A Rational Approach to Estimating the Cost of Laterite-Cement Bricks

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Abstract

A numerical method to estimate the cost of component proportions for laterite-cement brick production is developed using an all-in rate estimation of cost. The procedure employed a method related approach to minimize material, labour and plant cost which will enable achieving meeting specified requirement of cost. Three (3) mixture design approaches were employed for building up the material composition which enabled it possible to develop prediction equations for the cost: namely, the Scheffe's mixture theory, the Central Composite Design (CCD) method and a Traditional Trial Mix method. In using these approaches, a three component formulation of mixture using water, cement and laterite to produce laterite-cement bricks was carried out with cement content ranging within the domains of 8-20% by weight of laterite. The procedure is adaptable for a 10MN/m^2 compactive effort using the Hydraform Twin-M7 machine.

Keywords

Bricks, method related, estimate, trial mix, laterite, Scheffe's mixture

1. Introduction

The selection of constituent mixture proportions is fundamental for the production of a strong and durable laterite-cement bricks. Cost, therefore is a determinant where desired specifications are to be met within a project cost limit. Laterite-cement brick may be used as a permanent load and non load bearing walling material even without any protective coating. (Hydraform, 2014) Cost estimation is a process which involves determination of an all inclusive estimate of cost of materials, labour and plant cost. It is therefore desirable to develop a procedure capable of deriving at a cost method based on a method related approach. This class of compressed earth bricks are produced from machines which are primarily designed to exert compactive pressure in uniaxial direction (NBRRI, 2016; Hydraform, 2014; Cinva Ram, 1999) or more precisely, produced as a one dimensional compressed soil sample mass. The specific volume of this class of bricks reduces on compaction because the pore spaces are reduced during the mechanical stabilization process. The aim of this study was develop a methodology for building up unit rates using a numerical approach for laterite-cement composite bricks material from a user-defined requirements point of view. The objectives of this study were to carry out mix design, develop cost estimate using the three (3) procedures, compare with sandcrete block production and develop predictive equations for cost of laterite-cement bricks production.

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2. Use of Statistical Mixture Experimental Design

In using this procedure, experimental design points are used and material variables are fitted to the designated points. Then, empirical models are fitted for each of the cost as responses to be measured. The method also allows fitting models simultaneously for as many responses simultaneously. After detecting insignificant terms in a model, the final refined equations now form the cost prediction equation.

One of the importance of this statistical experimental design procedure is that the responses can be characterized by an uncertainty (variability) which has an important implication for specification writing for other measured responses, especially mechanical properties (FHWA, 1999; Simons et al, 1999). A number of responses can be fitted, in this case, it is the cost. The requirement of a model fitting is that at least 95 percent of the results are expected to fall within the normal distribution curve or more precisely, with probability $p \leq 0.05$. The model can be used to obtain the laterite-cement mix proportions that can be afforded with a specified amount of money. The use of the optimisation model can also be used to eliminate the arbitrary choice of mixes design and its associated disadvantages. In addition, it can be used to yield optimum laterite-cement brick mixtures, which minimize costs and satisfy specific performance requirements.

2. 1 The Concept of the Scheffe Mixture Polynomial

The Scheffe mixture polynomial can be used to fit and obtain cost prediction for mixtures. A triangular Simplex can be used to explore the properties of the component mixtures where the vertices of the triangle represent numerically, the pure components for a three variable component mixture.

In order to satisfy the requirement of this approach, the constituent proportions are estimated in absolute volume which is fixed and constrained to be summed equal to unity. This is a pre condition for using this method (Simons et al, 1999; Montgomery, 2001). The components in this particular case are water, cement and laterite. The constraint equation therefore is (Montgomery, 2001):

$$\sum_{i=1}^{n} x_i = 1 \qquad (1)$$

and $x_i \geq 0$

The standard form for response prediction of this second order-quadratic polynomial is expressed (Montgomery, 2001) as:

$$E(y) = \sum_{i=1}^{p} \beta_i x_i + \sum \sum_{i<j}^{p} \beta_{ij}\, x_i x_j \qquad (2)$$

$where$: $x_1 = water, x_2 = cement, x_3 = laterite$

Here the expressions x_1x_2, x_1x_3, x_2x_3 are the interaction terms while b_{12}, b_{13}, b_{23} are refered to as the coefficients of the interaction terms of water, cement and laterite.

