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# Application of Scheffe's Model in Optimization of Compressive Strength of Lateritic Concrete 

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#### Abstract

In this research work, the use of Scheffe's simplex theory for the optimization of the compressive strength of lateritic concrete was investigated. The objective of the study is to develop a model that can predict the mix ratio when the desired compressive strength is known or vice-versa. A total of sixty (60) concrete cubes were cast. For each of the twenty mix ratios, three cubes were cast and the average determined. The first thirty cubes were used to determine the coefficients of the model while the other thirty cubes were used to validate the model (control test). The optimum compressive strength of concrete at 28 days curing was found to be $25.04 \mathrm{~N} / \mathrm{mm}^{2}$ and the corresponding mix ratio was 0.6:1:1.75:1.75 (water, cement, laterite, granite). The model was found to be adequate for prescribing concrete mix ratios, when the desired compressive strength is known and vice-versa.


Keywords: Compressive strength, Scheffe's model, Lateritic concrete, Curing.
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## INTRODUCTION

Concrete mix design could be carried out using either the empirical or statistical experimental method [1]. For instance, optimization of mix proportions of mineral aggregates for use in polymer concrete was attempted using statistical techniques [2]. There have been some advances in statistical experimental design for performing tests on concrete but these do not explicitly take into consideration the chemistry involved [3]. The supplementary cementitious materials optimization system has been developed [4]. The method is a decision making system that enables the reduction of portland cement in concrete by determining the optimum level of replacement by supplementary cementitious materials. New mix designs for fresh and hardened concrete were developed in order to create constructions materials with high performance [5]. Some of the statistical experimental methods include simplex design [6, 7] and [8], axial design, mixture experiments involving process variables, mixture models with inverse terms [9] and Kmodel [10]. Empirical methods are prone to trial and error which results in material wastage whenever they are used [11]. Sequel to this, statistical experimental method could be adopted using simplex design. The materials used in such experiments include water, cement, laterite and granite. There is the need to formulate mathematical models that will prescribe concrete mix ratios, when the desired compressive strength is known and vice-versa. Similarly, the need to determine the combination of the materials that would give the highest compressive strength should be met.
In this paper, the Scheffe's mathematical model was adopted in the optimization of compressive strength of lateritic concrete.

## LITERATURE REVIEW

Concrete is a mixture of several component such as cement, fine aggregate, coarse aggregate and water. According to [12], concrete is known to be a composite inert material comprising of binder course (cement) and mineral filler (body) or aggregate and water. Admixture could be added but for given set o of materials the proportion of the components influences the properties of the concrete mixture, hence, the need to optimize concrete properties such as strength. Mathematical modeling is the process of creating a mathematical representation of some phenomenon in order to gain a better understanding of that phenomenon [13]. Lasis, Ogunjimi [14] described a model as an abstract that uses mathematical language to control the behaviour of a giving system According to [15], modeling is mathematical equation of dependent variable (Response) and independent variable (Predictor). Manasce et al [16] from their studies
refers to it as a representation of a system. Simon etal, [1] stated that the area of application of mathematical modeling includes engineering and natural sciences.
Simon et al, [1]997) in their studies on high performance concrete, which contains many constituents and which are often subjected to several performance constrains can be a difficult and time consuming task. Simon et al [1], Ezeh, Ibearugbulem [11], Osadebe [15] in their different work demonstrated the application of mathematical modeling in Civil Engineering.

## MATERIALS AND METHODS

Simplex design formulation: The relation between the actual components and pseudo components is according to [6]
$\mathrm{Z}=\mathrm{AX}$ -
Z and X are four element vectors, where A is a four by four matrix. The value of matrix A will be obtained from the first four mix ratios. The mix ratios are $\mathrm{Z}_{1}$ [0.5:1:1:1], $\mathrm{Z}_{2}$ [0.55:1:1.5:2], $\mathrm{Z}_{3}[0.65: 1: 2: 1.5]$, $\mathrm{Z}_{4}[0.6: 1: 1.5: 1.5]$.
The corresponding pseudo mix ratios are $\mathrm{X}_{1}(1: 0: 0: 0], \mathrm{X}_{2}[0: 1: 0: 0], \mathrm{Z}_{3}[0: 0: 1: 0], \mathrm{Z}_{4}[0: 0: 0: 1]$. Substitution of $\mathrm{X}_{\mathrm{i}}$ and $Z_{i}$ into equation 1 gives the values of $A$ as
$\mathrm{A}=\left(\begin{array}{llll}0.5 & 0.55 & 0.65 & 0.6 \\ 1 & 1 & 1 & 1 \\ 1 & 1.5 & 2 & 1.5 \\ 1 & 2 & 1.5 & 1.5 \\ & & & \end{array}\right)$

The first four mix ratios are located at the vertices of the tetrahedron simplex. Six other pseudo mix ratios located at mid points of the lines joining the vertices of the simplex are
$\mathrm{X}_{12}\left[1 / 2:{ }^{1} / 2: 0: 0\right], \mathrm{X}_{13}\left[1 / 2: 0:{ }^{1} / 2: 0\right], \mathrm{X}_{14}\left[1 / 2: 0: 0:{ }^{1 / 2}\right], \mathrm{X}_{23}\left[0:{ }^{1 / 2}:^{1 / 2}: 0\right] \mathrm{X}_{24}\left[0:{ }^{1 / 2}: 0:{ }^{1} / 2\right], \mathrm{X}_{34}\left[0: 0:{ }^{1 / 2}:^{1 / 2}\right]$.
Substituting these values into equation (1) will give the corresponding actual mix ratios, Z as
$\mathrm{Z}_{12}[0.525: 1: 1.25: 1.5] \mathrm{Z}_{13}[0.575: 1: 1.5: 1.25]$
$\mathrm{Z}_{14}[0.55: 1: 1.25: 1.25] \mathrm{Z}_{23}[0.6: 1: 1.75: 1.75]$
$\mathrm{Z}_{24}[0.575: 1: 1.5: 1.75], \mathrm{Z}_{34}[0.625: 1: 1.75: 1.5]$
No pseudo component according to[6] should be more than one or less than zero. The summation of all the pseudo components in a mix ratio must be equal to one $[6,8]$.
That is
$0 \leq X_{i} \leq 1----------$ - 3 (3)
$\sum \mathrm{X}_{\mathrm{i}}=1$ -
The general equation for regression is given as

