Optimization Model for Mix Proportioning of Clay-Ricehusk-Cement Mixture for Animal Buildings

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ABSTRACT

Clay soil is one of the types of earth materials used for animal building constructions in Nigeria particularly in the rural areas. It is also used for other agricultural buildings. This clay soil generally has a very high swelling and shrinkage potential and is not favourable when used for building construction. The quality of clay as a building material can be improved but this depends on the addition of the correct stabilizer such as ricehusk and cement in a suitable proportion. In this study, a mathematical model was developed and used to optimize the mix proportion that will produce the maximum strength of clay-ricehusk-cement mixture using Scheffe's simplex lattice approach. The model formulated compares favourably with the experimental data. It also satisfies the student's t and Chi-square tests. The optimum value of strength predicted by this model is 18.204 N/mm^2 corresponding to a mix proportion of 77.80, 14.16 and 8.04 percent of clay, ricehusk and cement respectively at optimum water content of 23.22 %

Keywords: Animal buildings, optimization model, mix proportion, clay-ricehusk-cement mixture, Nigeria.

1. INTRODUCTION

Clay material is widely used for animal building constructions in Nigeria. It is also a material used for the provision of cheap houses and other rural infrastructures in most underdeveloped countries of the world. But a lot of problems are associated with the use of this material in building construction. Clay material has low resistance to rainwater penetration resulting in crumbling and structural failure. Its high shrinkage/swelling ratio results in major structural cracks when exposed to changing weather conditions and it has low resistance to abrasion and requires frequent repairs and maintenance. Recent research found that waste material such as ricehusk may be used for soil improvement (Agus and Gendut, 2000). Ricehusk ash based on pozzolanic activity has been noted as new horizons in construction materials and as cement replacement materials (Cook,et al., 1976; Cook, 1986). An encouraging results have been reported of wall panels made of mixture of rice husk and synthetic material (Beer et al; 1981). Ezeribe (1986) reported that ricehusk reduces the density of heavy soils. Rice husk either partly or completely burnt was a potential material for use in building construction

(Bodemuller, 1946; Stroeven and Bui, 1997; Agus and Gendut, 2000; Nicole et al., 2000; Jauberthie et al., 2003).

The objectives of this study are generally to explore the possibility of utilization of readily available and cheap raw materials such as rice husk and clay in conjunction with cement in producing blocks for animal building constructions. It is specifically to develop a statistically adequate model of clay-ricehusk-cement (CRC) mixture that is a predictor of the strength of the mixture given any mix proportion of the components of the mixture and vice versa.

2. MODEL DEVELOPMENT

Simplex lattice design proposed by Scheffe (1958) was used to formulate a mathematical model, which relates compressive strength of CRC mixture and its components ratios of clay, ricechusk, cement and water.

2.1 Simplex Lattice Design

In mixture experiment involving the study of properties of a q-component mixture which are dependent on the component ratio only, the factor space is a regular, (q – 1)-simplex. The relationship that holds for the component of the mixture is given as

$$\sum_{i=1}^{q} X_i = 1 \qquad (1)$$

where:

$X_i \geq 0$ = the component concentration

q = the number of components

Therefore, for a 4-component mixture the sum of all the proportions of the components must be unity. That means

$$X_1 + X_2 + X_3 + X_4 = 1 \qquad (2)$$

Where in this case:

X_1 = proportion of clay

X_2 = proportion of ricehusk

X_3 = proportion of cement

X_4 = proportion of water content

For quaternary system, q = 4, the regular simplex is a tetrahedron where each vertex represents a straight component, an edge represents a binary system, and a face a ternary one. Points inside the tetrahedron correspond to quaternary systems. (Fig.1). Each point in the tetrahedron therefore represents a certain composition of the quaternary system.

The component X_1 is therefore absent in the face X_2, X_3, X_4, but as tetrahedron sections parallel to the face approach vertex X_1, component X_1 in them grows in concentration.

