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Strength Prediction Model for Concrete Made with Different Grades of Nigerian Portland Limestone Cement

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ABSTRACT

An easy, rapid, cheap, and reliable means of predicting the 28-day compressive strength of structural concrete, at very early state and at very affordable cost, will be helpful in quality control measures of structural concrete produced in remote sites. This paper presents the results of a compressive strength model developed to predict the 28-day compressive strength within hours of casting. The model was developed on the basis that the strength of concrete is fundamentally a function of the volume of voids in it, together with the governing equation expressing this concept and that the concrete is a multi-phase system consisting of cement, fine aggregate, coarse aggregate, evaporable water and non-evaporable water. The equation arising from this model uses the properties of concrete ingredients and the wet density of freshly mixed concrete that can be easily measured on site in a small-scale laboratory. The variables of the equation were then inputted into appropriate spreadsheet to give the value of the 28-day compressive strength once the variables are imputed. The results of 28-day compressive strength obtained from the equation obtained from the model compared well with the results obtained from the laboratory. Also, for its simplicity, implementation of the model by Nigerian Constructors and Engineers will make quick strength determination at early stage easy, to forestall lower strength development in concrete, and the attendant failures.

1. INTRODUCTION

In structural concrete, the compressive strength of concrete developed after 28 days of curing is not only used in the design, but also as quality control measure to be complied with in practice (BS 8110, 1997; ACI, 2008; Bamforth et al., 2008). Thus, for economical quality control, it becomes necessary to find the 28-day compressive strength at an earlier time with a reasonable accuracy. This is because of the fact that, between the casting and testing of the concrete, there is a time lag of 28 days. There could be problems during this time lag. For example, if the strength fails to meet the specified characteristic strength, large amount of money will be required to pull down the structure and rebuild it. In the same vein, if the strength is excessive, a lot of resources would have been wasted. Both cases involve loss of resources which developing nations cannot afford. Laboratories with compression-testing machine are few in many developing countries, and the available ones are not only too far from sites, but also charged colossal amount of money to carry out such tests (Ikponmwosa et al., 2013; Falade, 2014).

Thus, in most cases, contractors don't carry out the compressive strength tests that ascertain compliance with relevant standards. In recent times, the concrete that were taken and tested, on inspection of collapse buildings in the Nigeria failed the test (Falade, 2014; Sadiq, 2014). This calls for an easy, rapid, cheap, and reliable means of predicting the 28-day strength of concrete at very affordable cost. The 28-day compressive strength of a concrete has been estimated in lesser time in many ways. According to Neelakantan et al. (2013), they include: (i) determining the chemical and physical characteristics of the ingredients of concrete and then finding 28-day strength using the previously established regression relationship between some of these characteristics and 28-day strength, (ii) determining the early (3 or 7 day) strength and then finding 28-day strength using the previously established regression relationship between the early strength and 28-day strength, and (iii) determining the strength at an early age with accelerated curing then determining 28-day strength using the previously established regression relationship between the early strength with accelerated curing and 28-day strength. These approaches have been used by Metwally (2013) and Eskandari and Tayyebinia (2016) in the Artificial Neural Network, as well as in the soft computing model by Chowdhury et al. (2015), amongst others. However, it is a well-established fact that the strength of concrete is fundamentally a function of the volume of voids in it (Mehta and Monteiro, 2001; Mindess et al, 2003; Neville, 2011).

However, taking into consideration the incidence of lack of equipment among the operatives in the concrete and construction industry in developing nations in general and in Nigeria in particular, the strength-porosity approach is most appropriate because of its simplicity and ease of application. In this model, properties of constituent materials of concrete, that can be measured with ease in the laboratory (not so elaborate) are used. The strength prediction from these models can be obtained in less than 1 hour once the properties of the material are known. There is this erroneous belief that a particular concrete mix ratio with a particular water/cement ratio will always give a particular compressive strength at 28 days of curing, irrespective of how it was produced and the quality of the materials. This assertion does not enjoy the support of researchers (Adewole, 2015; Joel and Mbapuum, 2016).

