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Special Issue

A Themed Issue in Honour of Professor Onukwuli Okechukwu Dominic (FAS).

This special issue is dedicated to Professor Onukwuli Okechukwu Dominic (FAS), marking his retirement and celebrating a remarkable career. His legacy of exemplary scholarship, mentorship, and commitment to advancing knowledge is commemorated in this collection of works.

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Prediction of flexural Strength of Concrete Containing Aloe Vera Gel as Admixture using Ibearugbulem's Regression Method

Oshim, U. E [1*], Onwuka, D. O [2], Njoku, F. C[3], Onwuka, U. S[4], and Anyaogu, L[5].

[1,2,3,5]Department of Civil Engineering, Federal University of Technology, Owerri, Nigeria

[4] Department of Project Management, Federal University of Technology, Owerri, Nigeria.

[*]Corresponding Author's E-mail: oshimuchechukwu61@gmail.com.

Abstract

This study examines how aloe vera gel (AVG) affects the flexural strength of concrete when used as an admixture. A mathematical model using the Ibearugbulem's Approach was developed to predict and optimize the flexural strength of AVG-cement concrete. The experimental study assessed both the fresh and hardened properties of AVG-cement concrete at curing intervals of 7, 21, and 28 days. Two concrete mix ratios, 1:1.5:3 and 1:3:5 were employed, each with a water-cement ratio of 0.6. The AVG content varied from 0.5% to 5% by weight of cement. Tests conducted included grain size analysis, specific gravity, workability, setting time, and flexural strength. The results indicate that the 1:1.5:3 mix ratio exhibited better workability than the 1:3:5 ratio. The addition of AVG improved workability and flexural strength. Optimal flexural strength was achieved with 2.0% AVG inclusion at 28 curing days. This study recommends using up to 2.0% AVG by weight of cement at a water-cement ratio of 0.6 for determination of flexural strength of Aloe vera gel-cement concrete. The mathematical model was validated with the Student's T-test, confirming its reliability.

Keywords: Concrete, Aloe Vera Gel (AVG), Flexural Strength, Ibearugbulem's Model, Optimization

1. Introduction

The construction industry's increasing adoption of concrete has resulted in a surge in demand for its constituent materials. Concrete is a multifaceted material comprising cement paste, water and aggregates. Adding admixtures to concrete before or during mixing enhances its performance characteristics by improving its properties (Adenaike et al., 2023; Awodiji et al., 2017; Nwa-David et al., 2023; Ibearugbulem et al., 2013; Charhate et al., 2018).
Admixtures can be broadly categorized into two main groups: mineral and chemical admixtures. Chemical admixtures, comprising water-soluble compounds, are added to cement to enhance concrete properties. These include accelerators, water reducers, retarders, and combination admixtures. In contrast, mineral admixtures are inorganic supplementary cementitious materials that exhibit pozzolanic properties, improving concrete's durability, strength, and permeability. Examples of mineral additives include ground granulated blast furnace slag, silica fume, and various ash materials such as sawdust ash, rice husk ash, cassava peel ash, coconut husk ash, cow dung ash, and periwinkle shell ash (Khan et al., 2014; Akindahunsi & Uzoegbo, 2015; Oni et al., 2019; Adetayo & Jubril, 2019; Nwa-David et al., 2024)

Research into the adoption of naturally occurring admixtures has gained momentum, driven by the need to reduce reliance on chemical admixtures and address issues related to their availability and cost in developing regions. Naturally occurring admixtures, such as cassava starch, maize starch, and aloe vera gel, offer a promising alternative, as they are plentifully available, affordable, environmentally friendly, and locally manufacturable

(Adamu et al., 2021; Nwa-David, 2023). Further studies on these local alternatives are necessary, and this research aims to contribute to this effort.

Aloe vera gel, a bio-based admixture derived from the aloe vera plant, offers a promising alternative to chemical admixtures in concrete production, particularly in regions with favorable climates for aloe vera cultivation. The gel is obtained through a process involving field collection, thorough cleaning under moving water, and subsequent processing into a usable form. It is then incorporated into concrete during the fresh mixing stage, typically at a percentage weight of cement (Oggu & Madupu, 2022; Nyabuto et al., 2024; Ahmed & Memon, 2022). Several researchers have investigated the use of aloe vera gel to modify concrete properties, including its compressive strength. For instance, Shalini et al, (2021), carried out a study on the effects of aloe vera gel on the compressive strength of M35 Grade concrete, with varying proportions of the admixture added to the mix.

Oggu and Madupu, (2021), investigated the impact of using aloe vera and marble waste powder as partial replacements for cement on the characteristics of pervious concrete. The study involved replacing 60% of the water content with aloe vera pulp and evaluating the permeability, compressive strength, and tensile strength of the porous concrete samples.

