.56	1.61	1.89
15	0.99	1.41	1.71
20	0.85	1.41	1.73

Fig. 9 Splitting Test Arrangement

Fig. 10 Cracking of the Cylinder Specimen

b) Modulus of Rupture

The values of the flexural tensile strength as determined by the Modulus of rupture are presented in Table 7. Typical failure mode of beam specimens is presented in figure 11. All the specimens tested failed at the middle third of the span. There was no reduction in modulus of rupture at 5% cement replacement level, at 28 days of curing, when compared with the values obtained for the control specimen for the curing ages. At all other curing ages and for all the cement replacement level, flexural tensile strength reduced in relation to the control. The reduction in modulus of rupture in relation to the control may be due to weakening effect that pulverized bone has on the paste formed by cement and pulverized bone, resulting in weak bond between the paste and the sand grains. The moduli of rupture obtained in the study were high compared to the value of 1.00N/mm^2 obtained by Brady et al. (24) for foamed concrete of the same density.

Table 7 Variation of Modulus of Rupture with Pulverised Bone

% PB Content	Modulus of Rupture (N/mm^2)		
	28-day	60-day	90-day
0	2.53	2.81	2.85
5	2.53	2.53	2.62
10	2.11	2.53	2.63
15	2.11	2.53	2.69
20	1.69	2.53	2.60

Fig. 11 Typical Failure mode of the beam specimens

3.7 Comparison of Compressive Strength with Tensile Strength

Table 8 shows the relationship between the compressive strength and the splitting tensile strength, while the relationship between the compressive strength and modulus of rupture is presented in Table 9.

Table 8 Comparison between Compressive Strength and Splitting Strength

PB Content	Compressive Strength, f_c (N/mm^2)	Splitting Strength, f_s (N/mm^2)	Ratio f_s/f_c
28	15.43	1.63	0.11
60	17.96	2.26	0.13
90	17.95	2.62	0.15

Table 9 Comparison between Compressive Strength and Modulus of Rupture

PB Content	Compressive Strength, f_c (N/mm^2)	Modulus of Rupture, f_r (N/mm^2)	Ratio f_r/f_c
28	15.43	2.53	0.17
60	17.96	2.81	0.15
90	17.95	2.85	0.16

The splitting strength varies between 11% and 15% of the compressive strength and the ratio increases with curing age. Using the statistical line of best fit, and with correlation and regression analysis, this relationship can be represented as:

$$f_c = 2.70f_s + 11.23 \tag{3}$$

where f_c = compressive strength and f_s = splitting tensile strength

It is observed that the modulus of rupture varies between 15% and 17% of the compressive strength, and the ratio decreases with the curing age. Using the statistical best fit, these relationships can be represented (through correlation and regression analysis) mathematically as:

$$f_c = 8.33f_r - 5.55 \tag{4}$$

where f_c = compressive strength and f_r = modulus of rupture. This expressions are valid for the curing ages used in this experimental program for foamed concrete.

4. Conclusions

From the result of this investigation, the following conclusions are made:

1) The 28-day compressive strength of 15.43N/mm^2 obtained for foamed aerated concrete in this work at the designed density of 1600kg/m^3 meets the minimum strength requirement for classification as a structural lightweight concrete. This exceeds 15N/mm^2 as per RILEM (1993) recommendation (Alengaram et al); [25].

2) The 28-day tensile strength for the foamed concrete evaluated through the splitting tensile and modulus of rupture tests of 1.63N/mm^2 and 2.53N/mm^2 respectively meets the ASTM specifications for lightweight concrete.

3) The foamed aerated concrete lost its self-levelling, self-flowing characteristics at the designed density of 1600kg/m^3 with or without pulverized bone as partial replacement of cement. It however retained its self-compacting characteristics.

4) Up to 20% of the cement component of foamed concrete can be replaced with pulverized bone for foamed concrete production without loosing its classification as lightweight structural concrete according to RILEM standard.

5) The use of pulverized bone in the production of foamed aerated concrete will help to clean the environment of potentially hazardous wastes, reduce the amount of cement used in concrete production thereby bringing down cost of cement and reduction in consumption of non-renewable resources.

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APPENDIX A – Dry Density of Foamed Concrete for all the curing ages and Percentage Replacements

% of PB	Curing Method	7-day	14-day	21-day	28-day	60-day	90-day
0%	Water	1603.19	1668.75	1672.78	1689.29	1713.75	1714.00
	Air	1577.50	1611.12	1660.01	1662.50	1669.56	1671.00
5%	Water	1601.20	1610.21	1658.98	1679.01	1680.00	1690.00
	Air	1565.79	1600.17	1649.98	1659.23	1665.78	1666.00
10%	Water	1600.29	1606.78	1621.29	1648.29	1661.25	1662.00
	Air	1550.01	1589.98	1611.89	1644.23	1651.11	1652.00
15%	Water	1598.65	1603.79	1615.90	1631.89	1656.89	1662.01
	Air	1550.00	1569.67	1598.99	1623.78	1640.00	1641.00
20%	Water	1589.26	1589.98	1610.37	1621.79	1650.01	1655.00
	Air	1545.01	1557.29	1581.71	1603.24	1608.35	1606.29

NOTE: PB = pulverized bone

APPENDIX B – The Compressive Strength of Foamed Concrete for all the curing ages and Percentage Replacements

		7-day	14-day	21-day	28-day	60-day	90-day
0%	Water	7.41	10.14	12.12	13.89	16.78	16.90
	Air	8.34	11.34	13.56	15.43	17.96	17.95
5%	Water	7.01	11.20	12.98	13.24	15.99	15.98
	Air	7.98	12.21	13.23	14.23	16.67	16.68
10%	Water	6.68	10.38	12.12	12.81	15.01	15.10
	Air	7.23	11.96	12.67	14.01	15.78	15.78
15%	Water	6.09	9.08	11.67	12.11	13.98	13.99
	Air	6.78	10.81	12.00	13.26	14.67	14.66
20%	Water	6.09	9.00	10.56	11.34	12.56	12.90
	Air	6.45	10.01	11.23	12.98	14.12	14.00

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