According to Walker and Bloem (1961), Neville (2011) and Gambhir (2013), the strength of well-compacted concrete results from the strength of the mortar, the bond between the mortar and coarse aggregate, that is, the properties of interfacial zone, and the strength of the coarse aggregate particle. Implicit in this conclusion is that every project is unique, and must be treated so. This is because quality control varies and materials properties, especially aggregate vary from place to place. However, there is the need to have a foreknowledge of what the compressive strength of a mix ratio (of sets of constituent materials), will give at the end of 28 days of curing. This will enable the engineer on site to adjust the mix design as appropriate with the 28-day strength in view. Thus, a shortfall in the 28-day compressive strength is averted with the attendant demolition such concrete will attract. It will also prevent uneconomic mix ratio if the 28-day compressive strength is greatly exceeded. Thus, the aim of this work is to develop a model that could be predict the 28-day compressive strength of concrete produced with cement grade 32. 5 R and 42. 5 R, using the strength-porosity relationship approach.

2. MATERIALS AND METHODS

2.1. Materials

The materials used for this work are: cement, fine aggregate, coarse aggregate and water. The cement was Portland limestone cement in the class of CEM II as defined by NIS 444 (2014). The fine aggregate was river sand obtained from a river adjacent to the Federal University, Oye-Ekiti (Ikole Campus), Nigeria. It was dried and sieved through to ensure that only materials passing through sieve no 4 (4.75 mm) but retained on sieve no. 200 (75 um) are used. It was them bagged and stored in a cool place. The coarse aggregate used was obtained from a quarry through a contraction company working on the campus. Portable water from the University borehole was used. A mix ratio of 1:2:4 with water/cement ratios of 0.40, 0.50, and 0.6 were adopted for this investigation. The mix proportion is presented in Table 1. Concreting in this investigation involved batching by weight, thorough mixing, casting into 150 x 150 x 150 mm moulds and application of adequate compaction. The concrete specimens were demoulded after 24 hours and moist-cured and tested at 28 days of curing.

Table 1: Mix proportion for the investigation

Cement grade	W/C* ratio	Mix designation	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water (kg/m^3)
32.5	0.4	M_{14}	343	686	1372	137
	0.5	M_{15}	343	686	1372	172
	0.6	M_{16}	343	686	1372	206
42.5	0.4	M_{24}	343	686	1372	137
	0.5	M_{25}	343	686	1372	172
	0.6	M_{26}	343	686	1372	206

*W/C ratio = water/cement ratio

2.2. Determination of Properties of the Cement

The properties that were of relevance to this work are the specific gravity of cement grades, the consistency and the setting times (initial and final) of mortars made from the cement grades. The consistency and setting times of the cement were determined in accordance to the provisions of BS EN 196-3 (2016). The specific gravity of cement was determined in accordance to the provisions of BS 4550 (1978).

2.3. Determination of the Fresh Density and Compressive strength of Concrete Samples

The fresh (or wet) density of the concrete samples was determined in according to BS 12350:6 (2000). The weight of a container of known volume was determined. Then the weight of the container plus the concrete was determined. The difference in the weight of container filled concrete and the weight of the empty container is the weight of the concrete. The weight of the concrete was then divided by the volume of the container to obtain the density. This process was repeated for each of the batches, before it was cast in moulds. The compressive strength of concrete specimens containing Portland limestone cement of grades 32.5 R and 42.5 R were determined by using 150 x 150 x 150 mm cube moulds. The determination of the compressive strength was carried out in accordance to the provisions of BS EN 12390-3 (2009). A 2000 kN WAW-2000B computerized electrohydraulic servo universal testing machine with accuracy of ± 1% of test force, was used to determine the compressive strength of the concrete samples at 28 days of curing. At the testing date, three (3) specimens were tested, and the average was used to evaluate the mean strength.

2.4. Model Development

The development of the model was based on the fact that the presence of voids or pores in concrete influence the strength of the concrete. These effects can be vividly seen as presented in Table 2, in which there is a progressive reduction in compressive strength with the presence of air voids.

Table 2: Effects of pores on compressive strength of concrete (Wilby, 2001; Neville, 2011)

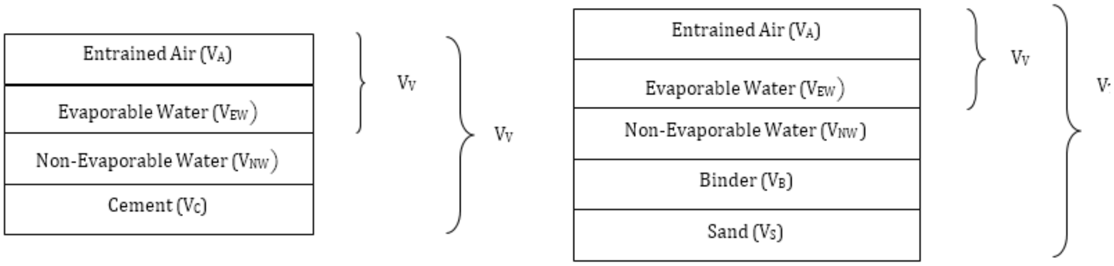
Air voids (%)	Lower strength by (%)
2	10
5	30
10	60
25	90

