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Statistical Modelling of Compressive Strength of Hollow Sandcrete Blocks

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ABSTRACT

Sandcrete blocks are used as load and non-load bearing walls in the construction of buildings, and structures. The variations in the quality and quantity of its constituent materials with the methods of curing affect the compressive strength of sandcrete blocks. Modelling using multiple regression approach was used to develop a compressive strength model in terms of constituent materials for 28 days curing age of hollow sandcrete blocks made with St Saviour fine aggregate sourced from Benin City, Edo State, Nigeria. The model formulated for 28 days compressive strength using Microsoft Excel gave coefficient of determination (R^2) of 0.9879 for the hollow sandcrete block, indicating good correlation. The student – t and F – distribution tests also showed that the model was adequate for hollow sandcrete blocks compressive strength prediction. The formulated model eliminates trial and error of mixes, reduce cost and time of production of hollow sandcrete blocks.

1. INTRODUCTION

Sandcrete block is a composite material made up of water, cement, and sand and it differs from concrete in terms of material composition due to the non-inclusion of coarse aggregate in the mix and from mortar in that the slump is zero (NIS, 2004). Anosike (2011) revealed that sandcrete technology or block moulding is becoming the backbone of infrastructural development of every country. The lack of adherence to standards and quality control result in the production of sub-standard materials, the use of which has dangerous consequences for the building delivery process such as rampant building failure or collapse which in many instances involve loss of human lives and high maintenance cost of buildings and structures. A study carried out in Benin City showed that the maximum and minimum strength of sandcrete blocks for 28 days curing period were 2.60 N/mm^2 and 0.96 N/mm^2, while 27% out of the 90 blocks tested did not meet the minimum requirements (Alohan, 2002). Sandcrete blocks are widely used in Nigeria and other countries like Ghana as walling units for load bearing and non-load bearing structures (Oyekan and Kamiyo, 2011; Anosike and Oyebade, 2012; Morenikeji et al., 2015). Sandcrete blocks can be made either in solid or hollow form and the most commonly available sizes are 450 mm x 225 mm x 225 mm for load bearing walls and 450 mm x 150 mm x 225 mm for non-load bearing walls (Odeyemi et al., 2015).

Building materials account for over 60 percent of the total cost of building construction projects. Therefore, their quality is of primary concern for their reliabilities and efficient performances in buildings (Okereke, 2002). One of the most important qualities of hollow sandcrete blocks is its compressive strength and there are many factors that affect it such as quality, grading and density of fine aggregates/sand, curing conditions, quality control, vibration time, quality/amount of water used, cement-sand mix ratios, cavity volume and centre-web to end-web ratio (Abdullahi, 2005; Oyekan, 2008; Mahmoud et al., 2010; Omoregie, 2012; Ezeokonkwo 2012; Adeyeye, 2013; Onwuka et al., 2013; Ewa and Ukpata, 2013).

Many researchers have developed and used different models to ascertain different properties of sandcrete blocks, and concrete, with a view to reducing cost of production and meeting the standards as stipulated in the relevant codes of practice (Sedat et al., 2004; Palika and Maneek, 2014; Osuji and Inerhunwa, 2015; Ibrearugbulem; Ajoke, 20s16; Iyeke et al., 2016). This work thus applied multiple regression approach (MRA) to solving invariable mix proportions of the constituent materials of hollow sandcrete blocks.

2. MATERIALS AND METHODS

2.1. Materials

The fine aggregate (sand) used for this work was collected from St Saviour pit in Benin City, Edo State. The cement used for this work was Ordinary Portland Cement (OPC), Dangote brand, grade 42.5 while the water used for this work was potable water, obtained from a tap and it was colourless, odourless, and tasteless.