In studying the effect of the properties of the mixture using a second-order quadratic polynomial design, it is possible to make predictions about the full properties within the Simplex by using an augmented [3, 2] lattice design. Mixtures proportions are fitted at the vertices of the Simplex within the range of mixture proportions considered. Additional runs in the interior of the Simplex are included (Montgomery, 2001; Mama and Osadebe, 2011; Mbadike and Osadebe, 2013). The augmented [3,2] Simplex lattice used and as shown in Figure 1 consists of ten runs of pure blend (1,0,0), (0,1,0), (0,0,1), (½, ½, 0), binary blends (½, 0, ½), (0, ½, ½), axial blends (⅔, ⅙, ⅙), (⅙, ⅔, ⅙), (⅙, ⅙, ⅔) and the centroid (⅓, ⅓, ⅓).

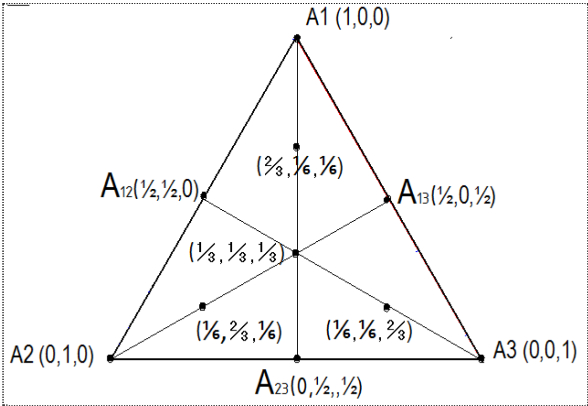

Figure 1: An augmented [3,2] Simplex lattice

In an attempt to keep within a practicable compositional boundary, which in this case all mixtures must be at optimum moisture content, a D-Optimal Design was used. The method of transformation to obtain mixtures for all design points can also be used as described by (Mama and Osadebe, 2011; Mbadike and Osadebe, 2013; Onwuka et al, 2011; Alao and Jimoh, 2017; Jimoh and Alao, 2017). Mixtures, specified in volumetric ratios called mix ratios at a given water cement ratio are fitted at the vertices in a manner as to yield an optimized mix.

2.2 The Central Composite Design

This is essentially a factorial experimental design employed for modeling a response as a second order quadratic model, (Simon et al, 1999). It is used to graphically depict the relationship between different mixture variables and their responses. The second order quadratic model is of the form (Montgomery, 2001):

$$y = \beta_0 + \sum_{i}^{k} \beta_i x_i + \sum \sum_{i<j} \beta_{ij} x_i x_j + \sum_{i}^{k} \beta_{ii} x_i^2 \qquad (3)$$

where *"y"* is the response. The values x_i's are the mixture variables and the parameters β_i and β_{ij} are calculated as the linear and quadratic coefficients fitting the experimental data, the x_i *and* x_{ij}*'s* are the linear and interactive terms respectively.

In the Central Composite Design method involving three components mixes here, the influence of all the mixture variables, factors and the interaction effects are investigated at two levels consisting 2^n experiments. This represents a cheaper design. The level of each factor is denoted by ± for low and high levels accordingly. A zero level is also included which represents the centre level. In addition to these factorial levels, three or four centre experiments are usually included in the factorial design (Montgomery, 2001).

A CCD therefore specifies $2^n + 2n + 1$ design points for a full quadratic model, where *n* is the number of factor variables. An advantage of the characteristic rotatability designs in CCD implies that it estimates the responses with equal precision at all points in the factor space that are equidistant from the centre point of the cube. This implies that predicted values should have equal variance at locations equidistant from the origin (Simon et al, 1999; Montgomery, 2001).

2. 3 The Traditional Trial Mix design method

This represents a progressive adjustment of mixture proportions within a selected design domain. This is however distinct from the Scheffe polynomial and the CCD Approach which have established design points capable of detecting curvatures, linear and curvi-linear relationships. The Traditional Trial Mix design method still however, represents a popular mix proportioning method. A good example is varying the mix ratios between two (2) percent cement content to weight of laterite through twenty (20) percent at an incremental step of two (2) percent (for example 2%, 4%, 6%, …, 20% cement content to the weight of laterite).

