The Potential of Laterite as Fine Aggregate in Foamed Concrete Production

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Abstract
This paper presents the results of an investigation into the potential use of laterite as fine aggregate in foamed concrete production.The influence of varying the proportion of laterite addition on the free flowing characteristic and the compressive strength properties of foamed concrete were determined. The results obtained show a decrease in free flowing capacity of the foamed concrete with increase in laterite content. The spread values obtained at w/c of 0.7 were 580 mm, 547 mm, 460 mm, 210 mm and 0 mm for 0%, 10%, 20%, 30% and 40% laterite contents respectively. Increase in water/cement ratio improved the spread values and allowed for higher percentage of laterite addition into the foamed concrete. The results further show that the compressive strength of the concrete produced at water/cement ratio of 0.7, 0.8 and 0.9 increased with increase in laterite content. The results also indicate that for a given value of laterite content, the compressive strength decreased with increase in water/cement ratio. Foamed concrete produced with w/c of 0.7 containing 20% laterite has better combine values of workability and compressive strength when compared to other laterized foamed concrete. Laterite has the potential as fine aggregate replacement in foamed concrete.
Keywords: Foamed Concrete, Laterite, Compressive Strength and workability

1. Introduction

The need for economic execution of civil engineering projects cannot be overemphasized because of its significant contribution to economic development and growth. Proximity and accessibility to construction materials required for a given project contribute to reduction in cost of projects. The traditional practice of using normal weight concrete for construction of some civil engineering projects in some areas in Nigeria does not encourage economic execution of such project.

Often, in Nigeria, designers recommend the use of normal weight concrete for construction of drains, low cost buildings, etc even in areas were the accessibility of well graded granite and sand for concrete production is almost impossible. Also it is a common practice in the building industry to use clay pots and clay bricks as solution to dead weight reduction in structures. These products are pre–cast element made by specialist companies and in some cases they escalate construction cost.

This research work examined foamed concrete as an alternative material to normal weight concrete in some areas of construction. Foamed concrete has been well developed and utilized in some parts of the world as alternative to normal weight concrete in some civil engineering projects and as a means of dead load reduction in building and civil engineering infrastructures.

Foamed Concrete

Foamed concrete is a lightweight material. Transport research laboratory (TRL) (2001) noted that foamed concrete has been defined in several ways; indeed it has a number of synonyms- such as cellular concrete and foamcrete. Foamed concrete has been defined in terms of material composition and production process. EBS-Associate (2001) defined foamed concrete as lightweight concrete which is made up of fine aggregate, cement, water and large amount of dispersed air pores in the mortar matrix. Van Deijk (1991) defined foamed concrete as cementitious material having a minimum of 20 per cent (by volume) of mechanically entrained foam in the plastic mortar.

Story-Beton Inc. (2008) observed that foamed concrete has diverse characteristics that are totally different from the conventional normal weight concrete. These characteristics are associated with the fresh state, and harden state of the foamed concrete.

Dransfield, (2000), Jones et al. (2005), Jones and McCarthy (2005a, 2005b, 2005c, 2006) all described foamed

concrete as free-flowing, self-leveling and self-compacting. This means that the workability of foamed concrete containing relatively large amounts of air pores is generally excellent; it has nearly fluid consistency, easily pourable, homogeneous and small possibility of bleeding and segregation.
Foamed concrete properties include wide range of densities (300- 1,600Kg/m^3), low water absorption and high fire resistant capacities, acoustic insulation property etc. These properties make foamed concrete suitable for a wide range of applications in engineering and construction. Magcon (2005) and Jones et al. (2005) demonstrated the ability of foamed concrete to easily incorporate recycle secondary aggregate (RSA) namely demolition fines, fly ash, incinerator bottom ash, recycled glass, rubber tyres (crumbs) foundry sand and china clay as fine aggregate.
Foamed concrete utilizes wide range of fine aggregate as raw material. The decision to examine the potential of laterite as partial replacement of fine in foamed concrete production is because it is available in large quantity in Nigeria as stated in Osunade (2002), Olawuyi and Olusola (2010).