2.2. Methods

2.2.1. Specific gravity determination

The procedure for its determination involves weighing density bottles and recorded as (M_1) g, some cooled quantities of oven dried sample was sieved through sieve 425 µm. Some sieved samples were used to fill the density bottles and weighed as (M_2) g. The bottles with the sample were then filled with distilled water, shaken to ensure removal of air, and then left for 24 hours. After shaking the bottle and its content, it was weighed and noted as M_3 (g). After the 24 hours, the density bottle was emptied, washed and filled the distilled water only, weighed and noted as M_4 (g). The readings were tabulated and the specific gravity were computed for each bottle and the average value taken as the specific gravity. The specific gravity was computed using Equation 1.

$$\text{Specific gravity (Gs)} = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (1)$$

2.2.2. Sieve analysis of the fine aggregate

The sieve analysis was carried out by shaking the fine aggregate through a stack of screen with openings of known sizes. The equipment used for this analysis includes British sieve, mechanical shaker and a balance device for measuring the weight of the sample. The procedure was carried out by weighing out a sample of the sand and oven dried for twenty-four hours at 110 ^oC (100 g of the sand sample). The sieves were arranged in order of decreasing diameter and a pan was placed after the smallest sieve. The fine aggregate was sieved through the nest of the sieves by using a mechanical shaker. The sieve sizes are numbered as follows: 236, 200, 1.18, 600, 425, 300, 212, 150, and 75 respectively and a pan arranged in that order with 5 mm carrying the sand at the top of the assembly which in turn was firmly clamped on the top of the shaker. After the sieving was conducted by mechanical shaker, the sand retained on each of sieve (including any material cleared from the mesh was weighed and expressed as percentage of the weight of the total sample.

$$\text{Percentage retained} = \frac{\text{weight retained}}{\text{total weight}} \times 100 \quad (2)$$

The gradation curve obtained from the sieve analysis is used to determine coefficient of uniformity (Cu) and the coefficient of gradation, (Cc).

$$C_U = \frac{D_{60}}{D_{10}} \quad (3)$$

$$C_C = \frac{D_{30}^2}{D_{10}D_{60}} \quad (4)$$

Where D_{10}, D_{30}, D_{60} are particle size diameters corresponding to 10, 30 and 60% passing on the cumulative size distribution(gradation) curve respectively.

2.2.3. Mix proportions

Findings from block industries in Nigeria showed that the average value of water cement ratio is between 0.6 to 0.7, while the sand-cement ratio is 8.0 (Obodoh, 1999). Cement/sand ratio of 1:6 was also recommended in for sandcrete block production (NBC, 2006). Based on these, values for water-cement ratios adopted were 0.50, 0.55, 0.6, 0.65 and 0.70 while cement-sand ratios of 1:4, 1:5, 1:6, 1:8, 1:9, 1:10, and 1:12 were used as shown in Table 1.

2.2.4. Batching and mixing

The fine aggregates were batched by mass in the proportions of water and cement ratios. The constituent materials were mixed with a mixer for about 75 seconds until a uniform colour and consistency were observed. The equivalent quantities of each constituent material based on the different mixes were done using the averages weight of 450 mm x 225 mm x 225 mm blocks (Nzeh, 2008).

Average weight of 450 mm x 225 mm x 225 mm is 23.50 kg. 15% was added to take care of wastes and slump to obtain: 23.50 × 1.15 = 27.025 kg.

Based on the ratios of constituent materials, their weights were calculated from 27.025 kg. For mix ratio of cement:sand (1:4) and water-cement ratio of 0.5.

Total ratio = 1 + 4 + 0.5 = 5.50

$$\frac{27.025}{5.5} \times 1 = 4.91 \text{ kg of cement}$$

$$\frac{27.025}{5.5} \times 4 = 19.65 \text{ kg of sand}$$

$$\frac{27.025}{5.5} \times 0.5 = 2.46 \text{ kg of water}$$

The results of the mix proportions by weight of (fine aggregates, cement and water) from each of the mix ratios are shown in Table 1.

