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Durability Assessment of Silica-Sand Blended Laterite-Cement Bricks

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Abstract

Standards and codes which are primary guidelines for meeting minimum strength requirement for laterite-cement bricks present erodibility problems in tropical environment. This impede the long term performance of load bearing laterite-cement bricks. The paper aims to assess durability performance of silica-sand blended laterite-cement bricks arising from component mixture selection process. The domain of mixture combinations to enhance a good performance was developed using the Mixture Method to test the durability performance of brick samples produced primarily using the ASTM D559-2003 and ASTM C97-02. The limiting requirements for both strength and durability were validated using NIS 87-2006 standard and other codes based on the domains of component mixture considered. This study is however, applicable to the hydraulically compressed Hydraform brick machine capable of exerting a compactive force of 10 MN/m^2 with particular reference to blending composite mixture using silica sand. The study has shown that component mixture selections within a cement content of 8-20 percent would enhance the durability of walls built with silica-sand blended laterite-cement bricks thus yielding a percentage particle eroded and water absorption less than 10% which was satisfied within the domain of constituents' proportions selected.

Keywords: Durability, laterite-cement bricks, blending, minimum strength

1. Introduction

The long-term performance characteristics of laterite-cement bricks for wall construction is regarded as a functional requirement of walls in order to be a desirable material, particularly where walls are built without protective coatings. This primary requirement of strength, stability and durability are desired in order to maintain acceptable life cycle cost of the building, (Ejeh and Adedeji, 1998; Ipinge, 2012; Alao and Ogunbode, 2019;). Therefore, limiting component mixture requirements through development of appropriate domain of component mixtures to enhance long term performance when exposed to agents of deterioration are desired for inclusion in specifications writing procedure. The requirement for minimum strength criterion as adopted by standards such as NIS 87-2006; SANS 1215 dwelled primarily on its use as load bearing and non-load bearing carrying capacity of laterite-cement bricks as a walling material.

In laterite samples for brick production as distinct from sandcrete bricks, certain physical and geotechnical properties of the material are required. This light to dark homogeneous, vesicular, unstratified and clinker like soil material consists mainly of oxides and hydroxides of aluminium, iron, manganese and silica. It contains cementing materials measured in terms of the sesquioxides content. It is generally a measure of the cohesiveness of the soil which indicates the degree of surface chemical activity as well as the bonding properties of fine clay and colloidal fraction of the materials (Amadi, et al, 2011; Aguwa, 2009). Characterization and determining the plasticity of a soil are usually carried out by indices such as Plastic Limit, Liquid Limit, Plasticity Index and Shrinkage limit. Example of test procedure is covered in BS 1377 (1990).

Several research output (Awoyera and Akinwumi, 2014; Hydraform, 2014; Jimoh and Alao, 2017) have tried to confirm the acceptability of laterite-cement brick properties for a series of acceptance criteria for various compaction regimes within 2.5 – 15MN/m^2. These properties include compressive strength, absorption characteristics and resistance to abrasion. Many research reports have also reported the performance under exposure to weather and other climatic conditions (Walker, 1995; Guettalla et al, 1995; Heathcote, 2002; Ipinge, 2012).

The paper seeks to address durability performance of laterite-cement bricks blended with silica sand within two grading zones to enhance better performance of laterite-cement bricks when exposed to weathering agents in service.

2.1 Durability of laterite-cement as a composite material

Durability studies have been considered inevitable in the use of laterite-cement bricks because it is believed that there is a reversal of stabilization associated with moisture intrusion within the stabilized materials (Heathcote, 2002). Although the addition of cement adds to stability, improves resilient properties, causes a reduction in excessive cracking and moisture sensitivity, the primary factor influencing the long-term performance of laterite-cement bricks is moisture.