3. Methodology

3.1 Estimating of constituent proportions using the Absolute Volume method

In order to satisfy the equality condition in Equation (1), the constituent proportions can be estimated in absolute volume and constrained to be equal to unity. The practical expression of the equality constraint in Equation (1) can now be expressed in the estimation of the absolute volumes of each of the mixture factors (Neville, 1999; Aguwa, 2009) as:

$$\frac{cement}{\rho_{cement} \times 1000} + \frac{water}{\rho_{water} \times 1000} + \frac{laterite}{\rho_{laterite} \times 1000} = 1 \qquad (4)$$

where: ρ = specific gravity

Using an example of cement content of 20% of the dry weight of laterite, the mix ratio can be expressed as 1:5. Here, a starting water/cement ratio can be adopted as 0.5, which represents the assumed starting water required for the hydration of cement to produce a maximum dry density of the laterite cement mix. This of course, will later be replaced with mixing water at optimum moisture content. These steps are:

i) The ratio 1:5 represents one (1) part of cement and five (5) parts of laterite and water represent 0.5 by weight of cement. This ratio can be expressed as water:cement:laterte ratio 0.5:1:5. The laterite content can be expressed as Laterite, L=5*C. Subsequently, the water required based on the adopted initial water/cement ratio can similarly be expressed as Water, W=0.5*C
ii) The equation which satisfies the equality constraint condition of equation (4) can be re-written as:

$$\frac{0.5C}{1000} + \frac{C}{3.15 \times 1000} + \frac{5C}{2.64 \times 1000} = 1 \qquad (5)$$

collecting the like term and solving for the unknown Cement C, the solution can be obtained as: Cement, C = 368.81kg/m^3 ; Water, W = 0.5*C = 184.41kg/m^3 and laterite, L = 5*C = 1844.07kg/m^3. The design matrices used for the mix design are shown in Appendix A.1 (a) and (b). The mixes were at optimum moisture content.

3.2 Estimate of Cost

In building up unit rates for items in a Bill of Quantity (BOQ) and Bill of Engineering Measurement and Evaluation (BEME), current rates normally subsists. There is usually no hard rule or procedure for carrying out this process and hence a logical procedure is followed. Work Study and Work Measurement is a process normally employed for estimating time required to carry out a site operation. Labour outputs and existing rates were used in the build-up of rates here. Labour items are not taken care of. Similarly, only basic rates were used instead of an all-in rate. Profits and overheads are also not included.

The rate build-up for construction of sandcrete blockwall bedded and jointed in cement sand mortar using 225mm blocks per square meters was compared with the rate for the construction of laterite cement brick of same size. The rate build-up for laterite cement brick include:

i) rate build-up for the brick constituent materials of laterite and cement,
ii) production cost using hydraform moulding machine, and
iii) labour cost for laying.

An example each, of rates build-up for laterite-cement and rate for sandcrete blocks is presented in Tables 1 and 2.

Table 1 Rate build-up for Laterite-cement Brick Moulding

No	Labour			SingleMould	Twin Mould
1	Operator Hopper	@	3000	3000	6000
1	Operator Bucket	@	1500	1500	3000
1	Filler Block	@	1500	1500	3000
2	Carriers Mixing &	@	1500	3000	6000
4	Sieving	@	1500	6000	12000
	Cost of Labour/day (₦)			**15000**	**30000**
5	Diesel fuel/day (10ltrs)	@	200	2000	4000
6	Machine Hire/day			15000	25000
	Cost of plant & lab/day			**32000**	**59000**
	Machine Output/day			1500 brks.	3000 brks.
	Cost/brick			21	20
	Cost of prodn/Brick (₦)			**N21 / brk**	**N20 / brk**

	MATERIAL			COST /m^3	COST /m^3
1	$4.0m^3$ Tipper load	@	15000	***Laterite/m^3***	3750
1	Bag of Cement	@	2500	***Cement/m^3***	70000
		@	28 bags/m^3		
		@	480 brks/day		
	Labour Output For Laying Brks/Day				
	Labour (Skilled) (₦)	@	3000		
	Labour (Unskilled) (₦)	@	1500		
			4500	9.375	per brick
	Cost/m^2 is for 220mm brick is (20+10+32.4)*40=		**₦2496**	**≈N10/ brick**	