Where $1 \leq i \leq q, 1 \leq i \leq j \leq q, 1 \leq i \leq j \leq k \leq q$ and $1 \leq i 1 \leq i 1 \leq----\leq i n \leq q$ respectively [ 1$]$.
Expanding equation (5) up to second order polynomial for four component mixture, we obtain:
$\mathrm{Y}=\mathrm{b}_{\mathrm{o}}+\mathrm{b}_{1} \mathrm{X}_{1}+\mathrm{b}_{2} \mathrm{X}_{2}+\mathrm{b}_{3} \mathrm{X}_{3}+\mathrm{b}_{4} \mathrm{X}_{4}+\mathrm{b}_{11 \mathrm{X}_{1}{ }^{2}+\mathrm{b}_{12} \mathrm{X}_{1} \mathrm{X}_{2}}$
$+b_{13} \mathrm{X}_{1} \mathrm{X}_{3}+\mathrm{b}_{14} \mathrm{X}_{1} \mathrm{X}_{4}+\mathrm{b}_{22 \mathrm{X}_{2}}{ }^{2}+\mathrm{b}_{23} \mathrm{X}_{2} \mathrm{X}_{3}$
$+b_{24} \mathrm{X}_{2} \mathrm{X}_{4}+\mathrm{b}_{33} \mathrm{X}_{3}{ }^{2}+\mathrm{b}_{34} \mathrm{X}_{3} \mathrm{X}_{4}+\mathrm{b}_{44} \mathrm{X}^{2}{ }_{4}+\mathrm{e}-----------(6)$
Multiplying equation 4 by $b_{o}$, we obtain
$\mathrm{b}_{0}=\mathrm{x}_{1} \mathrm{~b}_{\mathrm{o}}+\mathrm{x}_{2} \mathrm{~b}_{\mathrm{o}}+\mathrm{x}_{3} \mathrm{~b}_{0}+\mathrm{x}_{4} \mathrm{~b}_{0}---------------------(7)$
multiplying equation (4) again by $x_{i}$ and re-arranging we obtain
$\mathrm{x}_{1}{ }^{2}=\mathrm{x}_{1}-\mathrm{x}_{1} \mathrm{X}_{1}-\mathrm{x}_{2} \mathrm{Xi}------------------------(8)$
substituting equation (7) and (8) into equation (6) and collecting like terms together, we obtain
$Y=\theta_{1} X_{1}+\theta_{2} \mathrm{X}_{2}+\theta_{3} \mathrm{X}_{3}+\theta_{4} \mathrm{X}_{4}+\theta_{12} \mathrm{X}_{1} \mathrm{X}_{2}+\theta_{13} \mathrm{X}_{1} \mathrm{X}_{3}$
$+\theta_{14 X_{1} X_{4}}+\theta_{23} \mathrm{X}_{2} \mathrm{X}_{3}+\theta_{24 \mathrm{X}_{2} \mathrm{X}_{4}}$
$+\theta_{34 X_{3} X_{4}}+$ e-----------------------------(.9)
Where $\theta_{i}=b_{o}+b_{i}+b_{i i}$ and $\theta_{i j}=b_{i j}-b_{i}$

- $b_{i j}$ without loss of generality, $e$ is the estimated error and could be dropped from equation (9).

Hence
$\begin{aligned} \mathrm{Y}=\theta_{1} \mathrm{X}_{1} & +\theta_{2} \mathrm{X}_{2}+\theta_{3} \mathrm{X}_{3}+\theta_{4} \mathrm{X}_{4}+\theta_{12} \mathrm{X}_{1} \mathrm{X}_{2}+\theta_{13} \mathrm{X}_{1} \mathrm{X}_{3} \\ & +\theta_{14} \mathrm{X}_{1} \mathrm{X}_{4} \theta_{23} \mathrm{X}_{2} \mathrm{X}_{3}+\theta_{24} \mathrm{X}_{2} \mathrm{X}_{4}+\theta_{23} \mathrm{X}_{3} \mathrm{X}_{4}--\end{aligned}$

Let $n_{i}$ be the experimental compressive cube strength of any of the first four mix ratios, and $n_{i j}$ be the experimental compressive strength of the remaining six mix ratios that were used in this model formulation. Substituting for $n_{i}$ and the corresponding pseudo mix ratio into equation (10) gives

$$
\begin{equation*}
\mathrm{n}_{\mathrm{i}}=\theta_{\mathrm{i}} \tag{11}
\end{equation*}
$$

In the same way substituting $n_{i j}$ and the correspond pseudo mix ratio into equation (10) gives $n_{i j}=0.50_{i}+$ $0.05 \theta_{\mathrm{j}}+0.25 \theta_{\mathrm{ij}}--------------(12)$ Rearranging equations (11) and (12), we obtain $\theta_{\mathrm{i}}=\mathrm{n}_{\mathrm{i}}-------(13), \theta_{\mathrm{ij}}=$ $4 n_{i j}-2 n_{i}-2 n_{j}$ $\qquad$
Substituting equation (13) into equation (14) gives
$\theta_{i j}=4 n_{i j}-2 n_{i}-2 n_{j}-----------(15)$
Substituting equation (13) and (15) into equation (10) and collecting like terms will give $\mathrm{F}(\mathrm{x})=\mathrm{n}_{1} \mathrm{x}_{1}(1-$ $\left.2 \mathrm{x}_{2}-2 \mathrm{x}_{3}-2 \mathrm{x}_{4}\right)+\mathrm{n}_{2} \mathrm{x}_{2}\left(1-2 \mathrm{x}_{1}-2 \mathrm{x}_{3}-2 \mathrm{x}_{4}\right)+\mathrm{n}_{3} \mathrm{x}_{3}\left(1-2 \mathrm{x}_{1}-2 \mathrm{x}_{2}-2 \mathrm{x}_{4}\right)+\mathrm{n}_{4} \mathrm{x}_{4}\left(1-2 \mathrm{x}_{1}-2 \mathrm{x}_{2}-2 \mathrm{x}_{3}\right)+4 \mathrm{n}_{12} \mathrm{x}_{1} \mathrm{X}_{2}$
$+4 n_{13} X_{1} X_{3}+4 n_{14 X_{1} X_{4}}+4 n_{23} X_{2} X_{3}+4 n_{24 X_{2} X_{4}}+4 n_{34 X_{3} X_{4}-----------(16)}$
Now, multiplying equation (4) by 2 and subtracting 1 from both sides, we obtain
$2 x_{1}+2 x_{2}+2 x_{3}+2 x_{4}-1=1-----------------(17)$
Rearranging equation (17), we obtain
2x2-1=1-2x1-2x2-2x4---------------------[18]
Similarly
$2 \mathrm{x}_{2}-1=1-2 \mathrm{x}_{1}-2 \mathrm{x}_{3}-2 \mathrm{x}_{4}$
$2 \mathrm{x}_{3}-1=1-2 \mathrm{x}_{1}-2 \mathrm{x}_{2}-2 \mathrm{x}_{4}$
$2 \mathrm{x}_{4}-1=1-2 \mathrm{x}_{1}-2 \mathrm{x}_{2}-2 \mathrm{x}_{3}$
(21)