2. Materials and Methodology

2.1. Determination of Fine Aggregate Properties

Fine aggregate is a major component of foamed concrete. The quality of the fine aggregate also affects the properties of the foamed concrete. British Cement Association (1994) recommended that the maximum grain size of sand for foamed concrete production should be 2.0 mm with 60-90% of it passing through 600 micron sieve.
The particle size distribution of the sand and laterite were determined in accordance with BS EN 933-1 (1997). Also the physical properties of these aggregates in terms of the bulk density, and water absorption capacity were determined.

2.2 Mix Design

The characteristic strength of foamed concrete is dependent on several variables. The mathematical relationship between the compressive strength and these variables can be expressed as follows;

$$F_{cu} = f(w/c, D_o, C), D = f(F_m,)$$

Where;
F_{cu} - Compressive strength, w/c- water/cement ratio, D_o – dry density, C- Cement quantity.
D- Plastic density of the mix and F_m- foam quantity.

Design Equation

$$D = C + W + F \qquad (1)$$

Where;
W- Water quantity, F - Fine aggregate quantity.

$$W = (w/c) \times C \qquad (2)$$

$$D = D_0 + 150 \qquad (3) \quad \text{TRL (2001)}$$

D_0 - Specified dry density (kg/m^3) at 28-day =1,600 kg/m^3

In order to determine the minimum volume of foam X m^3 required, the plastic density of the base mix (slurry) Y kg/m^3 was measured in accordance with BS EN 12350: part 6:(2000) by weighing a sample in a pre-weighed container of a known volume of 5-litres.
Therefore the following relationship holds;

$$\frac{Y}{(1+X)} = D \text{ kg/m}^3 \qquad (4)$$

2.3 Slump Flow Test

The consistency of foamed concrete was assessed in terms of slump flow spread. The slump flow test is effectively the measurement of the diameter of a sample after a collapse slump has been obtained from frustum of a cone, conforming to BS EN 12350-2 (2000) (i.e. the slump cone). When the cone is withdrawn upwards, the distance that the foamed concrete had spread over a flat horizontal surface was measured. The average of the two measurements at right angles is taken as the slump flow results. In this study, the slump flows of the laterized foamed concrete at water/cement ratio of 0.7, 0.8 and 0.9 were examined. The objective of this is to ascertain the allowable percentage of sand that could be replace with laterite at a given water/cement ratio.

2.4 Compressive Strength Development

Cube compressive strength was measured with a compression machine in accordance with BS EN 12390-3(2002). 150mm cube specimens were made from the different mix combinations. Two different curing methods were used namely air and water. The compressive strength was determined at 7th, 21st and 28th day. The water cured specimens were tested immediately they were brought out of water (saturated state).

3. Results and Discussion

The results of this investigation are presented under the following headings:

3.1 Fine Aggregate Properties

Table 2 shows that the laterite has finer particle distribution than the sand. This property explains the difference in the water absorption capacity of both materials. The laterite was air dried to reduce its moisture content before use.

3.2. Workability Test

Figure 1 shows the effect of foam on the slurry. The base mix had a true slump. When the foam was injected into the base mix it became free flowing and spread over a horizontal surface.

Figure 2 shows that the control (0% laterite replacement) has spread value of 580mm. Workability of laterized foamed concrete at fixed water/cement ratio decreased with increase in laterite content. This observation can be attributed to difference in water absorption capacity of the sand and laterite which are 19.3% and 41.62% respectively and increase in surface area. At 40% laterite addition and water/cement ratio of 0.7, the foam injected had no effect in the slump values of the slurry and the laterized foamed concrete produced no spread rather a slump of 54 mm was observed.