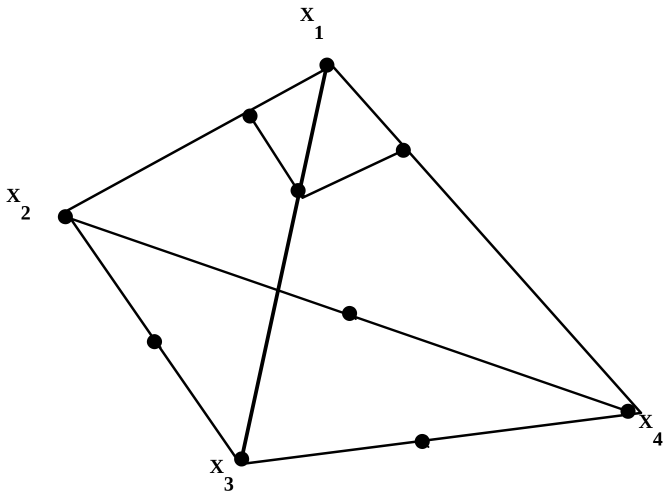

Figure 1. Tetrahedron and representative points

Scheffe (1958) showed that the response function (property) in multi-component system can be approximated by a polynomial. To describe such function adequately, high degree polynomials are required and hence a great many experimental trials. According to Scheffe (1958), a polynomial of degree n in q variable has $C_q^n + n - 1$ coefficients and is in the form:

$$\hat{y} = b_0 + \sum_{1\le i\le q} b_i X_i + \sum_{1\le i\le j\le q} b_{ij} X_i X_j + \sum_{1\le i\le j\le k\le q} b_{ijk} X_i X_j X_k + \dots + \sum b_{i_1 i_2 \dots i_n} x_{i_1} x_{i_2} x_{i_n} \quad \text{.......(3)}$$

The relationship given in equation (1) enables the equation component to be eliminated and the number of coefficients reduced to $C_q^n + n - 1$. But it is required that all the q components be introduced into the model.

Scheffe (1958) suggested that mixture properties can be described by reduced polynomials from Equation (3) subject to the normalization condition of Equation (1) for a sum of independent variables. The reduced second-degree polynomial for a quaternary system is derived as follows:

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{34}X_3X_4 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 \quad \text{......(4)}$$

since $X_1 + X_2 + X_3 + X_4 = 1$ … ……(5)

Then $b_0X_1 + b_0X_2 + b_0X_3 + b_0X_4 = b_0$ …… (6)

Multiplying Equation (4) by X_1, X_2, X_3, and X_4 in succession gives:

$$\left.\begin{aligned} X_1^2 &= X_1 - X_1X_2 - X_1X_3 - X_1X_4 \\ X_2^2 &= X_2 - X_1X_2 - X_2X_3 - X_2X_4 \\ X_3^2 &= X_3 - X_1X_3 - X_2X_3 - X_3X_4 \\ X_4^2 &= X_4 - X_1X_4 - X_2X_4 - X_3X_4 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Substituting Equation (6) and Equation (7) in Equation (4) and transforming, it gives:

$$\hat{Y} = (b_0 + b_1 + b_{11})X_1 + (b_0 + b_2 + b_{22})X_2 + (b_0 + b_3 + b_{33})X_3 + (b_0 + b_4 + b_{44})X_4 + (b_{12} - b_{11} - b_{22})X_1X_2 + (b_{13} - b_{11} - b_{33})X_1X_3 + (b_{14} - b_{11} - b_{44})X_1X_4 + (b_{23} - b_{22} - b_{33})X_2X_3 + (b_{24} - b_{22} - b_{44})X_2X_4 + (b_{34} - b_{33} - b_{44})X_3X_4 \quad \ldots\ldots\ldots\ldots (8)$$

Denoting:

$$\beta_i = b_0 + b_i + b_{ii}\,;\ \beta_{bj} = b_{ii} - b_{jj} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The reduced second-degree polynomial in four variables is thus arrived at as follows:

$$\hat{Y} = \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{14}X_1X_4 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{34}X_3X_4 \quad \ldots\ldots\ldots\ldots (10)$$

The solution of equation (9) as given by Scheffe (1958) for the coefficients of the polynomial is:

$$\beta_i = Y_i \text{ and } \beta_{ij} = 4Y_{ij} - 2Y_i - 2Y_j \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

where,

$\beta_i = \beta_1, \beta_2, \beta_3 \ldots\ldots, \beta_4$

$\beta_{ij} = \beta_{12}, \beta_{13}, \beta_{14} \ldots\ldots, \beta_{23}$

Y_i and Y_{ij} = reponse (property)