When concrete has 2% of air voids, there is strength reduction of 10%. However, a whopping 90% reduction in strength resulted with 25% air voids in the concrete. This is to underscore the adverse effects of voids on strength. These voids, consisting of entrapped air, capillary pores, gel pores, and entrained air, if present, collectively influence the strength of concrete. According to Nambiar and Ramamurthy (2008) and Neville (2011) the relationship between the volume of these pores and compressive strength is represented by Equation 1.

$$f_c = f_0(1 - p)^n \tag{1}$$

Where:
f_c = compressive strength at 28th day
f_0 = intrinsic compressive strength at zero porosity
p = porosity
n = is a coefficient, depending on the properties of the material, and need not be a constant (Neville, 2011).

They then combined this governing equation expressing with the concept that the concrete is a multi-phase system consisting of cement, fine aggregate, coarse aggregate, evaporable water and non-evaporable water. Using this expression and concept, Hoff (1972) developed expression relating the porosity and the compressive strength of foamed concrete with cement paste. In the development of the expression, he took the cognizance of the influence of volume of pores on the strength of mortar. Together with Equation 1, Hoff (1972) used a simple model in which foamed aerated concrete is composed of air, evaporable water, non-evaporable water, and cement as shown in Figure 1(a), to obtain an expression relating the compressive strength of paste to porosity. Nambiar and Ramamurthy (2008) extended this model to cement mortars, and Ikponmwosa et al. (2013) later modified this model, as shown in figure 1b, to obtain compressive strength expression for binary blends foamed aerated concrete at 28 days curing. The compressive strength results obtained from the experimental data correlated well with strengths predicted by the obtained models.



(a) (b)

Figure 1: (a) Hoff (1972) Model and (b) Ikponmwosa et al. (2013) model

The strength-predicting models developed by Hoff (1972), Nambiar and Ramamurthy (2008) and Ikponmwosa et al. (2013) were for aerated paste, aerated concrete, and blended aerated concrete respectively. The models were developed on the assumption that "air is the aggregate of aerated concrete", behaving like weightless aggregates (Mindess et al., 2003; Neville, 2011).

In the present work, the model was been modified by substituting the volume of gravel into the volume of air voids, as shown in Figure 2.

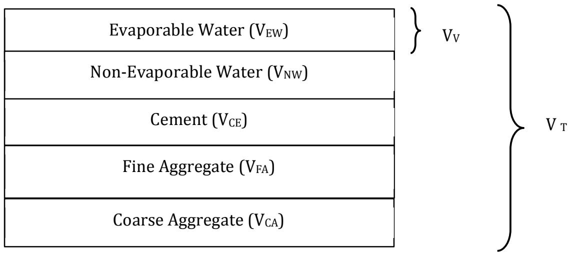


Figure 2: Model used for the present work

From Figure 2:

V_{EW} = volume of evaporable water
V_{NW} = volume of non-evaporable water

$$V_{NW} = 0.20 G_{CE} V_{CE} \text{ (Mindess et al; 2003)} \tag{2}$$

Where:

G_{CE} = specific gravity of cement
V_{CE} = volume of cement
V_{FA} = volume of fine aggregate
V_{CA} = volume of coarse aggregate

In multi-phase weight-volume relationships, the theoretical porosity, p for well-compacted concrete with volume of all the voids V_V and total volume V_T, can be expressed as:

$$p = \frac{V_V}{V_T} \tag{3a}$$

$$p = \frac{V_V}{V_{CE} + V_{WA} + V_{CA} + V_{FA}} \tag{3b}$$

Where:

V_{WA} = volume of evaporable water + volume of non-evaporable water ($V_{EW} + V_{NW}$)

If W_T is the total weight of the constituent materials and V_T is the total volume, then the wet density (d_w) of concrete can be expressed as:

$$d_w = \frac{W_T}{V_T} \tag{4}$$

$$d_w = \frac{W_{CE} + W_{WA} + W_{FA} + W_{CA}}{V_{CE} + V_{NW} + V_{CA} + V_{FA} + V_V} \tag{5}$$