Heathcote, (2002) summarized durability tests for laterite-cement bricks construction based on category source/type as:

i) Wire Brush tests ASTM D559 -indirect test
ii) Spray tests -accelerated and simulation tests
iii) Drip tests -indirect and accelerated tests
iv) Permeability and slake tests -indirect test
v) Strength tests (Wet/Dry Strength Ratio) -indirect test
vi) Surface hardness tests -indirect test

The primary objective of the ASTM D 559 standard otherwise called wire brush method which is an indirect test method is to determine the minimum amount of cement required in soil cement to achieve a degree of hardness that is adequate to resist field weathering., (ASTM D 559-03)

2.2 Effect of addition of lime to laterite-cement mixes

Primarily, two types of bond exist within a laterite-cement compressed brick. These are the 'plastic' and 'cement' bonds. The plastic bonding characteristics are influenced by the sesquioxides content, while the cement bond is influenced by the cementitious compounds during the reaction that takes place during the hydration of cement. Lime can be added especially where Plasticity Index is in excess of 20 percent to allow for flocculation of the particles because of excess clay in the laterite (Hydraform, 2014; Olutoge et al. 2018) thus preventing friable clay clods. Lime addition therefore alters the nature of adsorbed water layers in laterites. This is possible by the mechanism called "base exchange phenomenon" (Singh, 2006). In this method, the calcium ions displace all other ions, which is the sodium and hydrogen ions which are naturally carried by the laterite soil. Thus, shrinkage limit increases, a resistance to water absorption and capillary rise, reduces volume changes during wetting and drying, thereby increasing strength and durability. Lime is available as 'Quick lime' and 'Hydrated lime'.

2.3 Factors determining durability of laterite-cement bricks

The basic factors determining the durability of laterite cement bricks are identified as brick characteristic strength, conceptual design of the building, deterioration mechanism and environmental stress as depicted in Figure 1.

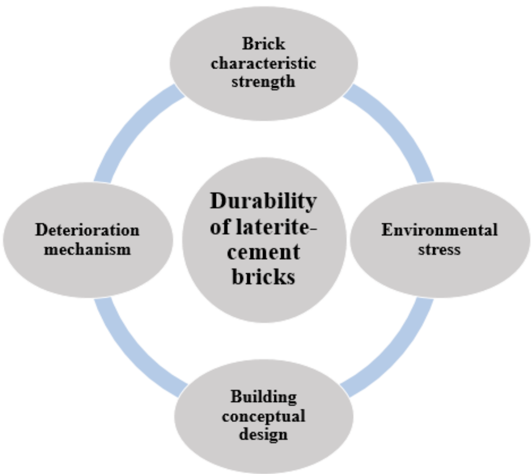

Figure 1: Factors influencing durability of laterite-cement bricks

2.3.1 Brick characteristic strength

The brick characteristic strength is a property of the composite material that is primarily prescribed for specifying the quality of laterite-cement bricks. This specification is often prescribed in standards and codes. The selection of constituent proportions to achieve a brick characteristic strength is often described as a minimum requirement which is commonly achieved based on what has worked for previous projects based on the builders' site experience. Methods popularly employed in estimating the quantities is the trial batching method. A more concise approach capable of predicting strength include experimental batching methods such as the absolute volume method, the taguchi method, the mixture method and the response surface methodology (Montgomery, 2000; Aguwa, 2009; Alao and Jimoh, 2018; Alao and Ogunbode, 2019). The cost of the component proportions can also be estimated more precisely depending on the method of batching employed (Alao, 2018).

Majority of the commercially available compressed earth bricks making machine are designed to exert the compactive pressure in uniaxial compression (NBRRI, 2018; Hydraform, 2014). It can be described more precisely to, as a one-dimensional compressed earth brick making machine. The specific volume reduces on uniaxial compression because the pore spaces are reduced during this mechanical stabilization. In general, durability is known to increase exponentially with the degree of compactive effort (Heathcote, 2002) thus, preventing crushing and eroding of walls by rain.

2.3.2 Building conceptual design

A conceptual design process allows designers to synthesize structural systems thereby focusing on the overall structural implications of alternative structural layout while considering multiple conflicting architectural design criteria (Mola, Mola and Pellegrini, 2011; Alao and Ogunbode, 2019). The effect of allocation of space and interaction of various building components on the overall durability of a design solutions are effectively considered in this process. The principle of conceptual design would translate to: An intuitive and knowledge based reasoning to allocate and maximize space for functionality, aesthetics and efficiency of a structural layout of a building frame to: i) Permit a development of adequate resistance to lateral forces in foreseeable directions exposed to strong wind loads; ii) Avoid undesirable stress distributions to ensure robustness of the building; iii) Redirecting load paths for optimal structural efficiency and; iv) Avoiding concepts that creates maintenance concerns.