Equation (10) is the governing equation. Scheffe's simplex lattice designs provide a uniform scatter of points over the (q – 1) – simplex. The points form a (q -1) – lattice on the simplex where q is the number of mixture components, 'n' is the degree of polynomial. Scheffe (1958) showed that for each component, there exist (n + 1) similar levels, $x_i = 0, \frac{1}{n}, \frac{2}{n}, \ldots, 1$, and all possible mixtures are derived with such values of component concentration. So for (4, 2)- lattice the proportion of every component the must be used are 0, $\frac{1}{2}$ and 1. He also showed that the number of points in (q, n) lattice is given as:

$$\frac{q(q+1)\ldots(q+n-1)}{n!} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

where n is a digit number. This implies that for a (4, 2) lattice, the number of points (coefficients)

$$\frac{4\,(4+1)}{2\,x1} = 10$$

The (4, 2) lattice is shown in Figure 2.

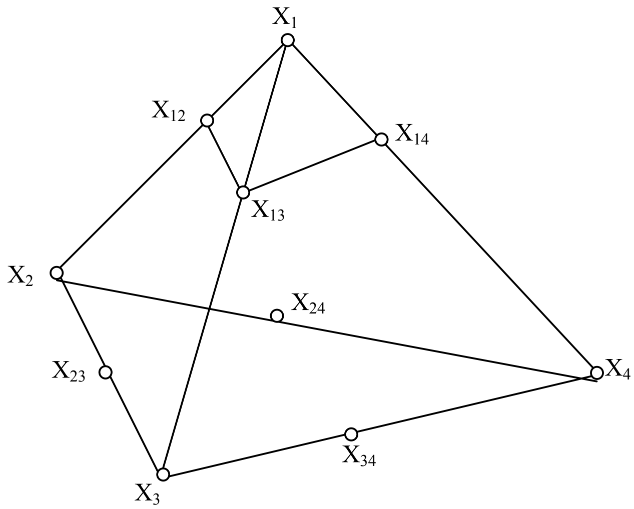

Figure 2. The (4, 2) – Lattice

2.2 Mix Design

In this design, the relationship that holds for the components of the mixture as given in equation (1) above was transformed to establish the actual component concentration. The transformed proportion X_i (I = 1-4) for each experimental points are called 'pseudo components'. For actual component Z_i the pseudo components X is given by

$X = BZ$

where B is the inverse of Z matrix. Similarly, the inverse transformation from pseudo components to Z_i (actual components) is expressed as

$Z = AX$

where A is the inverse transformation matrix.

The actual components for the first four points are chosen arbitrarily for the tetrahedron vertices (see Figure 3)

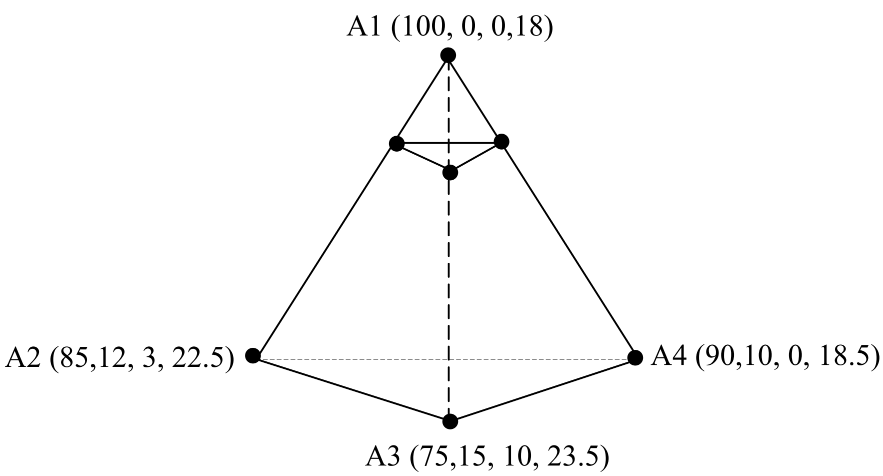

Figure 3. Tetrahedron Vertices for (4, 2) Lattice

The inverse transformation matrix 'A' is obtained since the Z_i (actual components) values and X_i (pseudo component) values are known. Thus for any pseudo component this is given by:

$$\begin{bmatrix} Z1 \\ Z2 \\ Z3 \\ Z4 \end{bmatrix} = \begin{bmatrix} 100 & 85 & 75 . & 90 \\ 0 & 12 & 15 & 10 \\ 0 & 3 & 10 & 0 \\ 18 & 22.5 & 23.5 & 18.5 \end{bmatrix} = \begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