Base on the results it was needless to further increase the proportion of laterite in the mix. The values in the Figure 2 show that the workability of foamed concrete at constant volume of foam is dependent on following;

3.2.1. The Proportion of Laterite

Figure 2 shows that at constant water/cement ratio the free flowing property of the foamed concrete reduced with increase in the percentage of laterite. At water/cement ratio of 0.7, the spread was 580mm for 0% laterite content, while at 10%, 20%, 30%, 40% and 50% the spread values were, 547mm, 460mm, 210mm, and 0mm respectively. At laterite content of 40% and 50%, the slump values were 54mm and 24mm respectively. This relationship can be explained by considering the particle size distribution of the laterite and the sand as represented in the result of sieve analysis. Laterite contains finer particle size and required more water to bring it to surface saturation when compared to the same quantity of sand. At water/cement ratio of 0.8 and 0.9 the same relationship was observed. Therefore, at constant water/cement ratio and fixed quantity of foam, the free flowing property of laterised foamed concrete decreased with increase in the proportion of laterite added.

3.2.2 Water/Cement Ratio

The free flowing property of foamed concrete increased with increase in water/cement ratio at a given value of laterite content and foam quantity. For example, at laterite content of 10%, the free flowing property of the foamed concrete at water/cement ratio of 0.7, 0.8 and 0.9 are 547mm, 800mm and 1000mm respectively. The addition of more water into the slurry makes it very workable and prevents possible collapse of foam, which resulted from inadequate quantity of water in the slurry required for uniform consistency. The same relationship was also observed for laterite content of 0% 20%, 30%, 40% and 50%.

3.3 Density

Table 3 presents the variation of the density of foamed concrete with different percentages of laterite content, curing methods and water/cement ratios.

The influence of variation of laterite content, curing method and water/cement ratio on the density of foamed concrete is presented under the following headings.

3.3.1 Curing Method

Two curing methods were used namely, air and water. The curing methods affected the density of the foamed concrete. All air cured specimens show continuous decrease in density with age. For example at 10% laterite replacement level and water/cement ratio of 0.7, the densities of foamed concrete were 1845, 1809, 1789 kg/m^3 at 7th, 21st and 28th days respectively. All other percentages of laterite replacement show the same trend. Conversely, all water cured specimens were found to increase in density with age. For example at 10% laterite replacement level and water/cement ratio of 0.7, the densities were 1914, 2091, 2130, kg/m^3 at 7th, 21st, and 28th days. This behaviour of foamed concrete in water curing can be attributed to the fact that foamed concrete contains voids in its internal structure. These voids are filled up when the specimens were left in water. It was also noted that at all curing ages and percentages laterite replacement, the densities of water cured specimens were more than those of air cured specimens. For example, at 7th day curing age and water/cement ratio of 0.7 for 0%, 10%, 20%, 30% and 40% laterised foamed concrete, the densities of air cured specimens were 1585, 1845, 1917, 2050, and 2121 kg/m^3 while the corresponding values for water cured specimens were 1638, 1914, 2023, 2100, and 2124 kg/m^3 respectively.

3.3.2 Laterite Content

Table 3 shows that at a given water/cement ratio, the density of the foamed concrete increased with increase in the percentage laterite content. The same trend was observed in both water cured and air cured cube specimens for the entire water/cement ratio. For example, at 7th day, the densities of air cured specimens for water/cement ratio of 0.7 are 1585, 1845, 1917, 2050 and 2121 kg/m^3 for 0, 10, 20, 30, 40% respectively. Water cured specimens, at water/cement ratio of 0.7 at 7th day; the densities are 1638, 1914, 2023, 2100 and 2124 kgm^3 for 0, 10, 20, 30 and 40% respectively. This observation can be attributed to fact that laterite has finer particles than sand which implied higher specific surface that requires more water for workability. As the laterite content is increased the quantity of water in the mix was not enough to produce consistence slurry. The extra water required to produce consistence in slurry were extracted from the foam. This action results into collapse of foam which causes increase in density.