Substituting equation (18), (19), (20) and (21) into equation (16), we obtain
$\mathrm{F}(\mathrm{x})=\mathrm{n}_{1} \mathrm{X}_{1}\left(2 \mathrm{x}_{1}-1\right)+\mathrm{n}_{2} \mathrm{X}_{2}\left(2 \mathrm{x}_{2}-1\right)+\mathrm{n}_{3} \mathrm{X}_{3}\left(2 \mathrm{x}_{3}-1\right)+\mathrm{n}_{4} \mathrm{X}_{4} \quad\left(2 \mathrm{x}_{4}-1\right)+4 \mathrm{n}_{12} \mathrm{X}_{1} \mathrm{X}_{2}+4 \mathrm{n}_{13} \mathrm{X}_{1} \mathrm{X}_{3}+\mathrm{n}_{14} \mathrm{X}_{1} \mathrm{X}_{4}+$ $4 \mathrm{n}_{23} \mathrm{X}_{2} \mathrm{X}_{3}+4 \mathrm{n}_{24 \mathrm{X}}^{2} \mathrm{X} 4+4 \mathrm{n}_{34 \mathrm{X}} \mathrm{XX}_{4}-------------------(22)$
Equation (22) is the mathematical model equation.

## PROGRAM FOR COMPRESSVE STRENGTH

```
Private Sub ENDMNU_Click()
End
End Sub
Private Sub STARTMNU_Click()
Rem ONE COMPONENT
        Cls
        ' SCHEFFE'S SIMPLEX MODEL
    Print " THE PROGRAM WAS WRITTEN BY"
    Print: Print
    Print " MBADIKE ELVIS"
    Print:
    WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls
    Print: Print " THIS PROJECT IS A RESEARCH PROJECT"
    Print " CIVIL ENGINEERING"
    WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls
    Print " I ACKNOWLEDGE REV. PROF. NKEMAKOLAM NWAOLISA OSADEBE"
    Print " FOR INITIATING AND SUPERVISING THIS WORK"
    WWWWW = InputBox("CLICK OK. TO CONTINUE"): Cls
' CIVIL ENGINEERING DEPARTMENT, FUTO
    CT = 0: OPSTRENGTH = 0
    ReDim X(10),A(4,4),Z(4),N(10), B(4,4),ZZ(4):QQQ = 1
    Cls
    N1 = 21.48: N2 = 13.63: N3 = 14.96: N4 = 18.07: N5 = 19.85
    N6 = 21.18: N7 = 16.30: N8 = 25.04: N9 = 20.74: N10 = 20.59
4 QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED
COMPRESSIVE STRENGTH OR CALCULATING COMPRESSIVE STRENGTH GIVEN MIX RATIO?", "IF THE
STRENGTH IS KNOWN TYPE 1 ELSE TYPE 0", "TYPE 1 OR 0 and CLICK OK")
```