Table 1: Mix ratios/proportions

Mix ratios			Mix proportions (kg)		
Water/cement	Cement	Sand	Water	Cement	Sand
0.50	1	4	2.46	4.91	19.65
0.50	1	5	2.08	4.16	20.79
0.55	1	6	1.97	3.58	21.48
0.60	1	8	1.65	2.78	22.06
0.60	1	9	1.53	2.55	22.95
0.65	1	10	1.51	2.32	23.20
0.70	1	12	1.38	1.97	23.67

2.2.5. Manufacture of hollow sandcrete blocks

The moulding of the sandcrete blocks were carried out with a machine with metal mould to produce 450 mm x 225 mm x 225 mm hollow block. The process involved filling the mould with the mixed components and vibrating it for 10 seconds for compaction. One block was moulded at a time (i.e. one pallet, one block). Ten blocks were moulded for each mix ratio, thus making a total of seventy (70) blocks moulded for the compressive strength test.

2.2.5.1. *Mould size and void computation of the sandcrete blocks*

As shown in figure 1, the size of the mould used in making the hollow sandcrete blocks is as follows: t = 50 mm, y = 150 mm, a = 125 mm, b = 225 mm

Net volume = 450 x 225 x 225 = 22781250 mm^3

Volume of void = 2 x 225 x 125 x 150 = 8437500 mm^3

Percentage of void $= \frac{8437500 \times 100}{22781250} = 37.04\%$.

The percentage volume of solid materials is given as 100 – 37.04 = 62.96%. This meant the sandcrete block mould condition of solid material between 50% and 75% of the total volume of sandcrete block, calculated from the overall dimensions (Nzeh, 2008). The web of the mould used in making the hollow sandcrete blocks was 50 mm as stipulated by NIS (2007).

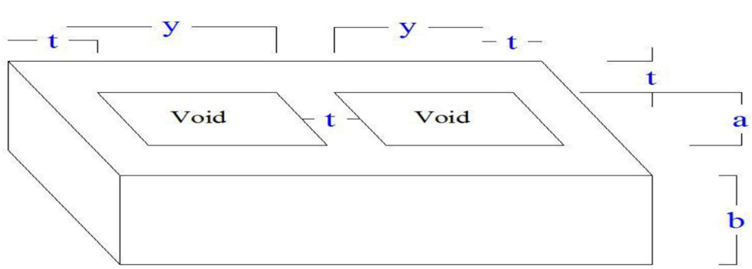

Figure 1: Mould size and void computation of the hollow sandcrete blocks

2.2.5.2. *Curing*

The sandcrete blocks were stacked in the block industry (CZ building and Construction services) in Benin City and later transported to the laboratory and cured by water sprinkling in the morning and evening. This was done on a daily basis for three days. It is stipulated by NIS (2004) that the blocks be left on the pallets for at least 24 hours and be cured for at least 3 days. The crushing test was carried out after 3, 7, 14, 21 and 28 days.

2.2.5.3. *Compressive strength test*

The blocks were crushed after 3, 7, 14, 21 and 28 days of curing. The blocks were placed in between two wooden plates of 5 mm thickness and wide enough as to cover the top and bottom of the blocks. Force was gradually applied through the platens of the testing machine until the block fails in compression.

$$\text{Crushing strength} = \frac{\text{Failure Load}}{\text{Loaded Area}} \tag{5}$$

Where Loaded area = (BL – 2ay) and B = 225 mm, L = 450 mm, a = 125 mm, and y = 150 mm. Two samples each were tested for a particular mix ratio and the average values taken as the compressive strength for the mix.

Table 2 gives the 28 days compressive strength of sandcrete blocks as specified in National Building Code (NBC 2006).