3.3.3 Water/Cement Ratio

The densities of the foamed concrete produced decreased with increase in water/cement ratio for both water and air cured specimens. An increase in water/cement ratio at a given quantity of laterite content improved the workability of the mix. An improved workability of the slurry contribute to stable foam, as little or no water is extracted from the foam which could have made it to collapsed. The result of this is lighter foamed concrete. For example, at 10% laterite content and 7th day curing the densities were 1845, 1777, 1568 kg/m^3 for water/cement ratio of 0.7, 0.8 and 0.9 respectively for air cured cube specimens. The same trend was observed for other percentages of laterite replacement.

3.4 Compressive Strength

The compressive strength of laterised foamed concrete is influenced by the following factors;

3.4.1 Laterite Content

The effects of laterite content on the average compressive strengths of test cubes at water/cement ratio of 0.7 are presented in Figures 3 and 4.

Figures 3 and 4 show that an increase in percentage of laterite in the foamed concrete produced increased compressive strengths of the cube specimens. This trend may be attributed to the relationship between density and compressive strength of foamed concrete. Compressive strength increased with increase in density provided other variables are kept constant such as water/cement ratio, curing condition and particle sizes. The compressive strength increased with increase in percentage of laterite. Even though, strength increased with increase in laterite content, beyond 30% laterite content, the mixture lost its characteristic (flowability) as foamed concrete.

3.4.2 Water/Cement Ratio

Figure 5 represents the variation of compressive strengths of foamed concrete with water/cement ratio.

At a given value of laterite content the compressive strength of the foamed concrete decreased with increase in water/cement ratio. This trend was observed both in air and water cured cubes. For example, at 10% laterite content the compressive strength values are 12, 6.8 and 4.5N/mm^2 for water/cement ratio of 0.7, 0.8 and 0.9 respectively. This relationship was observed for all other laterite contents and at all curing ages.

3.4.3 Curing method

Figure 6 indicates the variation of compressive strength of air-cured cube specimens with age. It shows that compressive strength values increased with curing age up to 28th -day for air cured specimens. For example, at 10% replacement level of sand with laterite the results are 6.7, 11.4 and 12.0 N/mm^2 for 7, 21 and 28 days respectively.

Figure 7 presents the results of compressive strengths for cube specimens that were cured in water. It shows the same trend of increase in compressive strength with age for water cured specimen. For example at 10% laterite, the results are 6.7, 9.3 and 10.2 N/mm^2 for 7, 21, and 28 days respectively while at 0% laterite content, the results are 3.1, 4.4 and 4N/mm^2 for the same curing ages. Generally, the strength values for water cured specimens are lower than those of air cured specimens. This agreed with earlier work by Falade et al. (2011).This may be attributed to the fact that foamed concrete generally has air voids within the concrete matrix and when tested in a saturated state (immediately the specimens are brought out from water), the voids are filled with pore water which causes reduction in the strength values. While the air cured specimens were tested in a dried state. Ordinarily the air cured specimens should have lower strength compared to water cure specimens because of hydration of water which could affect the chemical reaction in the cement paste

4. Conclusions

From the foregoing the following conclusions are reached;

(1) Foamed concrete produced with w/c of 0.7 containing up to 20% laterite performed better in terms of workability and compressive strength.

(ii) All air and water-cured laterized foamed concrete specimens showed increase in compressive strengths at all curing ages. Air cured specimens show greater gain in compressive strength than water cured specimens

(iii) The introduction of laterite into foamed concrete improved the compressive strength of the concrete.

(iv) Laterite has potential as fine aggregate in foamed concrete production.

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Fig 1: Spread Foamed Concrete and slump of slurry.