If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK and do so"): GoTo 5

If $\mathrm{QQ}=0$ Then GoTo 900
Rem ${ }^{* * *}$ CONVERSION MATRIX ***
$\mathrm{A}(1,1)=0.5: \mathrm{A}(1,2)=1: \mathrm{A}(1,3)=1: \mathrm{A}(1,4)=1$
$\mathrm{A}(2,1)=0.55: \mathrm{A}(2,2)=1: \mathrm{A}(2,3)=1.5: \mathrm{A}(2,4)=2$
$A(3,1)=0.65: A(3,2)=1: A(3,3)=2: A(3,4)=1.5$
$\mathrm{A}(4,1)=0.6: \mathrm{A}(4,2)=1: \mathrm{A}(4,3)=1.5: \mathrm{A}(4,4)=1.5$
YY = InputBox("WHAT IS THE DESIRED STRENGTH?"): YY = YY * 1
Rem ONE COMPONENT
$Q=-5: R=1: E=1$
50 For I = 1 To 4: X(I) = 0: Next I
$X(E)=1$
If $\mathrm{Q}=0$ Then GoTo 60
GoTo 2000
$55 \mathrm{E}=\mathrm{E}+1: \mathrm{Q}=\mathrm{Q}+1:$ GoTo 50
60 Rem TWO COMPONENTS
$\mathrm{R}=\mathrm{R}+1: \mathrm{F}=1: \mathrm{E}=2: \mathrm{T}=1: \mathrm{J}=1: \mathrm{W}=1: \mathrm{K} 1=0.9: \mathrm{K} 2=0.1: \mathrm{V}=6$
65 For $\mathrm{I}=1$ To 4 : $\mathrm{X}(\mathrm{I})=0$ : Next I
$X(F)=K 1: X(E)=K 2$
If $\mathrm{T}=6$ Then GoTo 70
If $\mathrm{J}=\mathrm{V}$ Then GoTo 80
If $\mathrm{W}=5$ Then GoTo 90
GoTo 2000
$67 \mathrm{~T}=\mathrm{T}+1: \mathrm{K} 1=\mathrm{K} 1-0.1: \mathrm{K} 2=\mathrm{K} 2+0.1:$ GoTo 65
$70 \mathrm{~J}=\mathrm{J}+1: \mathrm{E}=\mathrm{E}+1: \mathrm{K} 1=0.9: \mathrm{K} 2=0.1: \mathrm{T}=1:$ GoTo 65
$80 \mathrm{~J}=1: \mathrm{V}=\mathrm{V}-1: \mathrm{F}=\mathrm{F}+1: \mathrm{E}=\mathrm{F}+1: \mathrm{T}=1: \mathrm{W}=\mathrm{W}+1: \mathrm{K} 1=0.9: \mathrm{K} 2=0.1:$ GoTo 65
90 Rem THREE COMPONENTS
$\mathrm{R}=\mathrm{R}+1: \mathrm{E}=2: \mathrm{T}=1: \mathrm{J}=1: \mathrm{W}=1$
$\mathrm{K} 1=0.89: \mathrm{K} 2=0.01: \mathrm{K} 3=0.1$
100 For I = 1 To 5: X(I) $=0$ : Next I
If $\mathrm{E}=5$ Then $\mathrm{X}(2)=\mathrm{K} 3: \mathrm{X}(1)=\mathrm{K} 1: \mathrm{X}(\mathrm{E})=0.01$ : GoTo 110
$X(1)=K 1: X(E)=0.01: X(E+1)=K 3$
110 If $\mathrm{T}=99$ Then GoTo 120
If $\mathrm{J}=5$ Then GoTo 130
If $\mathrm{W}=10$ Then GoTo 140
GoTo 2000
$115 \mathrm{~T}=\mathrm{T}+1: \mathrm{X}(1)=\mathrm{X}(1)-0.01: \mathrm{X}(\mathrm{E})=\mathrm{X}(\mathrm{E})+0.01$ : GoTo 110
$120 \mathrm{~T}=1: \mathrm{J}=\mathrm{J}+1: \mathrm{E}=\mathrm{E}+1:$ GoTo 100
$130 \mathrm{~J}=1: \mathrm{T}=1: \mathrm{W}=\mathrm{W}+1: \mathrm{E}=2: \mathrm{K} 1=\mathrm{K} 1-0.1: \mathrm{K} 3=\mathrm{K} 3+0.1:$ GoTo 100
140 Rem THREE COMPONENTS CONTINUED
$\mathrm{R}=\mathrm{R}+1: \mathrm{E}=2: \mathrm{T}=1: \mathrm{J}=1: \mathrm{W}=1$
$\mathrm{K} 1=0.69: \mathrm{K} 2=0.11: \mathrm{K} 3=0.2$
150 For I = 1 To 5: X(I) = 0: Next I
If $\mathrm{E}=4$ Then $\mathrm{X}(2)=\mathrm{K} 3: \mathrm{X}(1)=\mathrm{K} 1: \mathrm{X}(\mathrm{E})=\mathrm{K} 2:$ GoTo 160
$\mathrm{X}(1)=\mathrm{K} 1: \mathrm{X}(\mathrm{E})=\mathrm{K} 2: \mathrm{X}(\mathrm{E}+1)=\mathrm{K} 3$
160 If $\mathrm{T}=99$ Then GoTo 170
If $\mathrm{J}=4$ Then GoTo 180
If $\mathrm{W}=8$ Then GoTo 190
GoTo 2000
$165 \mathrm{~T}=\mathrm{T}+1: \mathrm{X}(1)=\mathrm{X}(1)-0.01: \mathrm{X}(\mathrm{E})=\mathrm{X}(\mathrm{E})+0.01$ : GoTo 160
$170 \mathrm{~T}=1: \mathrm{J}=\mathrm{J}+1: \mathrm{E}=\mathrm{E}+1:$ GoTo 150
$180 \mathrm{~J}=1: \mathrm{T}=1: \mathrm{W}=\mathrm{W}+1: \mathrm{E}=2: \mathrm{K} 1=\mathrm{K} 1-0.1: \mathrm{K} 3=\mathrm{K} 3+0.1:$ GoTo 150
190 Rem FOUR COMPONENTS