Where:

W_{CE} = weight of cement
W_{WA} = weight of water
W_{FA} = weight of fine aggregate
W_{CA} = weight of coarse aggregate
V_{VV} = volume of voids

If K_{WSW} is water/solid ratio by weight (solid being cement, fine aggregate and coarse aggregate), then;

$$K_{WS} = \frac{W_{WA}}{W_{CE}+ W_{FA}+ W_{CA}}$$

and:

$$W_{WA} = K_{WSW}\ (W_{CE} +\ W_{FA} +\ W_{CA}) \tag{6}$$

Substituting Equation 6 into Equation 5, results in:

$$\begin{aligned} d_w &= \frac{W_{CE}+ K_{WSW}\ (W_{CE}+ W_{FA}+ W_{CA}) + W_{FA}+ W_{CA}}{V_{CE}+ V_{NW}+ V_{CA}+ V_{FA}+ V_V} \\ &= \frac{W_{CE}+ K_{WSW}\ W_{CE}+ K_{WSW}W_{FA}+K_{WSW}\ W_{CA} + W_{FA}+ W_{CA}}{V_{CE}+ V_{NW}+ V_{CA}+ V_{FA}+ V_V} \\ &= \frac{W_{CE}\ (1 + K_{WSW}\ )+ W_{FA}(1+K_{WSW}\ )+\ W_{CA}\ (1+ K_{WS})}{V_{CE}+ V_{NW}+ V_{CA}+ V_{FA}+ V_V} \end{aligned}$$

$$d_w = \frac{(1 + K_{WSW}\ )\ (W_{CE}+\ + W_{FA}+ W_{CA})}{V_{CE}+ V_{NW}+ V_{CA}+ V_{FA}+ V_V} \tag{7}$$

From Equation 4:

$$W_T = d_w V_T \tag{8}$$

$$V_T = \ V_{CE} + V_{NW}+ V_{CA} + V_{FA} + V_V \tag{9}$$

Substituting the values of d_w and V_T in Equation 8, results in:

$$W_T = \frac{(1 \ +\ K_{WSW}\ )\ (W_{CE} +\ W_{FA} +\ W_{CA})}{V_{CE} +\ V_{NW} +\ V_{CA} +\ V_{FA} +\ V_V} \times (\ V_{CE} +\ V_{NW} +\ V_{CA} +\ V_{FA} + V_V)$$

$$W_T = \ (1 + K_{WSW}\ )(W_{CE} + W_{FA} +\ W_{CA}) \tag{10}$$

Also, by substituting for W_T and V_T in Equation 8, yields:

$$d_W\ (\ V_{CE} +\ V_{NW} +\ V_{CA} +\ V_{FA} + V_V) = \ (1 \ +\ K_{WSW}\ )\ (W_{CE} +\ W_{FA} +\ W_{CA})$$

$$d_W\ \ V_{CE} +\ d_W\ V_{NW} +\ d_W\ V_{CA} +\ d_W\ V_{FA} +\ d_W\ V_V = \ (1 \ +\ K_{WS}\ )\ (W_{CE} +\ W_{FA} + W_{CA})$$

$$d_W\ V_V + d_W\ (\ V_{CE} +\ V_{NW} +\ V_{CA} +\ V_{FA}) = (1 \ +\ K_{WS}\ )\ (W_{CE} +\ W_{FA} +\ W_{CA})$$

Substituting the value of V_{NW} (Equation 2):

$$V_V = \frac{1}{d_W}\ \{(1 \ +\ K_{WSW}\ )\ (W_{CE} +\ W_{FA} +\ W_{CA}) - d_W\ (\ V_{CE} +\ 0.20 G_{CE} V_{CE} +\ V_{CA} +\ V_{FA})\} \tag{11}$$

Recalling the expression for the porosity p:

$$p = \frac{V_V}{V_T} \quad \text{(from Equation 3)}$$

$$= \frac{V_V}{\frac{W_T}{d_W}} \quad \text{(by replacing } V_T \text{ with } \frac{W_T}{d_W} \text{ in Equation 4)}$$