Ahmed and Memon (2022), conducted an experimental study to evaluate the effects of incorporating aloe vera gel (AVG) into concrete at varying dosages (0%, 0.5%, 1%, 1.5%, 2%, and 2.5%). The results demonstrated that AVG significantly improved both the workability and compressive strength of the concrete. The optimal dosage of 2.5% AVG resulted in a 57% increase in slump value, indicating improved workability, and a 10% enhancement in compressive strength. Based on these findings, the authors recommended the use of 2.5% AVG in concrete for applications involving heavily reinforced structures.

An experimental investigation by Nyabuto et al., (2024), examined the influence of incorporating aloe vera mucilage (AVM) as natural additive on the properties of self-consolidating concrete produced with ordinary Portland cement and limestone calcined clay cement. The researchers evaluated the effects of AVM dosages ranging from 2.5% to 10% on the concrete's fresh properties and mechanical performance. The results indicated that AVM acted as a set-retarder, increasing the setting time with higher dosages. Based on the findings, the authors recommended an optimal AVM inclusion of 7.5wt.% to achieve a balance between consistency, mobility, and concrete strength.

This research presents a new mathematical model for estimating the flexural strength of Aloe vera-cement concrete beams. The incorporation of Aloe vera gel as a natural admixture for concrete production, in conjunction with the proposed mathematical model, is anticipated to yield significant cost savings and time-consumption in concrete production for construction applications. Furthermore, the model provides a simplified and effective approach for determining the expected flexural performance thresholds and their corresponding mix ratios.

2.0 Materials and methods

2.1 Materials

The materials adopted in this study are locally available and they are Portland cement, aloe vera gel (AVG), drinkable water, fine and coarse aggregates. These materials are discussed below.

(a) Cement: The binding agent employed in this investigation was Super brand of Portland cement, whose properties align with the standards prescribed in BS 12 (1996).

(b) Aggregates: The aggregates used in this study were sourced locally. The granite aggregate had an angular shape with a maximum particle size of 20 mm, meeting the specifications outlined in BS 882 (1992). Additionally, sharp river sand was sieved through a 10 mm British Standard test sieve to remove cobbles, ensuring adherence to the standards specified in BS 882 (1992).

(c) Water: The water used for mixing and curing during the experiment was of potable quality and met the requirements outlined in BS 3140 (1980). It was sourced from the concrete laboratory of the Civil Engineering Department at the University of Cross River State, ensuring its appropriateness for the experimental processes.

(d) Aloe Vera Gel (AVG): Aloe vera plants were sourced from rural farmers in Calabar Municipal, Cross River State. The aloe vera pulp, consisting of cell walls, degenerated organelles, and viscous liquid, underwent a series of processing steps. The pulp was scraped, and the gel was extracted using a spoon. The gel was grounded, soaked in distilled water for 48 hours to separate fibers, and measured in 0.5% increments by cement weight. This gel was then incorporated into the concrete matrix to evaluate its effects on the material's properties.

2.2 Methods

The methods employed in this study are categorized as follows:

i. Experimental
ii. Model development
iii. Check for adequacy of the model

i. Experimental Method: The component materials, including cement and aggregates, were batched by weight. Two mix ratios were employed: 1:1.5:3 and 1:3:5, with a water-cement ratio of 0.6. Aloe vera gel (AVG) was incorporated in increments of 0.5% by weight of cement, with the range spanning from 0.5% to 5%. For each mix ratio, 66 concrete beams were prepared. The concrete constituents were thoroughly mixed to ensure uniformity before adding water. The homogenized mixture was poured into 100 × 100 × 400 mm metal molds in three layers, compacted using a tamping rod (25 strokes per layer), and finished with a trowel. The specimens were labeled accurately in accordance with BS 1881 (1983). The mold was removed from the concrete after 24 hours. The concrete specimens underwent three curing regimens until testing: immersion, sprinkling, and wrapping with plastic sheeting. The immersion method involved weighing and submerging specimens in a tank containing portable borehole water. The sprinkling method entailed weighing and keeping specimens moist by sprinkling water twice daily. The plastic sheeting method involved weighing, wrapping specimens in flexible plastic sheets, and sealing to prevent moisture movement. A minimum of two layers of wrapping was used. The curing temperature was maintained at 30°C for all regimens.
The beam specimens were tested for flexural strength using a flexural testing apparatus, following BS 1881, Part 118 (1983). Failure loads were determined, and flexural strength values were calculated using equation 1.

Flexural Strength, $\mathcal{F}_e = \frac{PL}{bd^2}$ (1’)

Where P is the failure load in Newton; b is the width of the specimen in “mm”; d is the depth of the specimen in “mm” and L is the length of the specimen in “mm”.