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    \(\mathrm{R}=\mathrm{R}+1: \mathrm{E}=2: \mathrm{T}=1: \mathrm{J}=1: \mathrm{W}=1\)
    \(\mathrm{K} 1=0.79: \mathrm{K} 2=0.01: \mathrm{K} 3=0.1: \mathrm{K} 4=0.1\)
200 For I = 1 To 5: X(I) = 0: Next I
    If \(E=4\) Then \(\mathrm{X}(1)=\mathrm{K} 1: \mathrm{X}(2)=\mathrm{K} 4: \mathrm{X}(\mathrm{E})=\mathrm{K} 2: \mathrm{X}(\mathrm{E}+1)=\mathrm{K} 3:\) GoTo 210
    If \(\mathrm{E}=5\) Then \(\mathrm{X}(1)=\mathrm{K} 1: \mathrm{X}(2)=\mathrm{K} 3: \mathrm{X}(3)=\mathrm{K} 4: \mathrm{X}(\mathrm{E})=\mathrm{K} 2:\) GoTo 210
    \(X(1)=K 1: X(E)=K 2: X(E+1)=K 3: X(E+2)=K 4\)
210 If \(\mathrm{T}=99\) Then GoTo 220
    If J = 5 Then GoTo 230
    If \(\mathrm{W}=9\) Then GoTo 240
    GoTo 2000
\(215 \mathrm{~T}=\mathrm{T}+1: \mathrm{X}(1)=\mathrm{X}(1)-0.01: \mathrm{X}(\mathrm{E})=\mathrm{X}(\mathrm{E})+0.01\) : GoTo 210
\(220 \mathrm{~T}=1: \mathrm{J}=\mathrm{J}+1: \mathrm{E}=\mathrm{E}+1:\) GoTo 200
\(230 \mathrm{~J}=1: \mathrm{T}=1: \mathrm{W}=\mathrm{W}+1: \mathrm{E}=2: \mathrm{K} 1=\mathrm{K} 1-0.1: \mathrm{K} 4=\mathrm{K} 4+0.1:\) GoTo 200
240 Rem FOUR COMPONENTS CONTINUED
    \(\mathrm{R}=\mathrm{R}+1: \mathrm{E}=2: \mathrm{T}=1: \mathrm{J}=1: \mathrm{W}=1\)
    \(\mathrm{K} 1=0.59: \mathrm{K} 2=0.01: \mathrm{K} 3=0.2: \mathrm{K} 4=0.2\)
250 For \(\mathrm{I}=1\) To 4 : \(\mathrm{X}(\mathrm{I})=0\) : Next I
    If \(\mathrm{E}=4\) Then \(\mathrm{X}(1)=\mathrm{K} 1: \mathrm{X}(2)=\mathrm{K} 4: \mathrm{X}(\mathrm{E})=\mathrm{K} 2: \mathrm{X}(\mathrm{E}+1)=\mathrm{K} 3:\) GoTo 260
    \(\mathrm{X}(1)=\mathrm{K} 1: \mathrm{X}(\mathrm{E})=\mathrm{K} 2: \mathrm{X}(\mathrm{E}+1)=\mathrm{K} 3: \mathrm{X}(\mathrm{E}+2)=\mathrm{K} 4\)
260 If \(\mathrm{T}=99\) Then GoTo 270
    If J = 5 Then GoTo 280
    If \(\mathrm{W}=7\) Then GoTo 290
    GoTo 2000
\(265 \mathrm{~T}=\mathrm{T}+1: \mathrm{X}(1)=\mathrm{X}(1)-0.01: \mathrm{X}(\mathrm{E})=\mathrm{X}(\mathrm{E})+0.01\) : GoTo 260
\(270 \mathrm{~T}=1: \mathrm{J}=\mathrm{J}+1: \mathrm{E}=\mathrm{E}+1:\) GoTo 250
\(280 \mathrm{~J}=1: \mathrm{T}=1: \mathrm{W}=\mathrm{W}+1: \mathrm{E}=2: \mathrm{K} 1=\mathrm{K} 1-0.1: \mathrm{K} 4=\mathrm{K} 4+0.1:\) GoTo 250
290 Rem FOUR COMPONENTS CONTINUED AGAIN
    \(\mathrm{R}=\mathrm{R}+1: \mathrm{E}=2: \mathrm{T}=1: \mathrm{J}=1: \mathrm{W}=1\)
    \(\mathrm{K} 1=0.29: \mathrm{K} 2=0.01: \mathrm{K} 3=0.4: \mathrm{K} 4=0.3\)
300 For I = 1 To 4: X(I) = 0: Next I
    If \(\mathrm{E}=4\) Then \(\mathrm{X}(1)=\mathrm{K} 1: \mathrm{X}(2)=\mathrm{K} 4: \mathrm{X}(\mathrm{E})=\mathrm{K} 2: \mathrm{X}(\mathrm{E}+1)=\mathrm{K} 3:\) GoTo 310
    \(\mathrm{X}(1)=\mathrm{K} 1: \mathrm{X}(\mathrm{E})=\mathrm{K} 2: \mathrm{X}(\mathrm{E}+1)=\mathrm{K} 3: \mathrm{X}(\mathrm{E}+2)=\mathrm{K} 4\)
310 If \(\mathrm{T}=99\) Then GoTo 320
    If J = 5 Then GoTo 330
    If \(W=4\) Then GoTo 340
    GoTo 2000
\(315 \mathrm{~T}=\mathrm{T}+1\) : \(\mathrm{X}(1)=\mathrm{X}(1)-0.01: \mathrm{X}(\mathrm{E})=\mathrm{X}(\mathrm{E})+0.01\) : GoTo 310
\(320 \mathrm{~T}=1\) : J = J + 1: E = E + 1: GoTo 300
\(330 \mathrm{~J}=1: \mathrm{T}=1: \mathrm{W}=\mathrm{W}+1: \mathrm{E}=2: \mathrm{K} 1=\mathrm{K} 1-0.1: \mathrm{K} 4=\mathrm{K} 4+0.1:\) GoTo 300
340 Rem FOUR COMPONENTS CONTINUED AGAIN AGAIN
    \(\mathrm{R}=\mathrm{R}+1: \mathrm{E}=2: \mathrm{T}=1\)
350 For I = 1 To 4: X(I) = 0.25: Next I
    \(X(E)=0\)
360 If \(\mathrm{T}=6\) Then GoTo 370
    GoTo 2000