By combining Equations 10 for W_T, and 11 for V_V, the expression for porosity p becomes:

$$p = \frac{\frac{1}{d_W}\{(1 + K_{WSW}\ )\ (W_{CE} + W_{FA}+ W_{CA}) - d_W\ (\ V_{CE}+ 0.20 G_{CE} V_{CE}+ V_{CA}+ V_{FA})\}}{\frac{(1 + K_{WSW}\ )\ (W_{CE}+\ + W_{FA}+ W_{CA})}{d_W}} \tag{12}$$

Simplification yields:

$$p = 1 - \frac{d_W\ (\ V_{CE}+ 0.20 G_{CE} V_{CE}+ V_{CA}+ V_{FA})}{(1 + K_{WSW}\ )\ (W_{CE}+\ + W_{FA}+ W_{CA})} \tag{13}$$

If fine aggregate/cement ratio by weight is represented as K_{FCW}, then:

$$K_{FCW} = \frac{W_{FA}}{W_{CE}} \tag{14}$$

So that:

$$W_{FA} = (K_{FCW})\ (W_{CE}) \tag{15}$$

Similarly, representing fine aggregate/cement ratio by volume as K_{FCV}, gives:

$$K_{FCV} = \frac{V_{FA}}{V_{CE}} \tag{16}$$

So that:

$$V_{FA} = (K_{FCV})\ (V_{CE}) \tag{17}$$

If coarse aggregate/cement ratio by weight is represented as K_{CCW}, then:

$$K_{CCW} = \frac{W_{CA}}{W_{CE}} \tag{18}$$

So that:

$$W_{CA} = \ (K_{CCW})(\ (W_{CE}) \tag{19}$$

Similarly, representing coarse aggregate/cement ratio by volume as K_{CCV}, gives:

$$K_{CCV} = \frac{V_{CA}}{V_{CE}} \tag{20}$$

So that:

$$V_{CA} = (K_{CCV})(V_{CE}) \tag{21}$$

Substituting Equations 15 and 17 for W_{FA} and V_{FA} Equations 19 and 21 for W_{CA} and V_{CA} in Equation 13, then becomes:

$$p = 1 - \frac{d_W\ (V_{CE} + 0.20G_{CE}V_{CE} + K_{CCV}\ V_{CE} + K_{FCV}\ V_{CE})}{(1 + K_{WSW})\ (W_{CE} + K_{FCW}\ W_{CE} + K_{CCW}\ W_{CE})}$$

$$= 1 - \frac{d_W\ V_{CE}(\ 1 + 0.20G_{CE} + K_{CCV} + K_{FCV}\ )}{(1 + K_{WSW})\ (1 + K_{FCW} + K_{CCW}\ )W_{CE}}$$

$$= 1 - \frac{d_W\ V_{CE}(\ 1 + 0.20G_{CE} + K_{CCV} + K_{FCV}\ )}{(1 + K_{WSW})\ (1 + K_{FCW} + K_{CCW}\ )G_{CE}\gamma_W V_{CE}}$$

$$p\ = 1 - \frac{d_W\ (\ 1 + 0.20G_{CE} + K_{CCV} + K_{FCV}\ )}{(1 + K_{WSW})\ (1 + K_{FCW} + K_{CCW}\ )G_{CE}\gamma_W} \tag{22}$$

Where γ_W is the unit weight of water.

Substituting Equation 22 into the strength-porosity expression of Equation 1 results in Equation 23.

$$f_c = \ f_0 \left(\frac{d_W\ (\ 1 + 0.20G_{CE} + K_{CCV} + K_{FCV}\ )}{(1 + K_{WSW})\ (1 + K_{FCW} + K_{CCW})G_{CE}\gamma_W}\right)^n \tag{23}$$

Using the bisection method of numerical analysis as described by Murthy (2007) and Scheid (1989), and following the algorithm developed by Ikponmwosa et al. (2013), the values of the model constants f_0 and n were found to be 103.55N/mm^2 and 5.20 respectively. The Equation 23 now becomes:

$$f_c = \ 103.55\left(\frac{d_W\ (\ 1 + 0.20G_{CE} + K_{CCV} + K_{FCV}\ )}{(1 + K_{WSW})\ (1 + K_{FCW} + K_{CCW}\ )G_{CE}\gamma_w}\right)^{5.20} \tag{24}$$