Table 1: Material Batching for AVG-Cement Concrete

Mix ratio	Mixture Label	Admixture (%)	Kg	Cement (Kg)	Sand (Kg)	Granite (Kg)	Water-cement Ratio
	C_0	0	0	19.216	29.017	66.49	0.6
	C_1	0.5	0.0961	19.216	29.017	66.49	0.6
	C_2	1.0	0.1922	19.216	29.017	66.49	0.6
	C_3	1.5	0.2882	19.216	29.017	66.49	0.6
1:1.5:3`	C_4	2.0	0.3843	19.216	29.017	66.49	0.6
	C_5	2..5	0.4804	19.216	29.017	66.49	0.6
	C_6	3.0	0.5765	19.216	29.017	66.49	0.6
	C_7	3.5	0.6726	19.216	29.017	66.49	0.6
	C_8	4.0	0.7686	19.216	29.017	66.49	0.6
	C_9	4.5	0.8647	19.216	29.017	66.49	0.6
	C_{10}	5.0	0.9608	19.216	29.017	66.49	0.6

(ii) Derivation of fundamental equation of the mathematical model:

The mix quantity (x_i) of each component on specific observation point was calculated by dividing the individual component (s_i) by the sum of all components (S). This can be written as:

$$x_i = \frac{s_i}{S} \quad (1)$$

$$S = s_1 + s_2 + s_3 + s_4 \quad (2)$$

This work limits the spatial domain of the model to mix ratio domains given as:

$$s_{1min} \leq s_1 \leq s_{1max} \quad (3)$$

$$s_{2min} \leq s_2 \leq s_{2max} \quad (4)$$

$$s_{3min} \leq s_3 \leq s_{3max} \quad (5)$$

$$s_{4min} \leq s_4 \leq s_{4max} \quad (6)$$

From Equation 1,

$$s_i = x_i \, . \, S \qquad [where\ 1 \leq i \leq 4\ ] \quad (7)$$

By Substituting Equation 7 into Equation 2, the sum of all the mix quantities is obtained as unity, expressed as:

$$x_1 + x_2 + x_3 + x_4 = 1 \quad (8)$$

The relationship between S and x_1 is:

$$\mathrm{S} = -4536.8\mathrm{x}_1^3 + 1946.1\mathrm{x}_1^2 - 313.04\mathrm{x}_1 + 22.38 \quad (9a)$$

$$\mathrm{S} = -33528\mathrm{x}_1^3 + 8722.7\mathrm{x}_1^2 - 851\mathrm{x}_1 + 36.9 \quad (9b)$$

Equations 9a and 9b is obtained from the third-degree-polynomial Trendline equation from the Microsoft Excel line graph of the variation of X_1 against S using the experimental data. Equations 9a and 9b are for mix ratios 1:1.5:3 and 1:3:5 respectively. The response function to be adopted herein is given as:

$$\mathrm{y} = \mathrm{a}_1\mathrm{x}_1 + \mathrm{a}_2\mathrm{x}_2 + \mathrm{a}_3\mathrm{x}_3 + \mathrm{a}_4\mathrm{x}_4 + \mathrm{a}_5{\mathrm{x}_1}^2 + \mathrm{a}_6{\mathrm{x}_2}^2 + \mathrm{a}_7{\mathrm{x}_3}^2 + \mathrm{a}_8{\mathrm{x}_4}^2 + \mathrm{a}_9\mathrm{x}_1\mathrm{x}_2 + \mathrm{a}_{10}\mathrm{x}_1\mathrm{x}_3 + \mathrm{a}_{11}\mathrm{x}_1\mathrm{x}_4 + \mathrm{a}_{12}\mathrm{x}_2\mathrm{x}_3 + \mathrm{a}_{13}\mathrm{x}_2\mathrm{x}_4 + \mathrm{a}_{14}\mathrm{x}_3\mathrm{x}_4 \quad (9c)$$

That is:

$$y = [x_i]\,[a_i] \quad (9d)$$

Equation 9d was utilized to determine the array response equation for the set of mix ratios used in the formulation as:

$$[y^k] = [{x_i}^k]\,[a_i] \quad (9e)$$

Where k represent the observation point number; $[a_i]$ is the coefficient vector, and $[x_i]$ is the shape function vector. They are defined as:

$$[a_i] = [a_1\ a_2\ a_3\ a_4\ a_5\ \ a_6\ a_7\ a_8\ a_9\ a_{10}\ a_{11}\ a_{12}\ a_{13}\ a_{14}]^T \quad (10)$$

$$[x_i]\ = [x_1\ \ x_2\ \ x_3\ \ x_4\ \ {x_1}^2\ \ {x_2}^2\ \ {x_3}^2\ \ {x_4}^2\ \ x_1x_2\ \ x_1x_3\ \ \ x_1x_4\ \ x_2x_3\ \ x_2x_4\ \ x_3x_4] \quad (11)$$