Table 2: 28 days compressive strength requirements

Compressive strength	
Average strength of six (6) blocks	Lowest strength of individual block
2.00 N/mm^2	1.75 N/mm^2

2.2.6. Multiple regression model

Multiple regression model (MRM) is a statistical process for estimating the relationship among variables (dependent or response and independent of predictor variables) as shown below.

$$y = b_o + b_1x_1 + b_2x_2 + b_3x_3 + \ldots.. + b_nx_n \tag{6}$$

Where Y is dependent variable and x_1, x_2, x_3......................x_n are the independent variables, and b_1, b_2, b_3........ b_n are coefficients which shows how the independent variables affect the dependent variable(y) while b_o is constant term, which takes the value of y when all the independent variables are equal to zero. Thus, for sandcrete block compressive strength prediction, the Equation (6) can be written as:

$$f = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \tag{7}$$

Where f is the compressive strength of sandcrete block, x_1 = water-cement ratio (w/c) in the mix, x_2 = quantity of water (w) in the mix, x_3 = quantity of fine aggregate (FA) in the mix, x_4 = quantity of cement© in the mix, and b_1, b_2, b_3, b_4 are the coefficients or multipliers which show how the sandcrete block constituents relate to its compressive strength, while b_o is a constant term. The multiple regression modelling has been summarised into:

a. Data Acquisition: The mix proportions and the compressive strength values are the data for model analysis

b. Analysis of Data using Model to Generate Model: This involves obtaining the regression coefficients (b_o, b_1, b_2, b_3, and b_4), and this was done using Microsoft excel regression analysis.

c. Test of Adequacy:

   i. Fisher's test was used to test the adequacy of the model by comparing the experimental compressive strengths with the predicted values. The values obtained from the model are said to adequate if:

$$\frac{1}{f_{\propto(v_1,v_2)}} < \frac{s_1^2}{s_2^2} < f_{\propto(v_1,v_2)} \tag{8}$$

Where S_1^2 is the greater of S_e^2 and S^2_m while S_2^2 is the smaller of the two, S_m^2 is the variance from the model, S^2_e is the variance from the experiment, $\frac{s_1^2}{s_2^2}$, is $f_{calculated}$ and $f_{\propto(v_1,v_2)}$, is the fisher value obtain from F-distribution table using significant level($\propto$) of 5% (0.05), $v_1 = v_2$ = N-1 = degree of freedom.

   ii. Student-t test was also used to test the adequacy of model:

Let y_e be response (compressive strength) from the experiment, and y_m be response (compressive strength) from the model, N be number of observations, D_i be difference of y_e and y_m, D_A be the mean difference of y_e and y_m and S be standard deviation of the difference of D_i and D_A.

$$D_A = \frac{\sum D_i}{N} \tag{9}$$

$$S = \sqrt{\frac{\sum(D_A - D_i)2}{N-1}} \tag{10}$$

$$t_{calculated} = \frac{D_A\sqrt{N}}{S} \tag{11}$$

Degree of freedom = N−1, 5% significant of two – tailed test = 2.5%, $\propto$ = 1−2.5% = 97.5% = 0.975, and $t_{(\propto,N-1)} = t_{tabulated}$ (obtained from statistical tables). A two-tailed test is a statistical test in which the critical area of a distribution is two-sided and tests whether a sample is greater than or less than a certain range of values. If the sample being tested falls into either of the critical areas, the alternative hypothesis is accepted instead of the null hypothesis. If $t_{tabulated} > t_{calculated}$, the null hypothesis is accepted and alternative hypothesis rejected, which then implies that the model is adequate. But if $t_{tabulated} < t_{calculated}$, we reject the hypothesis.

2.2.6.1. *Assumptions*

The models for the hollow sandcrete blocks (450 mm x 225 mm x 225 mm) were formulated with the following assumptions:

i. The fine aggregate was properly dried for the application of the various water/cement ratios for the mixes.

ii. The independent variables used for the models are linearly related in the production of hollow sandcrete blocks.

3. RESULTS AND DISCUSSION

3.1. Specific Gravity

The specific gravity of St Saviour fine aggregate was 2.65 while the percent passing for sieve No. 25 was 46.82%. Also, the coefficient of curvature (C_C) and uniformity (C_u) were 2.44 and 6.10 respectively. Thus, the fine aggregate sample was well graded soil as it met the conditions ($C_u \geq 6$ and $1 < C_c \geq 3$) for well graded soils (West, 1995; Tezaghi et al., 1996).