This is employed to determine the actual components for all the experimental and control points. The ten control points were chosen such that they could be incorporated in the new design eg. the (4, 3) lattice should the (4, 2) lattice not fit adequately, thus the model can be refined. The pseudo components (X_i) and the actual components (Z_i) for the ten experimental and ten control points are as shown in Tables 1and 2

Table 1. Actual (Z_i) and Pseudo (X_i)Components for the Ten Experimental Points of (4, 2) Lattice

N	X_1	X_2	X_3	X_4	Y_{exp}	Z_1	Z_2	Z_3	Z_4
1	1	0	0	0	Y_1	100	0	0	18
2	0	1	0	0	Y_2	85	12	3	22.5
3	0	0	1	0	Y_3	75	15	10	23.5
4	0	0	0	1	Y_4	90	10	0	18.5
5	0.5	0.5	0	0	Y_{12}	92.5	6	1.5	20.25
6	0.5	0	0.5	0	Y_{13}	87.5	7.5	5	20.75
7	0.5	0	0	0.5	Y_{14}	95	5	0	18.25
8	0	0.5	0.5	0	Y_{23}	80	13.5	6.5	23
9	0	0.5	0	0.5	Y_{24}	87.5	11	1.5	20.5
10	0	0	0.5	0.5	Y_{34}	82.5	12.5	5	21

Table 2. Actual Components for the Test Points

N	X_1	X_2	X_3	X_4	C_{ex}	Z_1	Z_2	Z_3	Z_4
1	0	0.75	0.25	0.25	C_1	82.25	11.5	2.25	21.5
2	0	0	0.25	0.25	C_2	91.25	6.25	2.5	19.5
3	0.25	0.25	0.25	0.25	C_3	87.5	9.25	3.25	20.625

3. MATERIALS AND METHODS

The material investigated is the mixture of clay, ricehusk, cement, and water. The clay was obtained from clay deposit at Nsukka in Enugu State, Nigeria. Rice husk was from ricehusk dump site while the Portland cement was procured from the local market and water drawn from the clean water source.

3.1 Sample Preparation/Batching

The air dried clay was crushed and pulverized into powder. The clay material was passed through 2 mm sieve to remove any trace of foreign matter. The batching was by weight using a weighing scale. The dried clay material was thoroughly mixed with the ground ricehusk and cement. The thorough mixing was followed by the gradual addition of predetermined amount of water already obtained from the compaction test to the mixture. The mixing process was performed manually using shovel to stir continuously until a workable mix was obtained.

3.2 Compressive Strength Test

Cube specimens of size 100 mm x 100 mm were made and tested for compressive strength. Each specimen was made by filling each mould in three layers. The compaction that followed was in accordance with BS 1377; part 4:1990. The cubes were demoulded immediately after casting because of their rigidity. The cubes were covered with wet sack as soon as they were hard enough to withstand damage by water. The wet sack was used to provide humid condition for curing. Curing of cubes lasted for 28 days. The cubes were weighed and then subjected to crushing using compression testing machine. The maximum load applied at crushing was recorded. Two replicates of each of the mixture compaction were made. Therefore, for the ten experimental points and three control points, a total of 26 cubes were tested. The compressive strength (response) of clay-ricehusk-cement mixture was estimated from the formular given as:

$$\frac{Maximum\ Load}{Cross\ Sectional\ Area}\ \text{N/mm}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

4. RESULTS AND DISCUSSION

The results of the compaction test for the first four design points of the (4, 2)-lattice are shown in Table 3. The results in Table 3 serve as guides to the quantity of water and compaction required for the clay-ricehusk-cement mixture of vary compositions.

Table 3. Compaction Test Result

Experimental No.	Optimum Moisture Content (%)	Dry density Kg/m3
1	18	120
2	22.5	95
3	23.5	100
4	18.5	102

Table 4 shows the results of each of the 10 design points and the 3 test points of the (4, 2)-lattice. The compressive strength (response, Y) of each cube was obtained from equation 14 above.