The weighted response equation (WRE) is derived by pre-multiplying both sides of Equation 9c with a weighting function (transpose of the shape function) for the set of mixes in the formulation, as follows:

$$[{x_i}^k]^T[y^k] = [{x_i}^k]^T.[{x_i}^k]\ [a_i] \quad (12a)$$

This multiplication did not change the generality of the regression function as the weighting function can easily cancel out from both the left and right hand sides of Equation 12a. It is clear from here that the approach used in the original work of Ibearugbulem model (Ibearugbulem et al., 2013) is weighted response approach (WRA).
The weighted response equation (Equation 12a) can be rewritten as:

$$[F] = [CC]\ [a_i] \quad (12b)$$

Where the weighted response vector, F and CC matrix are defined as:

$$[F] = [{x_i}^k]^T[y^k] \quad (13)$$

$$[CC] = [{x_i}^k]^T.[{x_i}^k] \quad (14)$$

[CC] is the matrix whose arbitrary element CC_{ij} is obtained by array multiplication of transpose of Column "i" with Column "j" of the shape function vector.

iii. **Check for adequacy of the model:** The student's t-test statistical technique was used to verify the adequacy of the model predictions against the experimental results. The equation was given in equation 15.

$$T = \frac{D_A\, X\sqrt{N}}{S} \quad (15)$$

Where, $D_A = \sum \frac{D_i}{N}$; $S = \Sigma\sqrt{S^2}$; $S^2 = (\sum \frac{(D_A - D_i)^2}{(N-1)})$; $D_i = Y_M - Y_E$.

3.0 Results and Discussion

3.1 Properties of Concrete Constituents

The granular characteristics of the sharp sand and coarse aggregate were evaluated through grain-size analysis, performed following the guidelines of BS EN 933. The grading limits were verified based on BS EN 882, as illustrated in Figures 1 and 2. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) values for the sharp sand were 2.16 and 0.82, respectively. Similarly, the coarse aggregate exhibited Cu and Cc values of 2.46 and 0.77, respectively. These values indicate that both aggregates were well-graded (Cc ≈ 1) and uniformly-graded (Cu ≤ 4). Furthermore, the specific gravity values of the river sand and granite were determined to be 2.55 and 2.65 respectively obtained from Table 2 and 3, which fall within the acceptable range of 2.30 to 2.90 for aggregates. These results confirm that the aggregates possess suitable properties for concrete production.