Table 2 Rate build-up for Sandcrete block-wall

• cement/m^3	1	@	28 bags	70000
• sand/m^3	4	@	3750/m^3	15000
• Unloading cement		@	N15/bag	420
				85420
• Add 25% voids				21355
• Cost per/m^3 of mortar	1 : 4			**21355**
• Labour (unskilled)/hrs for mixing	4	@	26.78571	107.1429
				21462.14
• 225mm/m^2 Blocks in cement mortar 1:4 (10 blocks/m^2)		@	170	1700
• Add 5% cutting waste				85
• Unload/10 blocks ($1m^2$)		@	0.12hrs	25.71429
• Mortar @ $0.011m^3/m^2$				236.0836
• Add 5% waste				11.80418
Cost of Laying 225mm Blocks				
• 1.2 Skilled Hours (per m^2)				514.2857
• 0.6 Unskilled Hours (per m^2)				128.5714
• Cost/m2 of 225mm sandcrete block bdd & jtd in cement sand mortar is:				**₦2701.459**

Cement	2500	per bag		
Labour (Unskilled)	1500	per day	214.2857	per hour
Labour (Skilled)	3000	per day	428.5714	per hour

4. Discussion of Results

The modeling of response predictions for laterite-cement mixes for cost were carried out using the second-order quadratic polynomial in equation for the Scheffe Mixture method and CCD with the Design-Expert software. The Traditional Trial Mix approach was modeled using a linear regression with Analyze-it software. The results have shown that brick with higher cement content corresponds with higher cost. The relationship is inherently linear. The response prediction models for cost can be used to achieve the Builder's all inclusive cost which will obviously allow planning and cost control to be achieved on a construction site.

4.1 The predictive equations for cost

The predicted equations for cost are shown in Equations (6), (7) and (8).

$$Cost - MX = -9.48243 * Water + 236.04554 * Cement \\ +24.41443 * Laterite \tag{6}$$

$$Cost - CCD = 22.97628 + 0.064321 * Cement \\ -0.00398027 * Laterite \tag{7}$$

$$Cost - Trial = -4.5816E - 011 + 0.1237 * Cement \\ +0.007906 * Laterite \tag{8}$$

4.2 Description of the Response Prediction

A low value of $p \leq 0.05$ statistical significance shows that a model and the coefficients are significant and should be included in the model. The response prediction equations obtained reflected the form of the statistical method. By default, the Mixture method does not include the intercept because in the Scheffe quadratic polynomial expression, the polynomial equation has been re-parameterized and therefore the constant term eliminated. There is a constant term in the CCD method. The Trial mix prediction model similarly has a constant term. Interaction terms that are not included in the model also shows that they are not significant because probability $p \geq 0.05$. The cost of material, machine moulding and labour forms the basis for an all-inclusive cost build-up for production of the brick. This however, is a dynamic process as it is continually influenced by market inflation rate. The cost of water is not included because water is normally priced under preliminaries in construction works.

5. Conclusions and Recommendations

In using the method of mixture proportioning, it has been shown that cost of laterite-cement bricks production can be modeled and can be useful in cost planning and decision making process. The predictive equations can similarly be used to estimate the cost per component mixes for laterite-cement mixes.

References

Aguwa, J. I (2009), Study of Compressive Strength of Laterite-Cement Mixes as a Building Material, Assumption University Journal of Technology. 13(2), 114-120.

Alao, T. O and Jimoh, A. A. (2017). Performance Criteria Design of Mixture Proportions for Laterite-Cement Bricks using The Schéffé Mixture Approach,. Journal of Research Information in Civil Engineering, University of Ilorin, Ilorin, Nigeria, 14 (3),. 1626-1649.

Cinva Ram (1999). A technical handbook/manual for the CINVARAM Brick Machine.

Design-Expert (2000). Stat-Ease Corporation, Available at www.stat-ease.com

FHWA (1999). Concrete Mixture Optimization Using Statistical Methods. http://www.fhwa.dot.gov/publications. [November 10, 2014]

Hydraform (2014). Available at www.hydraform.com. [June 10, 2014].

Jimoh A. A. and Alao, T. O. (2017). A Central Composite Design Method for Design of Mixture Proportion for Laterite-Cement Brick. Journal of Epistemics in Science, Engineering and Technology (ESET), 7(1), 499-512.

Mama, B. O. and Osadebe, N. N. (2011). Mathematical Model for the Optimization of Compressive Strength of Laterized Sandcrete Blocks,. Nigerian Journal of Technology 30(2), June 2011.

Mbadike, E. M and Osadebe, N. N (2013). Application of Scheffe's Model In Optimization of Compressive Strength of Lateritic Concrete. Journal of Civil Engineering and Construction Technology, Volume 4(9), Available at http://www.academic journals.org/JCECT. [November 20, 2015].