The principle of a conceptual design approach could therefore be considered not only as an intuitive reasoning but also a creative act to produce a structure that is both functional and safe and also at a reduced cost. This implies that performance is not only achieved based on component material selection alone. Designs lacking basic principles of structural mechanics should be avoided. This is to prevent structures that do not comply with codes which may inherently not meet some safety levels. This implies that the engineered structures must exhibit proven mechanics and construction technique to produce a durable design.

2.3.3 Deterioration mechanism

In contrast to structural failure in laterite-cement brick walls, there occur other agents of deterioration. Of particular importance is the natural degradation agent of weather. These weathering agents can be minimized through component selection process. An investigation into the erodibility of earth wall units by Heathcote (2002) showed that the major climatic factors influencing the erosion of earth walls primarily due to wind-driven rain are:

i) impacting rainfall volume; ii) drop impact velocity (as determined by wind conditions); and
iii) raindrop size and; and iv) duration of rainfall.

The effect of these factors varies over time and between climatic conditions. This often have a significant impact where walls are left unprotected in unrendered or unplastered walls, including walls without protective coatings.

2.3.4 Environmental stress

A life cycle cost of a property generally represents the replacement cost over a given number of years. This is of concern to a property owner as building materials deteriorate progressively over a period of time not only as a result of its use but because of their exposure to the environment. Several environmental degradation elements such as humidity, cycles of drying and wetting seasons, environmental pollution, constitute agents of deterioration. The maintenance expenditure aimed at maintaining or restoring such assets are generally planned to be controlled. This is of importance especially where laterite-cement walls are to be left without protective coatings and exposed to environmental degradation elements. The characteristic nature of reversal of stabilization associated with moisture intrusion within the laterite-cement stabilized bricks occur particularly at low cement content (Heathcote, 2002; Alao and Ogunbode, 2019). This often causes a reduction in the compressive strength of the laterite-cement bricks.

2.2 The experimental mixture design

Scheffe's experimental design method was used to select design points within a triangular simplex for this three-component mixture. The triangular Simplex was used to explore the properties of the mixture particularly for detecting curvatures in the response model formulation.

The vertices of the triangular simplex as shown in Figure 2 represent numerically, the three actual variable component mixtures (Montgomery, 2001). These vertices represent A1 equal 8%, A2 equal 14% and A3 equal 20% cement contents respectively. The pseudo components at the vertices are represented by A1 equal (1, 0, 0), A2 equal (0, 1, 0) and A3 equal (0, 0, 1). One of the importance of this statistical experimental design procedure is that each response of interest can be characterized by a variability which has an important implication for specification writing, (Simons et al, 1999). This implies that at least 95 percent of the results are expected to fall within the normal distribution curve or more precisely, with a probability $p \leq 0.05$.

In order to satisfy the requirement of this mixture approach, the constituent proportions for the mixtures 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 of solution procedure (Montgomery, 2001). The components in this particular case are water, cement and laterite. This equality constraint equation therefore is (Montgomery, 2001):

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

and $x_i \geq 0$

The standard form for all response predictions of this second order-quadratic polynomial can be expressed as:

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

The expressions x_1x_2, x_1x_3, x_2x_3 are the interaction terms while b_{12}, b_{13}, b_{23} are the coefficients of the interaction terms of x_1 = water, x_2 = cement and x_3 = laterite(+ sand).

In addition to estimating the component proportions for all other design points of a Simplex, a transformation between pseudo and actual components in the factor space were used. This selection of design points enables the full properties within the Simplex to be obtained using an augmented [3, 2] lattice design. This 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) as depicted in Figure 2. This procedure is also implementable using Design Expert Software (Design Expert, 2000).