Table 4. Compressive Strength Test Results of the (4, 2)

Expt. No (N)	**Replication**	**Response (Y_1)** N/mm^2	**Response Symbol**	$\sum_{i=1}^{n} Y_i$	$\bar{Y} = \frac{(\sum_{i=1}^{n} Y_i)}{n}$
1	1 2	12.0 10.0	Y_1	22	11
2	1 2	11.0 10.0	Y_2	21	10.5
3	1 2	18.0 16.0	Y_3	34	17
4	1 2	11.0 12.0	Y_4	23	11.5
5	1 2	9.0 10.0	Y_5	19	9.5
6	1 2	16.0 16.0	Y_6	32	16
7	1 2	13.0 14.0	Y_7	27	13.5
8	1 2	17.0 18.0	Y_8	35	17.5
9	1 2	10.0 10.0	Y_9	20	10
10	1 2	14.0 15.0	Y_{10}	29	14.5
11	1 2	9.0 12.0	C_1	21	10.5
12	1 2	13.0 15.0	C_2	28	14
13	1 2	13.0 17.0	C_3	30	15
					$\sum_{i=1}^{13} S_i^2 = 21.5$

4.1 The Regression Equation

From equation (11) and Table 4 the coefficients of the second degree polynomial equation are determined as follows:
$\beta_1 = 11$, $\beta_2 = 10.5$, $\beta_3 = 17$, $\beta_4 = 11.5$
$\beta_{12} = -5$; $\beta_{13} = 8$, $\beta_{14} = 9$, $\beta_{23} = 15$, $\beta_{24} = -4$, $\beta_{34} = 1.0$
Thus from Equation (10)

$$\hat{Y} = 11X_1 + 10.5X_2 + 17X_3 + 11.5X_4 - 5X_1X_2 + 8X_1X_3 + 9X_1X_4 + 15X_2X_3 - 4X_2X_4 - 1.0X_3X_4 \qquad (15)$$

Equation (15) is the regression equation for the compressive strength of CRC mixture as obtained in this study.

4.2 Test of Adequacy of Regression Model

The model was statistically analyzed using student-t and χ^2-test. The adequacy of the models was tested against the experimental results of the control points.
The t-table (= 2.65 is far greater than t-calculated in all the three test points (see Table 5.) Chi-square table (= 6.0) was also greater than chi-square calculated (0.139). The model is found adequate in both student-t and χ^2-tests.

Table 5. t-Statistics for the Test Points

N	Control points	$Y_{observed}$	$Y_{expt.}$	ΔY	T
1	C_1	10.5	10	0.5	0.42
2	C_2	14	14.8	0.8	0.69
3	C_3	15	14	1.0	0.91

4.3 Program Testing and Test Results

The optimization was achieved by a computer code written in Q-basic. Fig. 4 shows a flow chart that was developed for the computation of the proportions of clay-ricehusk-cement mixture corresponding to a desired strength. The optimization of strength using this model, gives a model predicted optimum value of strength of 18.204 N/mm^2. This corresponds to the optimum mix proportions of 8.04, 14.16, and 77.80 percent of cement, ricehusk and clay respectively at 23.22 % optimum water content. Relevant data that are synthesized from the raw printed data matching combinations for each of the desired strength are shown in Table 6.

From the synthesized data shown in Table 6, it is clearly observed that there is increase in the compressive strength property of clay when mixed with small quantity of ricehusk and cement.

The clay alone gives the least strength while the mixture of clay with highest percentage ratio of ricehusk and cement gives the highest strength value.