Where:

f_c = compressive strength at 28th day
d_W = wet density of concrete
G_{CE} = specific gravity of cement
K_{FCV} = fine aggregate/cement ratio by volume
K_{FCW} = fine aggregate/cement ratio by weight
K_{CCW} = coarse aggregate/cement ratio by volume
K_{CCW} = coarse aggregate/cement ratio by weight
K_{WSW} = water/solid ratio by weight

It can be observed that Equation 24 depends on the physical properties of the constituent materials alone. These physical properties are such that they can be easily measured in the laboratory without sophisticated equipment, thus making it easy for use as quality control measure. Having pre-determined the physical properties of the constituent materials, the variables and parameters of the Equation 24 can now be inputted into MS Excel spreadsheet. The 28-day compressive strength for the concrete was then obtained automatically by just imputing the values of those parameters into the spreadsheet. The whole process of obtaining the 28-day compressive strength can be completed in less than 1 hour by using a small trial mix. This allows the engineer to adjust the mix proportion as appropriate with the target compressive strength view, before the actual concreting works begin.

3. RESULTS AND DISCUSSION

3.1. Physical Properties of Cement and Mortar

The physical properties of cement and mortars, that are relevant to the development of the strength models are the specific gravity of the cement and the setting times mortars containing the cement grades. The results are presented in Table 3.

Table 3: Physical properties of cement and mortar

Properties	Cement grade	
	32.5 R	42.5 R
Specific gravity	3.14	3.12
Consistency (%)	29.5	33
Initial setting time (minutes)	170	175
Final setting time (minutes)	362	342

3.2. Wet Density and Compressive Strength of the Concrete

The wet densities of fresh concrete samples before casting and the compressive strength at 28 days of curing are presented in Table 4. The wet densities have been converted from kg/m^3 to N/mm^3, since Newtons (N) and millimeters (mm) are the ruling unit of the compressive strength.

Table 4: The wet density and the 28-day compressive strength of concrete specimens

Cement grade	W/C ratio	Fresh density (N/mm^3)	Compressive strength (N/mm^2)
32.5	0.4	0.0000215	17.28
	0.5	0.0000231	23.47
	0.6	0.0000240	26.40
42.5	0.4	0.0000219	19.81
	0.5	0.0000241	31.67
	0.6	0.0000248	36.93

As can be observed, the wet densities increased with water/cement ratio. Obviously, at higher water content, the packing configuration of the components of the concrete was enhanced. Also, cement grade 42.5 R developed higher densities at all the water/cement ratios. Another observation from Table 4 is that the compressive strength of the concrete samples increased with water/cement ratio for the two cement grades. The concrete specimens with 42.5 R however developed higher strength than concrete produced with cement grade 32. 5 R.

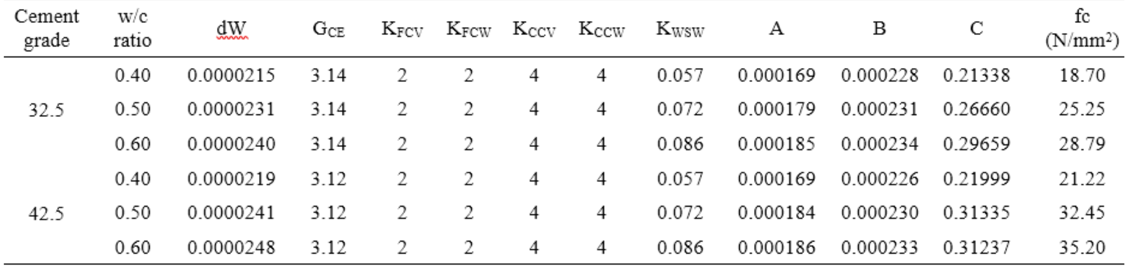
3.3. Compressive Strength of Concrete from the Model

In order assess the developed model, Equation 24 was inputted using MS Excel workbook as shown in Table 5. From Table 2, for cement grade 32.5 R and water/cement ratio of 0.40, the variables K_{FCV}, K_{FCW}, K_{CCW}, K_{CCW}, and K_{WSW} were obtained as follows:

K_{FCV} = fine aggregate/cement ratio by volume $= \frac{686}{342} = 2$
K_{FCW} = fine aggregate/cement ratio by weight $= \frac{686}{342} = 2$
K_{CCW} = coarse aggregate/cement ratio by volume $= \frac{1372}{343} = 4$
K_{CCW} = coarse aggregate/cement ratio by weight $= \frac{1372}{343} = 4$
K_{WSW} = water/solid ratio by weight $= \frac{137}{313+686+1372} = 0.057$

These were similarly determined for other cement grade and water/cement ratios. The values are presented in Table 5.