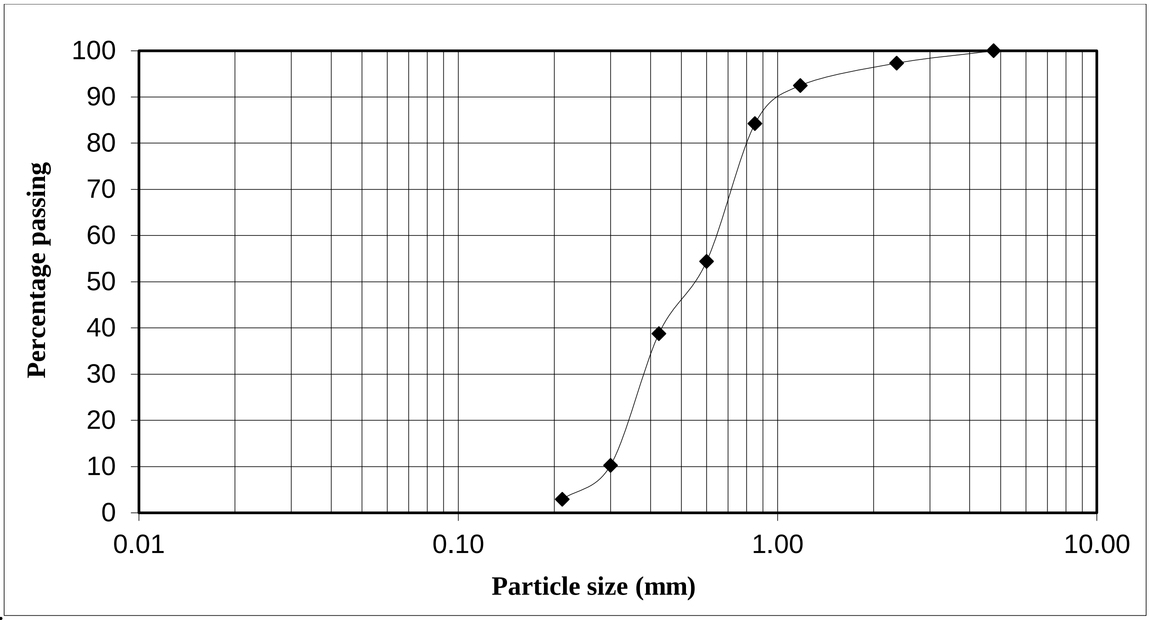

Figure 1: Particle size distribution curves for fine aggregate

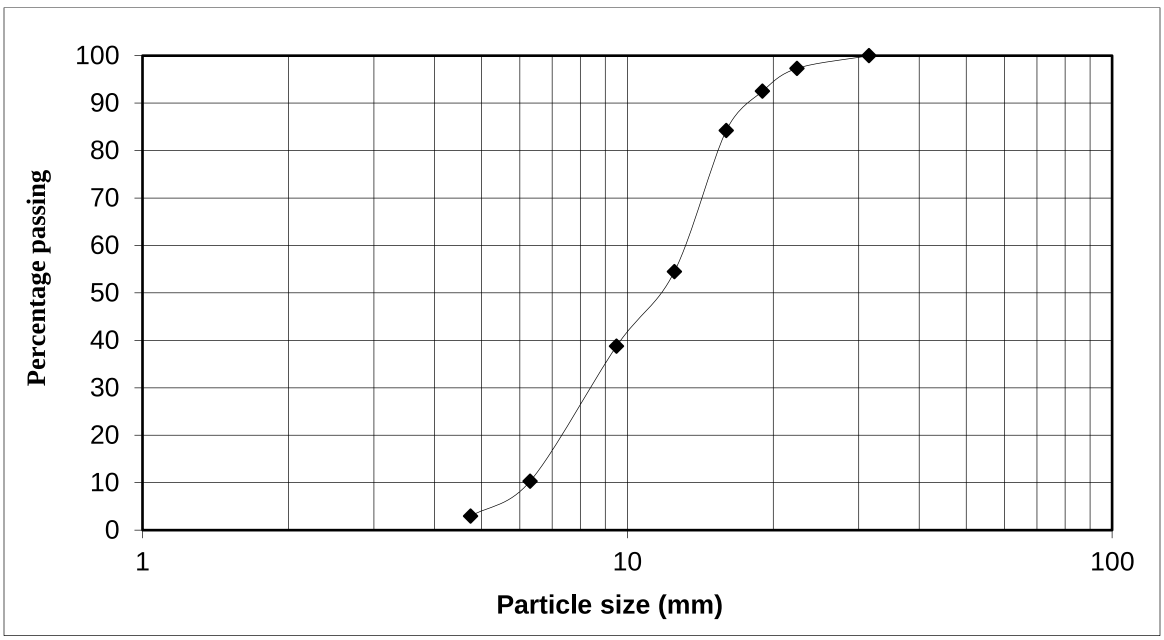

Figure 2: Particle size distribution curves for coarse aggregate

Table 2: Results of the Specific Gravity of Fine Aggregates

Specific gravity of fine aggregates		
Determinants	**Test 1**	**Test 2**
Weight of Empty Density Bottle (g) A	124.50	125.12
Weight of Bottle + Sample (g) B	134.48	135.10
Weight of Bottle + Sample +Water (g) C	184.43	185.03
Weight of Bottle + Water (g) D	178.35	178.93
Specific Gravity, Gs= (B-A)/((B-A)-(C-D))	2.56	2.53
Average Specific Gravity $(Gs_1+Gs_2)/2$	**2.55**	

Table 3: Results of the Specific Gravity of Coarse Aggregates

Specific gravity of coarse aggregates		
Determinants	**Test 1**	**Test 2**
Weight of Empty Bottle (g) A	930.12	930.58
Weight of Bottle + Sample (g) B	2395.57	2234.81
Weight of Bottle + Sample +Water (g) C	3104.93	3004.05
Weight of Bottle + Water (g) D	2193.00	2193.00
Specific Gravity Gs= (B-A)/((B-A)-(C-D))	2.65	2.64
Average Specific Gravity $(Gs_1+Gs_2)/2$	**2.65**	

3.2 Flexural Strength of AVG-Cement Concrete

3.2.1 Experimental Outcome

It was noted that the value of flexural strength increased as percentage addition of the admixture increased until an optimum percentage of 2.0% AVG was attained. After this point, values of flexural strength began to reduce. The experimental values of flexural strength of mix ratios 1:1.5:3 and 1:3:5 are plotted against their corresponding percentage AVG content as shown in Figures 3 and 4 respectively.

Flexural strength peaked at 9.78 N/mm² for 1:1.5:3 mix and 9.81 N/mm² for 1:3:5 mix at 28 curing days.