\(365 \mathrm{~T}=\mathrm{T}+1\) : \(\mathrm{E}=\mathrm{E}+1\) : GoTo 350
    Rem PRINTING OF RESULTS
    For I = 1 To 4: Z(I) = 0: Next I
    For \(\mathrm{I}=1\) To 4: For JJ = 1 To 4: Z(I) = Z(I) + A(I, JJ) * X(JJ): Next JJ: Next I
    If \(\mathrm{Z}(1)<0\) Or Z(2) < 0 Or Z(3) < 0 Or Z(4) < 0 Then GoTo 830
    If \(\mathrm{X}(1)<0\) Or X(2) < 0 Or X(3) < 0 Or X(4) < 0 Then GoTo 830
    If \(X(1)>1\) Or X(2) > 1 Or X(3) > 1 Or X(4) > 1 Then GoTo 830
    'If Z(2) \(+\mathrm{Z}(3)<1\) Then GoTo 830
```

If $\mathrm{Z}(2)>1$ Then GoTo 830
$\mathrm{Y}=\mathrm{X}(1){ }^{*}(1-2 * \mathrm{X}(2)-2 * \mathrm{X}(3)-2 * \mathrm{X}(4)-* \mathrm{~N} 1+\mathrm{X}(2) *(1-2 * \mathrm{X}(1)-2 * \mathrm{X}(3)-2 * \mathrm{X}(4)-* \mathrm{~N} 2+\mathrm{X}(3)$ * $(1-2$ * $\mathrm{X}(1)-2$ * $\mathrm{X}(2)-2$ * X(4) -2 * $\mathrm{X}(5))$ *N3
$\mathrm{Y}=\mathrm{Y}+\mathrm{X}(4) *(1-2 * \mathrm{X}(1)-2 * \mathrm{X}(2)-2 * \mathrm{X}(3)-* N 4+)^{*}(1-2 * \mathrm{X}(1)-2 * \mathrm{X}(2)-2 * \mathrm{X}(3)-2 * \mathrm{X}(4)) *+$ $4^{*} \mathrm{~N} 6 * \mathrm{X}(1) * \mathrm{X}(2)+4^{*} \mathrm{~N} 7$ * $\mathrm{X}(1)$ * $\mathrm{X}(3)$
$\mathrm{Y}=\mathrm{Y}+4^{*} \mathrm{~N} 8 * \mathrm{X}(1) * \mathrm{X}(4)+4 * \mathrm{~N} 9 * \mathrm{X}(1) * \mathrm{X}(5)+4 * \mathrm{~N} 10 * \mathrm{X}(2) * \mathrm{X}(3)$
If $\mathrm{Y}>$ OPSTRENGTH Then For $\mathrm{I}=1$ To $4: \mathrm{ZZ}(\mathrm{I})=0$ : Next I
If $\mathrm{Y}>$ OPSTRENGTH Then OPSTRENGTH = Y: For $\mathrm{I}=1$ To 4: For $\mathrm{JJ}=1$ To 4: ZZ(I) $=\mathrm{ZZ}(\mathrm{I})+\mathrm{A}(\mathrm{I}, \mathrm{JJ})$ * X(JJ): Next JJ: Next I

If Y > YY-0.05 And $Y<Y Y+0.05$ Then GoTo 810 Else GoTo 830
$810 \mathrm{CT}=\mathrm{CT}+1$
For $\mathrm{I}=1$ To 4: $\mathrm{Z}(\mathrm{I})=0$ : Next I
For $\mathrm{I}=1$ To 4
For JJ = 1 To 4
$\mathrm{Z}(\mathrm{I})=\mathrm{Z}(\mathrm{I})+\mathrm{A}(\mathrm{I}, \mathrm{JJ}) * \mathrm{X}(\mathrm{JJ})$
Next JJ
Next I
'If Z(2) > 1.01 Or Z(2) < 0.9998 Then GoTo 830
'If Z(1) < 0 Or Z(2) < 0 Or Z(3) < 0 Or Z(4) < 0 Or Z(4) < 0 Then GoTo 830
If QQQ = 25 Then QQQQ = InputBox("PRESS OK TO CONTINUE", , , 5500, 8500): QQQ = 1: Cls
QQQ = QQQ + 1
820 Print " Y = "; Format(Y, "0.00\#"),
Print " WATER "; Format(Z(1), "0.00\#"), ;
Print " CEMENT ", Format(Z(2), "0.00\#");
Print" LT ", Format(Z(3), "0.00\#");
Print " CA "; Format(Z(4), "0.00\#");
830
If $\mathrm{R}=1$ Then GoTo 55
If $R=2$ Then GoTo 67
If $\mathrm{R}=3$ Then GoTo 115
If $\mathrm{R}=4$ Then GoTo 165
If $\mathrm{R}=5$ Then GoTo 215
If $\mathrm{R}=6$ Then GoTo 265
If $R=7$ Then GoTo 315
If $\mathrm{R}=8$ Then GoTo 365
If $\mathrm{R}=9$ Then GoTo 395
If $R=10$ Then GoTo 455
If $R=11$ Then GoTo 515
If $\mathrm{R}=12$ Then GoTo 525 2100

Print: Print
If CT $=0$ Then Print " ${ }^{* * *}$ SORRY THE HARDNESS IS OUTSIDE THE FACTOR SPACE ***"
Print: Print
Print " OPTIMUM STRENGTH PREDICTABLE BY THIS MODEL IS "
Print OPSTRENGTH: Print
Print " THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:"
Print" WATER ="; ZZ(1); " CEMENT ="; ZZ(2); " LT ="; ZZ(3);
Print" CA="; ZZ(4);"
GoTo 22222
900
Cls
$\mathrm{Y}=0$
For $\mathrm{I}=1$ To 5: $\mathrm{X}(\mathrm{I})=0$ : Next I
Rem ${ }^{* * *}$ RESPONSE AT THE CHOSEN 10 POINTS ON THE FACTOR SPACE FOR THE MODEL ***
$\mathrm{N} 1=21.48: \mathrm{N} 2=13.63: \mathrm{N} 3=14.96: \mathrm{N} 4=18.07: \mathrm{N} 5=19.85$
$\mathrm{N} 6=21.18: \mathrm{N} 7=16.30: \mathrm{N} 8=25.04: \mathrm{N} 9=20.74: \mathrm{N} 10=20.59$
GoTo 3010