Montgomery, D. C (2001). Design and Analysis of Experiments, 5th Edition, John Wiley & Sons, New York. 427 – 473.

NBRRI (2016). Available at www.nbrri.gov.ng [February 10, 2016]

Neville, A. M., (1993). Properties of Concrete. Third Edition. Pitman Publishing Limited, London, 648-711

Onwuka, D. O.; Okere, C. E.; Arimanwa, J. I. and Onwuka, S. U. (2011). Prediction of Concrete Mix Ratios Using Modified Regression Theory. Computational Methods in Civil Engineering, Volume 2, No. 1. Available at: http://research.guilan.ac.ir/cmce. [November 20, 2015].

Simon, M.; Snyder, K. and Frohnsdorff, G. (1999). Advances in Concrete Mixture Optimization. Advances in Concrete Durability and Repair Technology Conference, University of Dundee, Scotland, UK. Thomas Telford Publishing, 21 – 32

Appendix

Table A.1 (a): Design matrix at Optimum Moisture Content using an augmented [3, 2] Simplex lattice by weight

S/no.	Coordinate Points		Pseudo component ratios x_1=water, x_2=cement, x_3=laterite			Actual components ratios			Actual component mixes, kg/m^3 (0% sand replacement)		
			X1	X2	X3	x_1 water	x_2 Cement	x_3 Laterite	water	cement	laterite
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1		A1	1	0	0	1.83	1.00	12.50	265.75	145.33	1816.63
2	PURE	A2	0	1	0	1.09	1.00	7.14	264.69	243.32	1737.29
3		A3	0	0	1	0.78	1.00	5.00	261.26	334.06	1670.30
4		A12	½	½	0	1.46	1.00	9.82	265.66	181.90	1786.22
5	BINARY	A13	½	0	½	1.31	1.00	8.75	265.45	202.25	1769.70
6		A23	0	½	½	0.94	1.00	6.07	263.55	281.44	1708.35
7		C1	⅙	⅔	⅙	1.16	1.00	7.68	265.03	227.79	1749.40
8	CONTROL	C2	⅔	⅙	⅙	1.53	1.00	10.36	265.71	173.11	1793.44
9		C3	⅙	⅙	⅔	1.01	1.00	6.61	264.22	260.80	1723.88
10	CENTRE	O	⅓	⅓	⅓	1.24	1.00	8.21	265.28	214.37	1760.00

*The highlighted are the upper and the lower limits on the domains of constituent proportions by weight

*The quantities in columns 9, 10, 11 are the respective unit weights per m^3 of the mixture proportions for water, cement and laterites respectively

*A1, A2, A3 represent pure blends, A12, A13, A23 represent binary blends, C1, C2, C3 represent control points and O represents centre point fitted in the factor space.

Table A.1 (b): Design matrix at optimum moisture content using an augmented [3, 2] simplex lattice by volume

S/no.	Coordinate Points		Pseudo component ratios x_1=water, x_2=cement, x_3=laterite			Actual components ratios			Actual component mixes, m^3		
			X1	X2	X3	x_1 water	x_2 Cement	x_3 Laterite	x_1 water	x_2 cement	x_3 laterite
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1		A1	1	0	0	1.83	1.00	12.50	0.266	0.046	0.688
2	PURE	A2	0	1	0	1.09	1.00	7.14	0.265	0.077	0.658
3		A3	0	0	1	0.78	1.00	5.00	0.261	0.106	0.633
4		A12	½	½	0	1.46	1.00	9.82	0.266	0.058	0.677
5	BINARY	A13	½	0	½	1.31	1.00	8.75	0.265	0.064	0.670
6		A23	0	½	½	0.94	1.00	6.07	0.264	0.089	0.647
7		C1	⅙	⅔	⅙	1.16	1.00	7.68	0.265	0.072	0.663
8	CONTROL	C2	⅔	⅙	⅙	1.53	1.00	10.36	0.266	0.055	0.679
9		C3	⅙	⅙	⅔	1.01	1.00	6.61	0.264	0.083	0.653
10	CENTRE	O	⅓	⅓	⅓	1.24	1.00	8.21	0.265	0.068	0.667

*The highlighted are the upper and the lower limits on the domains of constituent proportions by volume

*The quantities in columns 9,10,11 are divided by the respective unit weights of 1000, 3150 and 2640kg/m^3 for water, cement and laterites respectively