Table 5: Equation 24 as inputted into MS Excel



Cement grade	w/c ratio	dW	G_{CE}	K_{FCV}	K_{FCW}	K_{CCV}	K_{CCW}	K_{WSW}	A	B	C	fc (N/mm^2)
	0.40	0.0000215	3.14	2	2	4	4	0.057	0.000169	0.000228	0.21338	18.70
32.5	0.50	0.0000231	3.14	2	2	4	4	0.072	0.000179	0.000231	0.26660	25.25
	0.60	0.0000240	3.14	2	2	4	4	0.086	0.000185	0.000234	0.29659	28.79
	0.40	0.0000219	3.12	2	2	4	4	0.057	0.000169	0.000226	0.21999	21.22
42.5	0.50	0.0000241	3.12	2	2	4	4	0.072	0.000184	0.000230	0.31335	32.45
	0.60	0.0000248	3.12	2	2	4	4	0.086	0.000186	0.000233	0.31237	35.20

In Table 4, A = the numerator of Equation 24, B = the denominator of Equation 24, C = $(\frac{A}{B})^{5.20}$, and $f_c = 103.55(C)$. The mix proportion is as presented in Table 2, while Table 3 gives the values of the specific gravity. The last column in Table 5 contains the values of the 28-day compressive strength according to the model developed. The 28-day compressive strengths obtained from the model Equation 24 were compared with the 28-day compressive strength obtained in the laboratory and presented in Table 6. Relative to the model compressive strengths, the compressive strengths were overestimated for all the specimens except for the specimens of concrete made with grade 42.5 R and water/cement ratio of 0.60. However, the difference between the model and experimental 28-day compressive strengths varied from – 4.92 (for concrete made with cement grade 42.5 R and water/cement ratio of 0.60) to + 8.30 (for concrete made with cement grade 32.5 R and water/cement ratio of 0.60). Since the differences are less than 10% for all the specimens, the model can be considered to compare well with experimental results, and thus acceptable (Jones and McCarthy, 2005).

Table 6: Comparison of experimental to the model compressive strength

Cement grade	W/C ratio	Compressive strength (N/mm^2)		% difference relative to model
		experimental	model	
	0.4	17.28	18.70	+ 7.59
32.5	0.5	23.47	25.25	+ 7.05
	0.6	26.40	28.79	+ 8.30
	0.4	19.81	21.22	+ 6.65
42.5	0.5	31.67	32.45	+ 2.40
	0.6	36.93	35.20	- 4.92

The actual experimental compressive strength (f_E) values were plotted against the corresponding compressive strengths (f_M) predicted by the developed model equation to determine the nature of relationship between the two sets of strengths. This is shown in Figure 3. It can be observed in Figure 3 that a near perfect relationship exist between the sets of strength. The expressions representing these relationships are presented in Equations 25 and 26.

$$f_M = 1.0989f_E - 0.35 \qquad \text{for cement grade 32.5 R} \qquad (25)$$

$$f_M = 1.08387f_E + 4.9071 \qquad \text{for cement grade 32.5 R} \qquad (26)$$

The coefficient of determination R^2 for the concrete with cement grades of 32.5 R and 42.5R were respectively 0.9989 and 0.9862.

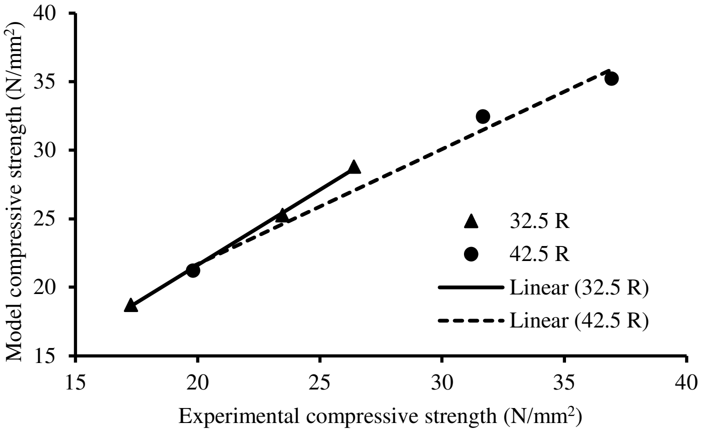


Figure 3: The relationship between model 28-day compressive strength and the experimental 28-day compressive strength