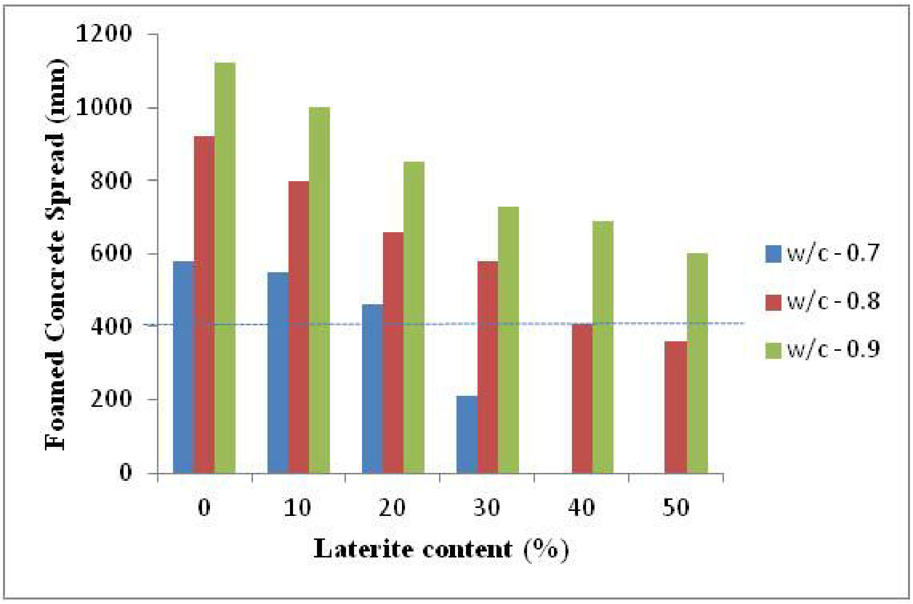

Figure 2: Variation of workability of laterised foamed concrete with water/cement ratio at varying proportion of laterite content.

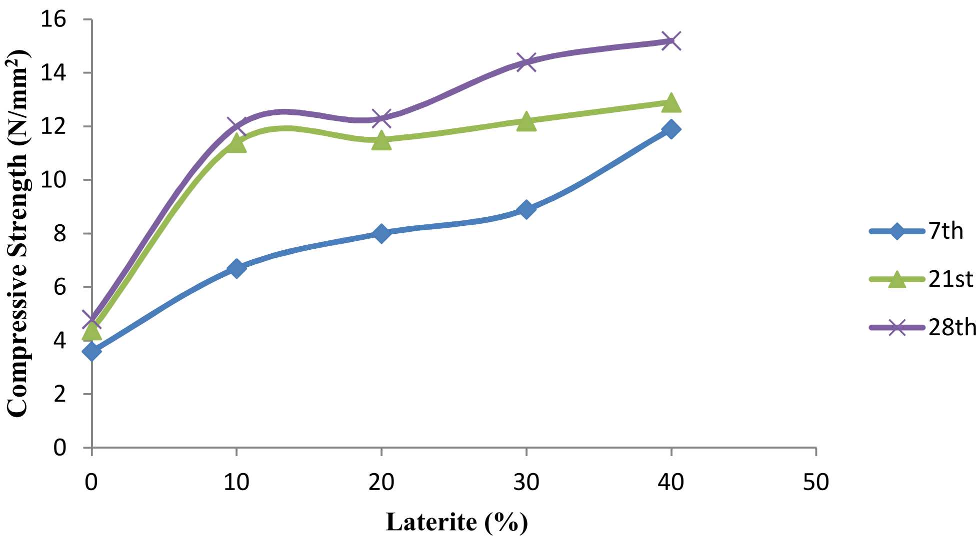

Figure 3: Variation of compressive strength of cube specimens with different laterite contents at different curing ages (Air cured specimens) for water/cement ratio of 0.7