```
3010 Rem *** CONVERSION MATRIX ****
B}(1,1)=4.680851064: B(1,2)=3.358297872: B(1,3) = -0.323404255: B(1,4) =-1.787234043: B(1,5)
-2.740425532
B}(2,1)=-6.382978723:B(2,2)=-12.83404255: B(2,3)=3.531914894:B(2,4)=4.255319149:B(2,5)
5.191489362
B(3, 1) = -1.276595745: B(3,2) = 16.19319149: B(3,3) =-4.093617021: B(3,4)=-3.14893617: B(3,5) =
-4.161702128
B(4, 1) = 2.127659574: B(4, 2) =-4.855319149: B(4,3) =-0.510638298: B(4,4)=1.914893617
```

    Rem \({ }^{* * *}\) ACTUAL MIXTURE COMPONENTS ****
    Z(1) = InputBox("ENTER THE VALUE OF Water")
    Z(2) = InputBox("ENTER THE VALUE OF Cement")
    \(\mathrm{Z}(3)=\) InputBox("ENTER THE VALUE OF LT")
    \(\mathrm{Z}(4)\) = InputBox("ENTER THE VALUE OF CA")
    Rem *** PSEUDO MIXTURE COMPONENTS ***
    For I = 1 To 4
    For JJ = 1 To 4
    \(\mathrm{X}(\mathrm{I})=\mathrm{X}(\mathrm{I})+\mathrm{B}(\mathrm{I}, \mathrm{JJ}) * \mathrm{Z}(\mathrm{JJ})\)
    Next JJ
    Next I
    Rem \({ }^{* * *}\) CALCULATING THE STRENGTH (RESPONSE) \({ }^{* * * *}\)
    \(\mathrm{Y}=\mathrm{X}(1) *(1-2 * \mathrm{X}(2)-2 * \mathrm{X}(3)-2 * \mathrm{X}(4)-2 * \mathrm{X}(5)) * \mathrm{~N} 1+\mathrm{X}(2) *(1-2 * \mathrm{X}(1)-2 * \mathrm{X}(3)-2 * \mathrm{X}(4)-2\) *
    $\mathrm{X}(5))$ * $\mathrm{N} 2+\mathrm{X}(3) *(1-2 * \mathrm{X}(1)-2 * X(2)-2 * X(4)-2$ * $\mathrm{X}(5))$ * N3
$\mathrm{Y}=\mathrm{Y}+\mathrm{X}(4) *(1-2 * \mathrm{X}(1)-2 * \mathrm{X}(2)-2 * \mathrm{X}(3)-2 * \mathrm{X}(5)) * \mathrm{~N} 4+\mathrm{X}(5) *(1-2 * \mathrm{X}(1)-2 * \mathrm{X}(2)-2 * \mathrm{X}(3)-$
2 * $\mathrm{X}(4))$ *N5 + 4 * N6 * X(1) * X(2) + 4 * N7 * X(1) * X(3)
$\mathrm{Y}=\mathrm{Y}+4^{*} \mathrm{~N} 8 * \mathrm{X}(1) * \mathrm{X}(4)+4^{*} \mathrm{~N} 9 * \mathrm{X}(1) * \mathrm{X}(5)+4 * \mathrm{~N} 10$ *X(2) *X(3)
Print " Y = "; Format(Y, "0.00\#"),
Print " WATER "; Format(Z(1), "0.00\#"), ;
Print " CEMENT ", Format(Z(2), "0.00\#");
Print " LT ", Format(Z(3), "0.00\#");
Print " CA "; Format(Z(4), "0.00\#");
For I = 1 To 4: Print X(I),: Next I
22222
End

To validate the model, extra ten mix ratios (control) were determined and used in the ANOVA test. The aim of the test was to ascertain whether the different between the results of compressive strength from experiment and model was significant or not. If the different between the two results is significant, alternative hypothesis will be adopted. If the different between the two results is not significant, null hypothesis will be adopted. The mix ratios are shown in Table 1:

Table 1: Pseudo and actual mix ratios for the control test

| Points | Ratio of materials |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Water | Cement | Laterite | Granite | Water | Cement | Laterite | Granite |
|  | $\mathrm{X}_{1}$ | X2 | $\mathrm{X}_{3}$ | $\mathrm{X}_{4}$ | $\mathrm{Z}_{1}$ | $\mathrm{Z}_{2}$ | $\mathrm{Z}_{3}$ | $\mathrm{Z}_{4}$ |
| $\mathrm{C}_{1}$ | 0 | 0.5 | 0 | 0.5 | 0.575 | 1 | 1.5 | 1.75 |
| $\mathrm{C}_{2}$ | 0.15 | 0.15 | 0.35 | 0.35 | 0.595 | 1 | 1.6 | 1.5 |
| $\mathrm{C}_{3}$ | 0.4 | 0.1 | 0.2 | 0.3 | 0.565 | 1 | 1.4 | 1.35 |
| $\mathrm{C}_{4}$ | 0.1 | 0.1 | 0.4 | 0.4 | 0.34 | 1 | 1.65 | 1.5 |
| $\mathrm{C}_{5}$ | 0.25 | 0.3 | 0.25 | 0.2 | 0.5725 | 1 | 1.5 | 1.525 |
| $\mathrm{C}_{6}$ | 0.16 | 0.34 | 0.22 | 0.28 | 0.578 | 1 | 1.53 | 1.59 |
| $\mathrm{C}_{7}$ | 0.17 | 0.31 | 0.25 | 0.27 | 0.58 | 1 | 1.54 | 1.57 |
| $\mathrm{C}_{8}$ | 0.32 | 0.18 | 0.33 | 0.17 | 0.5755 | 1 | 1.505 | 1.43 |
| C9 | 0.26 | 0.34 | 0.30 | 0.10 | 0.572 | 1 | 1.52 | 1.54 |
| $\mathrm{C}_{10}$ | 0.5 | 0.25 | 0.25 | 0 | 0.55 | 1 | 1.375 | 1.375 |

Compressive strength test: The materials used for this test includes:

- Granite, which is free from deleterious substance with a maximum size of 20 mm .
- The cement used is dangote cement which is a brand of Ordinary Portland Cement and conform [17].
- The laterite used was obtained from Nekede in Owerri North L.G.A of Imo State; Nigeria.
- The water used is clean water from bore-hole.

The materials were batched by weight. Mixing was done manually using spade and hand trowel. $150 \mathrm{~mm} x$ $150 \mathrm{~mm} \times 150 \mathrm{~mm}$ concrete moulds were used for casting the concrete cubes. The concrete cubes were cured in water for 28 days. At the end of the hydration period the cubes were crushed and their compressive strength were determined according to the requirement of (BS [18].