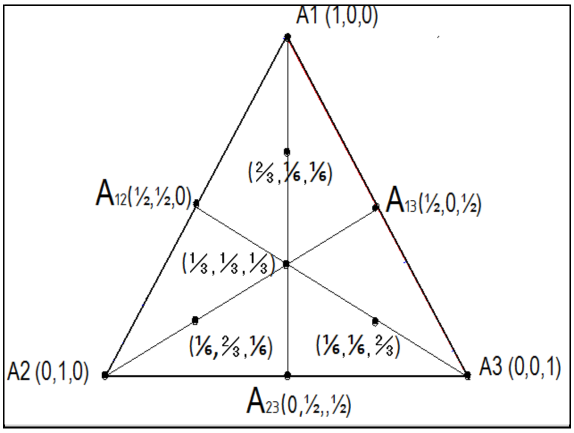

Figure 2: An augmented [3,2] Simplex lattice

3. Methodology

The physical properties of the laterite sample include: specific gravity 2.64, plasticity index 18.40%, linear shrinkage 10.10mm, optimum moisture content 14.06%, condition of sample: air-dry, AASHTO soil classification A-2-7. Mineralogical properties include: iron oxide content 18.01%, sesquioxide content 42.21%. The specimen samples were mixed with mechanical pan mixer and compacted using a hydraulically compressed M7-Twin Hydraform brick moulding machine.

3.1 Estimating component proportions

The component proportions of these design points are estimated using absolute volume expression of Equation 3 thus satisfying the equality constraint of equation (1) which is summed equal to unity.

$$\frac{water}{\gamma_{water} \times 1000} + \frac{cement}{\gamma_{cement} \times 1000} + \frac{laterite}{\gamma_{laterite} \times 1000} = 1 \qquad (3)$$

$where: \gamma = specific\ gravity$

The vertices A1, A2 and A3 in Figure 2 were fitted with 8% 14% and 20% cement content of the dry weight of laterite, representing mix ratio of 1:12.5, 1:7.14 and 1:5. Mix ratios of other design points were derived using inverse relationship transformation corresponding to the points in the factor space (Onuamah, 2015; Onwuka et al, 2011; Anya and Osadebe, 2015).

The constituent proportions for each of the design points at optimum moisture content also enables derivations of some basic predicting equations based on cement quantities to be obtained. These relationships are of the form in Equation 4 for laterite quantity, water requirement in Equation 5 and strength in Equation 6, (Alao and Jimoh, 2017).

$$x_{3i} = p_i - q_i * x_{2i} \qquad (4)$$

$$x_{1i} = a_i - b_i * \left(\frac{x_{2i}}{x_{3i}}\right) \qquad (5)$$

$$a_{1i}x_{1i} + a_{2i}x_{2i} + a_{3i}x_{3i} = {}^{1}/_{fc_{28}} \qquad (6)$$

3.2 Domains of the constituent proportions

The domain of 8-20 percent cement content representing the vertices of the simplex were used to define the limits of the constituent proportions. This represents the lower and upper limits respectively on water, cement and laterite. Dividing the proportions by the corresponding unit weights of water, cement and laterite (laterite + sand) yields the absolute volumes of the constituent proportions. This is represented in Equations 7(a) – (e) (Jimoh and Alao, 2017).

$$MX-0; \quad \left.\begin{array}{l} 0.261 \leq x_1 \leq 0.266 \\ 0.046 \leq x_2 \leq 0.106 \\ 0.633 \leq x_3 \leq 0.688 \end{array}\right\} \qquad (7a)$$

$$MX-C1; \quad \left.\begin{array}{l} 0.262 \leq x_1 \leq 0.267 \\ 0.046 \leq x_2 \leq 0.105 \\ 0.628 \leq x_3 \leq 0.691 \end{array}\right\} \qquad (7b)$$

$$MX-F1; \quad \left.\begin{array}{l} 0.259 \leq x_1 \leq 0.262 \\ 0.046 \leq x_2 \leq 0.106 \\ 0.633 \leq x_3 \leq 0.694 \end{array}\right\} \qquad (7c)$$

$$MX-C2; \quad \left.\begin{array}{l} 0.263 \leq x_1 \leq 0.266 \\ 0.046 \leq x_2 \leq 0.106 \\ 0.631 \leq x_3 \leq 0.688 \end{array}\right\} \qquad (7d)$$

$$MX-F2; \quad \left.\begin{array}{l} 0.256 \leq x_1 \leq 0.268 \\ 0.046 \leq x_2 \leq 0.107 \\ 0.637 \leq x_3 \leq 0.687 \end{array}\right\} \qquad (7e)$$

The limits avoid extrusion difficulties while still maintaining maintain plastic bonds of laterites.