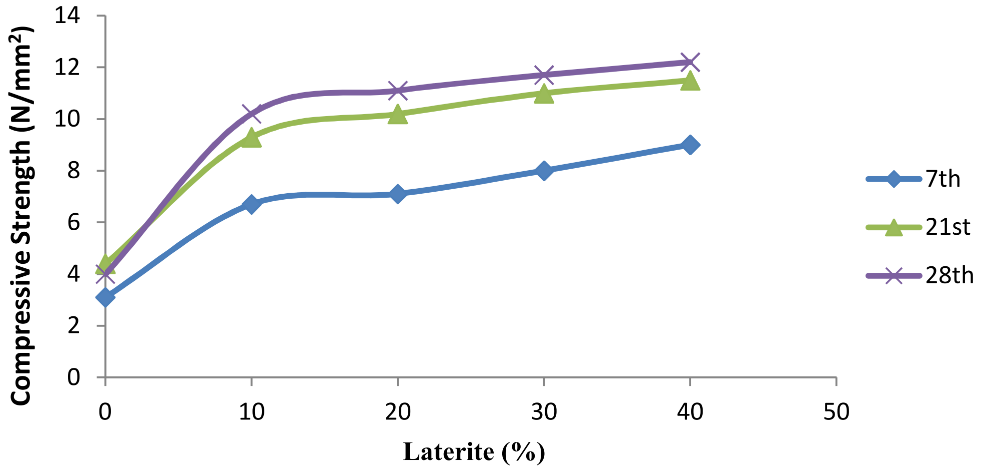

Figure 4: Variation of compressive strength of cube specimens with different laterite contents at different curing ages (water cured specimens) for water/cement ratio of 0.7

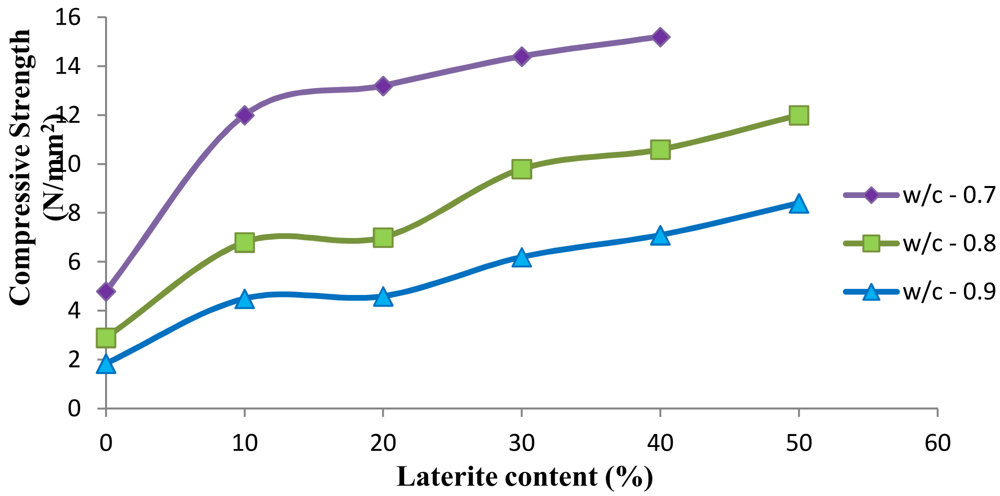

Figure 5: Variation of compressive strength of cube specimens with water/cement ratio at the 28th day (air cured specimens)

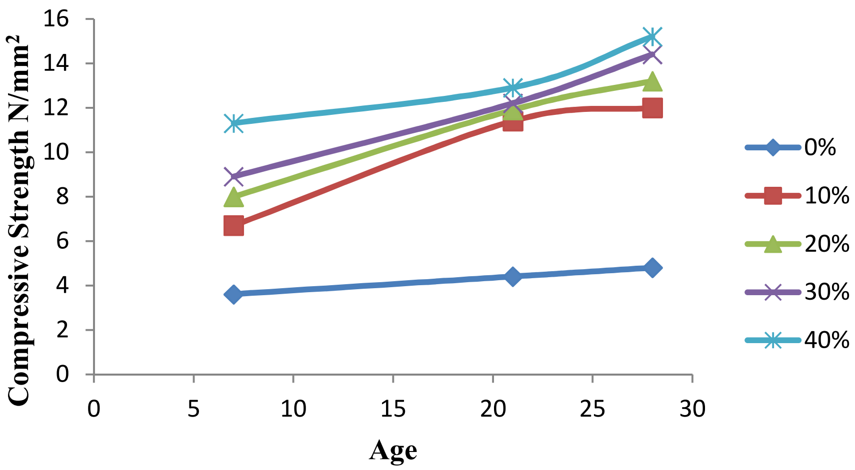

Figure 6: Variation of compressive strength of specimens with Age for different laterite Contents (Air cured specimens) at w/c of 0.7