## RESULTS AND DISCUSSION

The compressive strength test results are shown in table 2. Higher compressive strength was recorded at point $23\left(25.04 \mathrm{~N} / \mathrm{mm}^{2}\right)$. Although the mix ratio of $0.6: 1: 1.75: 1.75$ had low cement content, the high water/cement ratio of 0.6 seemed to be the major reason for this. Point 1 should have given higher compressive strength going by its high cement content but it had low water cement ratio of 0.5 it could be observed that water/cement ratio and cement content were not the only factors responsible for the behaviour of the compressive strength. This is so because the strength at point 23 is higher than that at point 1 irrespective of the fact that point 1 has lower water/cement ratio and higher cement content than point 23. According to Ezeh, Ibearugbulem [11], the hlghest compresslve strength predicted by the application of Sheffe's model in optimization of compressive strength of River Stone aggregate concrete is $37.62 \mathrm{~N} / \mathrm{mm}^{2}$ when the mix ratio is $0.5: 1: 2.4: 3.6$ (water-cement ratio, cement, river sand, river stone). Also the result obtained when Osadebe's model [15] was used to predict the compressive strength of concrete containing water-cement ratio, cement, fine aggregate, coarse aggregate in a mix ratio of 0.6:1:0.7:2.5 is $25.39 \mathrm{~N} / \mathrm{mm}^{2}$. These results shows that both Sheffe and Osadebe's model can be used in the optimization of compressive strength of concrete containing four or five mixture ingredients.

Table 2: Compressive strength results

| Points | Replicate $1\left(\mathrm{~N} / \mathrm{mm}^{2}\right)$ | Replicate 2 (N/mm $\left.{ }^{2}\right)$ | Replicate <br> $\left(\mathrm{N} / \mathrm{mm}^{2}\right)$ | Average compressive strength (N/mm $\left.{ }^{2}\right)$ |
| :--- | :--- | :--- | :--- | :--- |
| 1 | 19.69 | 23.40 | 21.36 | 21.48 |
| 2 | 13.58 | 11.82 | 15.50 | 13.63 |
| 3 | 17.10 | 14.00 | 13.78 | 14.96 |
| 4 | 17.00 | 19.30 | 17.91 | 18.07 |
| 12 | 18.90 | 20.90 | 19.76 | 19.85 |
| 13 | 25.40 | 17.15 | 21.00 | 21.18 |
| 14 | 12.60 | 20.20 | 16.09 | 16.30 |
| 23 | 24.76 | 22.05 | 28.31 | 25.04 |
| 24 | 20.45 | 15.78 | 26.00 | 20.74 |
| 34 | 17.72 | 24.15 | 19.90 | 20.59 |
| $\mathrm{C}_{1}$ | 17.52 | 26.10 | 20.81 | 21.48 |
| $\mathrm{C}_{2}$ | 29.10 | 22.85 | 28.92 | 26.96 |
| $\mathrm{C}_{3}$ | 21.90 | 28.10 | 23.33 | 24.44 |
| $\mathrm{C}_{4}$ | 5.60 | 3.70 | 4.03 | 4.44 |
| $\mathrm{C}_{5}$ | 20.45 | 29.10 | 26.90 | 25.48 |
| $\mathrm{C}_{6}$ | 25.60 | 18.21 | 25.98 | 23.26 |
| $\mathrm{C}_{7}$ | 26.41 | 24.00 | 19.81 | 23.41 |
| $\mathrm{C}_{8}$ | 20.75 | 25.15 | 27.00 | 24.30 |
| $\mathrm{C}_{9}$ | 19.85 | 27.74 | 25.90 | 23.85 |
| $\mathrm{C}_{10}$ | 23.90 | 19.08 | 22.96 |  |

The ANOVA test of the generated data are shown in table 3.

| $\mathrm{S}_{\mathrm{E}}{ }^{2}=\frac{\sum(\mathrm{YT}-\mathrm{YAT})^{2}}{\mathrm{~N}-1}=\frac{157.5374}{9}$ | $=17.504$ |
| :--- | :--- | :--- | :--- | :--- |
| $\mathrm{~S}_{\mathrm{T}}{ }^{2}=\frac{\sum(\mathrm{YE}-\mathrm{YAE})^{2}}{\mathrm{~N}-1}=\frac{364.4661}{9}$ | $=40.496$ |

Hence $S_{T}{ }^{2}=S_{j}{ }^{2}=40.496$
$\mathrm{S}_{\mathrm{E}}{ }^{2}=\mathrm{S}_{2}{ }^{2}=17.504$
$\frac{\mathrm{~S}_{1}{ }^{2}}{\mathrm{~S}_{2}{ }^{2}}=\quad \frac{40.496}{17.504}=2.31$

F-value from table is $\mathrm{F}_{\alpha}\left(\mathrm{V}_{1}, \mathrm{~V}_{2}\right)$
$=F_{0.05}(9,9)=3.18$
$\frac{1}{\mathrm{~F}}=\frac{1}{3.18}=0.3145$
Consequently, $\underline{1} \leq \underline{\mathrm{S}_{1}{ }^{2}} \leq \mathrm{F}$
F $\mathrm{S}_{2}{ }^{2}$

## $\therefore 0.3145 \leq 2.31 \leq 3.18$

Therefore, the difference between the experiment result and the model result was not significant. Hence, the model is adequate for use in predicting the probable compressive strength when the mix ratio is known and vice-versa.

Table 3: ANOVA test

| Points | YE | YT | YE-YAE | YT-YAT | $\left(\right.$ YE-YAE ${ }^{2}$ | $(\mathrm{YT}-\mathrm{YAT})^{2}$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\mathrm{C}_{1}$ | 21.48 | 21.48 | -0.578 | 1.696 | 0.3341 | 2.6764 |
| $\mathrm{C}_{2}$ | 26.96 | 13.63 | 4.902 | -6.154 | 24.030 | 37.8717 |
| $\mathrm{C}_{3}$ | 24.44 | 14.96 | 2.382 | -4.824 | 5.6739 | 23.2718 |
| $\mathrm{C}_{4}$ | 4.44 | 18.07 | -17.618 | -1.714 | 310.394 | 2.9378 |
| $\mathrm{C}_{5}$ | 25.48 | 19.85 | 3.422 | 0.066 | 11.710 | 0.00436 |
| $\mathrm{C}_{6}$ | 23.26 | 21.18 | 1.202 | 1.406 | 1.4448 | 1.9768 |
| $\mathrm{C}_{7}$ | 23.41 | 16.30 | 1.352 | -3.484 | 1.8279 | 12.1383 |
| $\mathrm{C}_{8}$ | 24.30 | 25.04 | 2.242 | 5.256 | 5.0265 | 27.6255 |
| $\mathrm{C}_{9}$ | 23.85 | 26.74 | 1.792 | 6.956 | 3.2113 | 48.3859 |
| $\mathrm{C}_{10}$ | 22.96 | 20.59 | 0.902 | 0.806 | 0.8136 | 0.6496 |
| Total | $\mathbf{2 2 0 . 5 8}$ | $\mathbf{1 9 7 . 8 4}$ |  |  | $\mathbf{3 6 4 . 4 6 6 1}$ | $\mathbf{1 5 7 . 5 3 7 4}$ |
| Average | $\mathbf{2 2 . 0 5 8}$ | $\mathbf{1 9 . 7 8 4}$ |  |  |  |  |

Legend: $\mathrm{YE}=$ experimental strength; $\mathrm{YAE}=$ average of the experimental strength.
YT = the model strength; YAT = average of the model strength
$\mathrm{N}=$ number of points of observation
$\mathrm{V}=$ degree of freedom, $\alpha=$ significant level.

## CONCLUSION

It was concluded that the highest compressive strength predicted by this model is $25.04 \mathrm{~N} / \mathrm{mm}^{2}$. The corresponding mix ratio is 0.6:1:1.75:1.75 [water, cement, laterite granite]. Again, the sheffe's model formulated was adequate and reliable at $5 \%$ risk for predicting the compressive strength of concrete made with the above mentioned materials.

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