3.2. Compressive Strength

The compressive strengths of the hollow sandcrete blocks as shown in Tables 3 increased with increase in cement contents and curing ages with the maximum values obtained at 28 days. The compressive strength of the hollow sandcrete blocks were high in that they were produced with block vibrating machine thus conforming to the conclusion given by Odeyemi et al. (2015). The 28 days compressive strength of the hollow sandcrete blocks made with cement/sand ratio of 1:6 as commended by NBC (2006) and water cement ratio of 0.55, met the minimum compressive strength requirement of 1.75 N/mm^2 and 2.76 N/mm^2 as recommended by NIS (2007) and reported by Anya, (2015).

Table 3: Compressive strengths of the hollow sandcrete blocks

Mix ratios	Compressive strength (N/mm^2)				
	3	7	14	21	28
0.50:1:4	1.89	2.15	2.63	3.10	3.78
0.50:1:5	1.60	1.75	2.46	2.89	3.55
0.55:1:6	1.36	1.69	2.38	2.58	3.49
0.60:1:8	1.02	1.33	1.69	2.10	2.88
0.60:1:9	0.93	1.21	1.49	1.89	2.65
0.65:1:10	0.81	1.13	1.32	1.69	2.23
0.70:1:12	0.62	0.78	1.02	1.25	1.88

3.3. Determination Model Fit

The 28 days compressive strength model of hollow sandcrete block obtained is given as:

$$F_{28} = 12.6166 - 11.8026x_1 + 3.4563x_2 - 0.1747x_3 - 1.6201x_4 \quad (12)$$

Where F = the compressive strength (N/mm^2) of the sandcrete blocks, x_1 = water-cement ratio(w/c), x_2 = quantity of water(w) in (kg), x_3 = quantity of fine aggregate (kg), and x_4= quantity of cement (kg).

As seen in Table 4, the coefficient of determination (R^2) was 0.9879 which indicates that the independent variables had 98.79% of variation of the dependent variable (compressive strength) for 28 days curing of the hollow sandcrete blocks. The correlation between predicted and observed compressive strength was 0.9939. The multiple regression approach (MRA) - which is a statistical process used for this study was found to be adequate for the prediction of compressive strength of hollow sandcrete blocks, as shown in Table 5 and the test of adequacy.

Table 4: 28 days compressive strength coefficient and regression statistics

Regression Statistics	
Multiple R	0.9939
R Squared	0.9879
Adjusted R Squared	0.9638

Table 5: 28 days observed and predicted compressive strength for the hollow sandcrete blocks

S/N	Observed compressive Strength (N/mm^2)	Predicted compressive strength (N/mm^2)
1	3.78	3.83
2	3.55	3.53
3	3.49	3.38
4	2.88	2.88
5	2.65	2.68
6	2.23	2.35
7	1.88	1.80

3.4. Tests of Adequacy of the Models

a) Fisher Test: The regression analysis of the hollow sandcrete blocks had value of $f_{computed}$ to be 1.0122 while $f_{tabulated}$ to be 4.2839 for 28 days of curing using significance level of 0.05 and degree of freedom of 6, thus satisfying $\frac{1}{f_{\propto(v_1,v_2)}} < \frac{s_1{}^2}{s_2{}^2} < f_{\propto(v_1,v_2)}$. Hence the 28 days model is adequate for the hollow sandcrete block.

b) Student t – test: The regression analysis of the hollow sandcrete blocks had value of $t_{computed}$ to be 1.06 x 10^{-14}, while $t_{tabulated}$ to be 2.4469, for 28days of curing using significance level of 0.05 and degree of freedom of 6. Since the $t_{tatulated}>t_{computed}$, the null hypothesis is accepted while alternate hypothesis is rejected, hence the model is adequate.

4. CONCLUSION

The major objective of this work was to model the compressive strength of hollow sandcrete blocks made with fine aggregate sourced from Benin City, Edo State, for 28 days ages. It was recommended that the developed model can be used in predicting the compressive strength of hollow sandcrete blocks for 28 days curing period.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work**.**

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