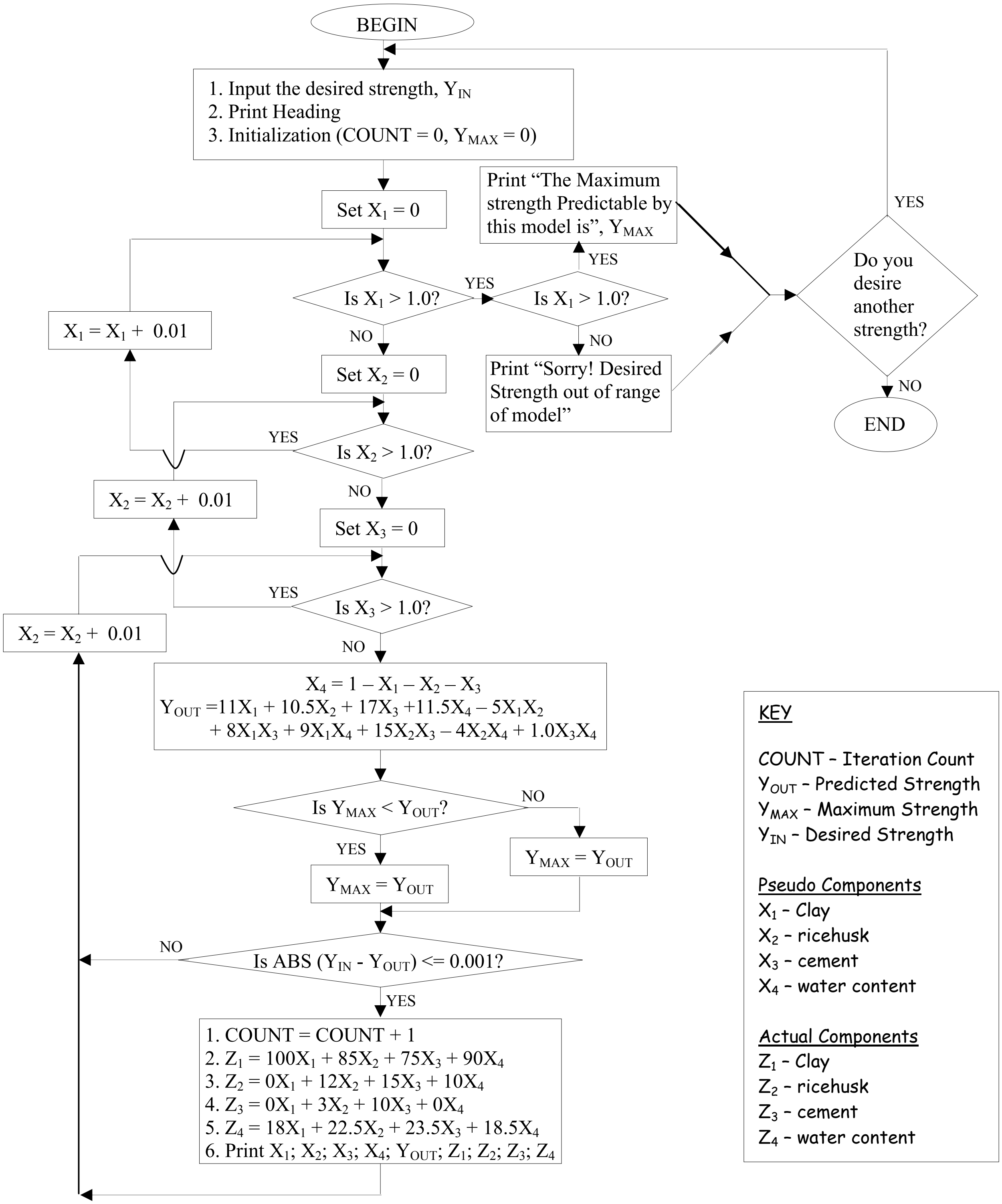

Figure 4. Flow Chart for Computation of Mix Proportions of CRC Mixture corresponding to a desired Strength

Table 6. Program Test Results

Desired Strength N/mm^2	Mix Proportions(kg)			
	Clay	Rice husk	Cement	Water content
11	100	0.00	0.00	18.0
12	90.3	9.32	0.38	18.80
13	91.60	7.88	0.52	18.74
14	92.50	6.11	1.39	19.04
15	90.10	6.97	2.93	19.76
16	87.10	7.97	.93	20.76
17	81.50	12.30	6.20	22.55
18	79.00	13.80	7.20	23.10
18.204 (optimum)	77.80	14.16	8.04	23.22

5. CONCLUSION

The experimental data is in very good agreement with the model formulated. The model parameters estimated are therefore acceptable. For optimum strength, the CRC mixture must contain 77.80, 14.16 and 8.046 percent at an optimum water content of 23.22%

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