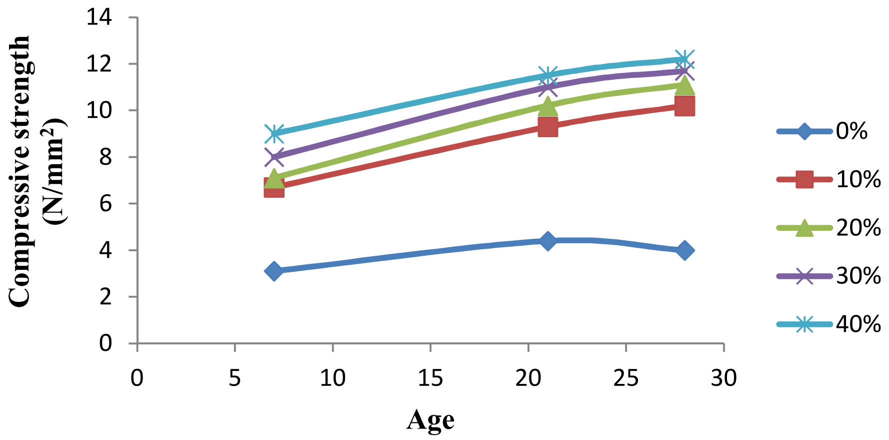

Figure 7: Variation of compressive strength of specimens with curing Ages. (Water cured specimens) at w/c of 0.7

Table 1: Mix combination at different w/c ratios.

w/c	Cement Kg/m^3	Sand Kg/m^3	Water Kg/m^3 (slurry)	Water Kg/m^3 (foam)	Foam concentrate Kg/m^3
0.7	350kg	1155	245	43	1.35
0.8	350	1155	280	43	1.35
0.9	350	1155	315	43	1.35

Table 2: Properties of sand and laterite

Physical Properties	Sand	Laterite
Gravel (50mm - 2mm)	2.9%	0%
Sand (2mm- 0.05mm)	97.1%	67%
Silt (0.05mm- 0.002mm)	0%	21%
Clay (< 0.002mm)	0%	12%
Water absorption %	19.3	41.6
Specific gravity	2.66	2.56
Bulk density (kg/m^3)	1529	1479
Moisture content %	1.3	5.2

Table 3: Variation of density of foamed concrete with laterite content, curing method and w/c

Laterite Content %	Age	Densities					
		Air Cured (kg/m^3)			Water Cured (Kg/m^3)		
		0.7	0.8	0.9	0.7	0.8	0.9
0	7 21 28	1585 1526 1487	1515 1410 1365	1480 1400 1305	1638 1777 1857	1565 1625 1706	1545 1590 1635
10	7 21 28	1845 1809 1789	1777 1730 1600	1508 1481 1470	1914 2091 2130	1786 1929 2001	1579 1608 1736
20	7 21 28	1917 1896 1866	1800 1680 1570	1626 1540 1523	2023 2163 2142	1840 1943 2010	1837 1866 1905
30	7 21 28	2050 2014 1985	1896 1880 1852	1653 1603 1587	2100 2115 2252	1955 2050 2120	2014 2019 2020
40	7 21 28	2121 2017 1955	1982 1926 1869	1748 1686 1589	2124 2163 2219	2006 2038 2074	1896 2009 2019
50	7 21 28		1955 1934 1930	1801 1704 1630		2044 2145 2154	2017 2050 2059