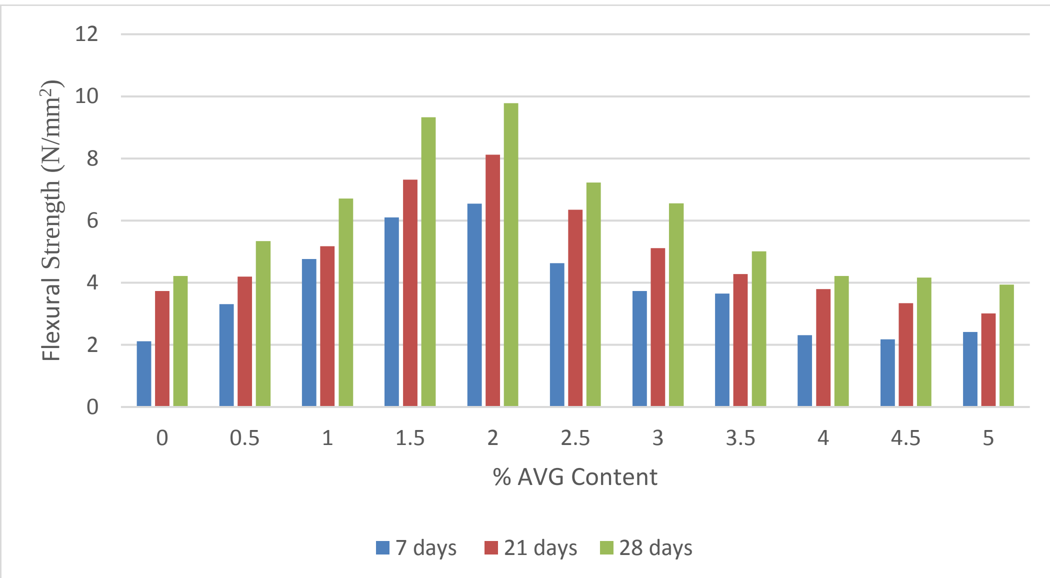

Figure 3: Variation of Flexural strength with different Curing periods for different percentage content of AVG-cement concrete at mix ratio of 1:1.5:3

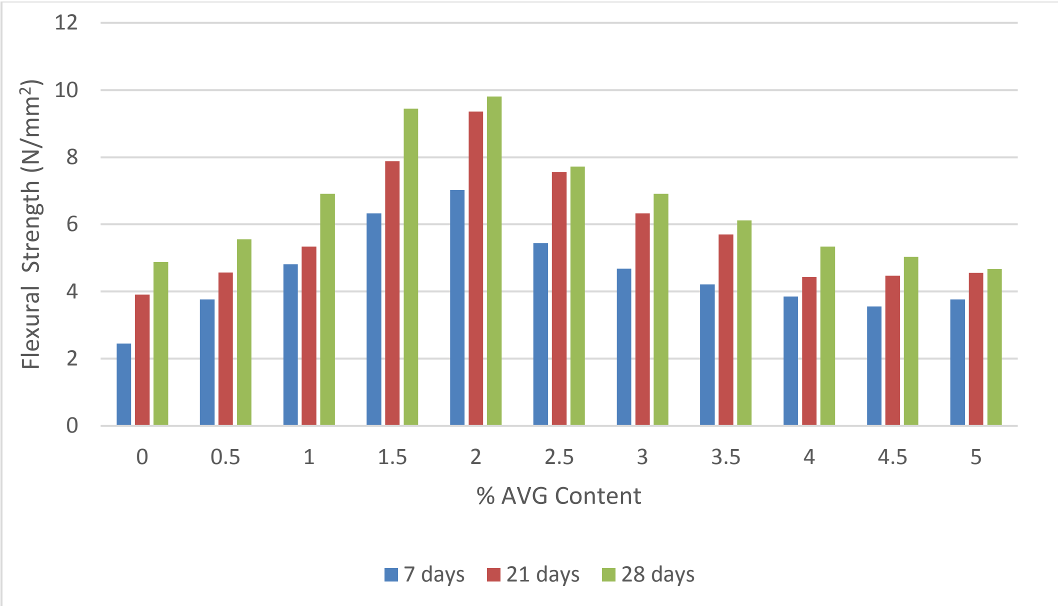

Figure 4: Variation of flexural strength with different Curing periods for different percentage content of AVG-cement concrete at mix ratio of 1:3:5

3.2.2 Fitting the model with the mixes used herein

Table 1 contain the values of quantities of mix components, x_1. x_1 was normalized and approximated at four decimal places such that condition of Equation 8 was not violated. The summation of x_1 in each mix ratio obtained from Table 1, was ensured to be equal to unity (in accordance with Equation 8). The values of x_1 obtained from Table 1 were used to determine the shape function and weighted response.

The transpose of the response of the odd number mix ratios is taken directly from mix proportions and is given as:

$[y^k]$ = [4.22 6.71 9.78 6.56 4.22 3.94]

The shape function for the 6 mixes (mix C1, C3, C5, C7, C9 and C11) was taken from mix proportions and substituted into Equations 1 and 2.