These values show that the experimental results were well replicated by the model, thus indicating the validity of the proposed model, without prejudice to little data used in the plot. Practical implementation of the model can be represented diagrammatically as shown in Figure 4. The Figure has three sections A, B, and C. All the activities that can be considered as preliminaries and normal site activities perform on materials on site are grouped together to form section A. Such activities include determination of physical properties of cement, aggregates and other materials, as well as determination of the concrete mix design. Also, inputted the model (Equation 24), using Excel software also forms part of this section. The process of determining the compressive strength starts with the carrying out of the trial mix on a small scale. This is grouped into section B. With the activities in section A in place, the whole process of determining the 28-day compressive strength will take between 30 minutes and 1 hour. Section C contains the evaluation of results and evaluation, which either lead to termination of the program, or return for another trial mix.

If the first run did not produce the expected 28-day compressive strength, then the mix design can be adjusted as appropriate. Then whole process begins from “carry out the trial mix”. This model is very easy and flexible to use and can serve as efficient site quality control mechanism in a remote construction site, where testing laboratories are far from the site.

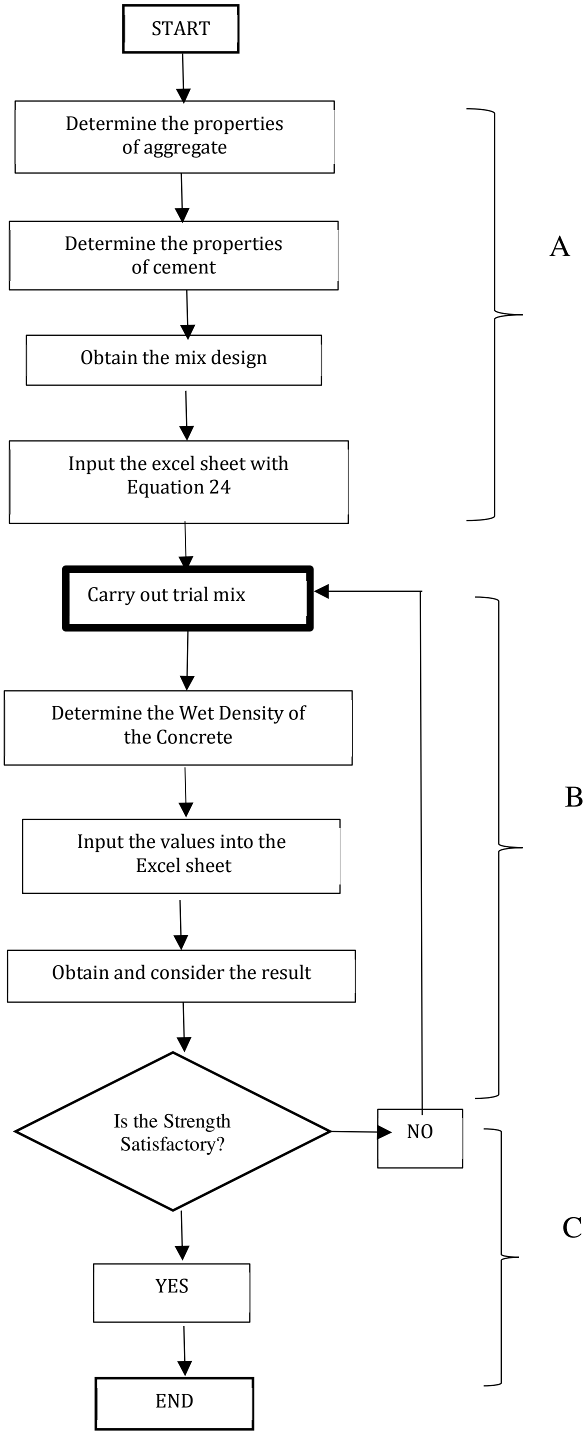


Figure 4: Flow chart for the implementation of the model

4. CONCLUSION

A model was developed in this investigation, to predict the 28-day compressive strength of concrete. From the analysis of the results presented in this work, it can be concluded that results of 28-day compressive strength obtained using the equation developed is reliable. Also, for its simplicity, implementation of the model by Nigerian Constructors and Engineers will make strength determination easy at early stage quickly, to forestall lower strength development in concrete, and the attendant failures.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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