The transpose of the shape function is:

$[x^k] =$

5.57	0.108	0.271	0.621	0.000	0.012	0.073	0.386	0.000	0.029	0.067	0.000	0.168	0.000	0.000
5.58	0.108	0.271	0.62	0.002	0.012	0.073	0.384	0.000	0.029	0.066	0.000	0.168	0.000	0.001
5.59	0.107	0.27	0.619	0.004	0.011	0.073	0.383	0.000	0.029	0.066	0.000	0.167	0.001	0.002
5.6	0.107	0.269	0.618	0.005	0.011	0.072	0.382	0.000	0.029	0.066	0.000	0.166	0.001	0.003
5.61	0.107	0.269	0.617	0.007	0.011	0.072	0.381	0.000	0.029	0.066	0.000	0.166	0.002	0.004
5.62	0.107	0.269	0.616	0.009	0.011	0.072	0.379	0.000	0.029	0.066	0.001	0.166	0.002	0.005

The shape function and its transpose were substituted into Equation 14 to obtain CC matrix. In the same manner, the transpose of the shape function and the response vector from the first ten mixes were Substituted into Equation 13 to obtain the weighted response vector. The CC matrix and the weighted response vector are respectively presented as:

CC Matrix =

0.06913	0.17378	0.39832	0.00289	0.00730	0.04669	0.24634	0.01000	0.01868	0.04261	0.00011	0.10744	0.00064	0.00161
0.17378	0.43687	1.00136	0.00727	0.01835	0.11738	0.61928	0.01000	0.04695	0.10713	0.00027	0.27011	0.00162	0.00404
0.39839	1.00136	2.29527	0.01667	0.04206	0.26905	1.41948	0.01000	0.10762	0.24555	0.00062	0.61913	0.00370	0.00926
0.00289	0.00727	0.01667	0.00018	0.00030	0.00195	0.01029	0.01000	0.00078	0.00178	0.00001	0.00449	0.00004	0.00010
0.0073	0.01835	0.04206	0.00030	0.00077	0.00493	0.02602	0.01000	0.00197	0.00450	0.00001	0.01135	0.00007	0.00017
0.04669	0.11738	0.26905	0.00195	0.00493	0.03154	0.16639	0.01000	0.01262	0.02878	0.00007	0.07258	0.00043	0.00108
0.24633	0.61928	1.41948	0.01029	0.02602	0.16639	0.87787	0.01000	0.06656	0.15186	0.00038	0.38289	0.00229	0.00572
0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010	0.01000	0.00010	0.00010	0.00010	0.00010	0.00010	0.00010
0.01868	0.04695	0.10762	0.00078	0.00197	0.01262	0.06656	0.01000	0.00505	0.01151	0.00003	0.02903	0.00017	0.00044
0.04261	0.10713	0.24555	0.00178	0.00450	0.02878	0.15186	0.01000	0.01151	0.02627	0.00007	0.06623	0.00040	0.00100
0.00011	0.00027	0.00062	0.00001	0.00001	0.00007	0.00038	0.01000	0.00003	0.00007	0.00001	0.00017	0.00000	0.00001
0.10744	0.27011	0.61913	0.00450	0.01135	0.07258	0.38289	0.01000	0.02903	0.06623	0.00017	0.16701	0.00100	0.00249
0.00064	0.00162	0.00370	0.00004	0.00007	0.00043	0.00229	0.01000	0.00017	0.00040	0.00000	0.00100	0.00001	0.00002
0.00161	0.00404	0.00926	0.00010	0.00017	0.00108	0.00572	0.01000	0.00044	0.00099	0.00001	0.00249	0.00002	0.00006

Weighted Response Matrix, F

$$F = \begin{vmatrix} 3.80194 \\ 9.56231 \\ 21.9195 \\ 0.15034 \\ 0.40066 \\ 2.57167 \\ 13.5583 \\ 0 \\ 1.02747 \\ 2.3426 \\ 0.00394 \\ 5.91302 \\ 0.03266 \\ 0.08253 \end{vmatrix}$$

Substituting the CC matrix and the weighted response vector obtained hitherto into equation 12b and solving the equation gave the coefficient vector of the model as:
Coefficient vector:

$[a]^T =$

$[55.41 \quad -202.49 \quad 278.01 \quad -199.05 \quad 258.25 \quad 180.11 \quad -367.90 \quad 0.14 \quad 141.93 \quad 243.31 \quad -323.62 \quad -70.53 \quad 62.33 \quad -69.65]^T$

Substituting the model coefficients into Equation 9c gives the response function for the mix ratios used herein as

$$\begin{aligned} y_1 = {} & 55.41x_1 - 202.49x_2 + 278.01\,x_3 - 199.05\,x_4 + 258.25\,x_1{}^2 + 180.11x_2{}^2 - 367.90x_3{}^2 + 0.14\,x_4{}^2 \\ & + 141.93x_1x_2 + 243.31x_1x_3 - 323.62x_1x_4 - 70.53\,x_2x_3 + 62.33x_2x_4 \\ & - 69.65\,x_3x_4 \end{aligned} \tag{16}$$

$$\begin{aligned} y_2 = {} & -1.01x_1 + 8.01x_2 + 6.39\,x_3 - 0.84\,x_4 - 2.60\,x_1{}^2 + 0.14x_2{}^2 + 10.77x_3{}^2 - 2.37\,x_4{}^2 + 11.51\,x_1x_2 \\ & - 23.70\,x_1x_3 + 2.43\,x_1x_4 - 14.59\,x_2x_3 - 1.67\,x_2x_4 \\ & + 2.86\,x_3x_4 \end{aligned} \tag{17}$$

Equation 16 and 17 are the models for prediction of 28days' of flexural strength of AVG-cement concrete for mix ratio 1:1.5:3 and 1:3:5 respectively for the selected mix ratios

3.2.3 Test for adequacy of the model

A two-tailed Student's T-test was conducted, and the results are presented in Tables 4 and 5. The property of AVG-cement concrete used to validate this model is its flexural strength, which is crucial for predicting and optimizing concrete performance and sustainability. The computed T-value for the model was -0.94, which is lower than the standard T-value of 2.78 derived from standard statistical tables. The adequacy test confirms that the model's results are dependable and can be used to predict the flexural strength of AVG-cement concrete at 7, 21, and 28 days of curing with a 95% confidence level. This demonstrates that Ibearugbulem's model is reliable and suitable for strength prediction.

Table 4: Statistical student's T-test for Ibearugbulem's model validation using the 28 days Flexural strength of mix ratio 1:1.5:3

S/No.	E_x	N_p	$D_i=E_x-N_p$	$D_A=(\sum D_i)/N$	D_A-D_i	$(D_A-D_i)^2$
1	5.34	6.46	-1.12	-0.6	0.54	0.29
2	7.33	5.94	1.39	-0.6	-1.99	3.96
3	7.23	6.02	1.21	-0.6	-1.81	3.28
4	5.01	5.81	-0.80	-0.6	0.20	0.04
5	4.17	5.45	-1.28	-0.6	0.68	0.46

Table 5: Statistical student's T-test for Ibearugbulem's model validation using the 28 days Flexural strength of mix ratio 1:3:5

S/No.	E_x	N_p	$D_i=E_x-N_p$	$D_A=(\sum D_i)/N$	D_A-D_i	$(D_A-D_i)^2$
1	5.56	6.346	-0.79	-0.78	0.01	0.0001
2	9.44	10.256	-0.82	-0.78	0.04	0.002
3	7.72	8.234	-0.51	-0.78	-0.27	0.07
4	6.12	7.278	-1.15	-0.78	-0.37	0.14
5	5.58	6.234	-0.65	-0.78	-0.13	0..02

Where;
E_x = Experimental responses.
N_p=Ibearugbulem Model responses.
N = the Number of Responses = 5
For Mix ratio 1:1.5:3;
$\sum D_i$= -0.52
$\sum (D_A - D_i)^2 = 8.03$
$s^2 = [\sum (D_A - D_i)^2] / (N-1) = 2.01$
$S=\sqrt{s^2} = 1.42$
$D_A \times \sqrt{N} = -1.34$
$T = [D_A \times \sqrt{N}]/S = -0.94$
Degree of freedom = N-1
5% significance for a two-tailed test = 0.05
From standard statistical table, $T = T_{(0.05, n-1)} = T_{(0.05,4)} = 2.78$
For Mix ratio 1:3:5;
$\sum D_i$= -3.92
$\sum (D_A - D_i)^2 = 0.23$
$s^2 = [\sum (D_A - D_i)^2] / (N-1) = 0.058$
$S = \sqrt{s^2} = 0.48$

$D_A \times \sqrt{N} = -1.56$
$T = [D_A \times \sqrt{N}]/S = -3.25$
Degree of freedom = N-1
5% significance for a two-tailed test = 0.05
From standard statistical table, $T = T_{(0.05,\ n-1)} = T_{(0.05,4)} = 2.78$

4.0. Conclusion

A statistical analysis was conducted on the regression model created to estimate the flexural strengths of AVG-cement concrete at 1:1.5:3 mix ratio. The computed t-value of 0.94 was determined to be lower than the critical t-value of 2.78 from the statistical table at a 5% significance level. This suggests that the flexural strength results from both the experiment and the model are well-aligned. Therefore, It can be concluded that the regression model is appropriate for forecasting the 28th-day flexural strengths of AVG-cement concrete with a 95% confidence level.. This model is practically applicable in the concrete and construction industries for forecasting the flexural strengths of AVG-cement concretes with mix ratios that fall within the defined limits.

5.0 Recommendation

i. Extensive research should be carried out on the use of advanced models like artificial intelligence techniques such as artificial neural network, fuzzy-logic and adaptive network based fuzzy-inference system, to predict fresh and hardened properties of AVG-cement concrete.
ii. Extra studies should be carried be out on the adoption of other natural admixtures such as potato starch, cassava starch, eggshell, jiggery powder etc

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