3.3 The 'Wire brush' test

The ASTM D559-03 standard, otherwise called wire brush test is considered severe in comparison with actual field performance for building bricks (Walker, 1995; Ipinge, 2012; Heathcote, 2002). However, it is still considered as a preferred test. The brushing of specimen samples is carried out to determine the amount of eroded particles after 12 cycles of test and recorded accordingly. In accordance with this test procedure, the wire scratch brush is made of 50.8 by 1.588-mm flat No. 26 gauge (0.46mm) wire bristles assembled in 50 groups of 10 bristles each which is mounted to form 5 longitudinal rows and 10 transverse rows of bristles on a 190.0 by 63.5mm hardwood. The soaked specimens are removed from water after 5 hours and are placed in a thermostatically controlled oven at 70 ± 3^0 temperatures for 42 hours after which they were removed and brushing is applied. Each of the specimen samples are given two firm strokes on all the areas with the wire scratch brush. The brush, held with the long axis parallel to the longitudinal axis of the specimen and also parallel to the ends as required to cover all areas of the specimen, corresponding to an approximately 13.3-N force. This procedure measures the amount of particles eroded as a percentage of the original oven-dry mass of brick specimen.

4. Result of durability test by wire brush

The result of the wire brush test is presented in Table 1. The acceptance criterion is that the percentage of eroded particles should not exceed 10 percent and this is satisfied based on the feasible domain considered.

Table 1: Percent weight loss for laterite-cement bricks

DESIGN POINTS		PSEUDO COMPONENT VARIABLES			WEIGHT LOSS (%)				
					BLEND-0	BLEND-C1	BLEND-F1	BLEND-C2	BLEND-F2
(1)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VERTICES	A1	1	0	0	**6.32**	**6.85**	**7.24**	**6.96**	**5.09**
	A2	0	1	0	**4.56**	**3.22**	**4.04**	**3.39**	**5.57**
	A3	0	0	1	**2.56**	**4.49**	**5.93**	**5.49**	**3.63**
BINARY	A12	½	½	0	**4.60**	**4.21**	**5.19**	**5.17**	**3.84**
	A13	½	0	½	**4.74**	**4.42**	**4.61**	**3.64**	**3.20**
	A23	0	½	½	**5.09**	**4.44**	**3.26**	**5.77**	**5.10**
CONTROL	C1	⅙	⅔	⅙	**4.61**	**4.28**	**3.86**	**3.54**	**3.62**
	C2	⅔	⅙	⅙	**4.30**	**4.34**	**4.61**	**4.66**	**4.10**
	C3	⅙	⅙	⅔	**5.15**	**5.73**	**3.50**	**3.19**	**3.05**
CENTROID	X0	⅓	⅓	⅓	**4.24**	**3.24**	**4.38**	**3.17**	**4.05**

** The Letters 0, C1, F1 and C2, F2 immediately after the hyphen represent zero blend, Coarse and Fine sand, 10 percent and 20 percent blends respectively*

4.1 Water absorption test

In determining volume stability, water absorption was carried out in accordance with ASTM C97-02 to obtain the amount of water absorbed when the bricks were completely immersed in water. This is a measurement of the amount of water absorbed by the oven dry specimen over a 24-hour immersion in water at ambient temperature of 28^0 – 30^oC. The design matrix and results of percentage absorption is shown in Table 2.

Table 2: Design matrix and percentage absorption

Design Points	Coded Variables			Response fc28 (N/mm^2)				
				BLEND-0	BLEND-C1	BLEND-F1	BLEND-C2	BLEND-F2
A1	1	0	0	8.406	12.745	12.069	8.951	13.869
A2	0	1	0	14.445	10.853	12.4713	12.9	9.371
A3	0	0	1	8.4	11.516	11.77	13.597	18.998
A12	½	½	0	11.976	11.2901	16.142	11.11	10.41
A13	½	0	½	10.551	17.751	11.804	10.1144	10.959
A23	0	½	½	10.359	10.5716	12.6724	10.8	9.216
C1	⅙	⅔	⅙	16.653	14.435	11.099	11.1259	10.4055
C2	⅔	⅙	⅙	10.432	15.544	13.576	9.857	11.951
C3	⅙	⅙	⅔	12.991	10.7769	12.086	10.6202	13.702
X0	⅓	⅓	⅓	10.8807	10.6743	8.247	12.168	10.8483
X0	⅓	⅓	⅓	10.551	13.566	10.3	11.3507	11.453
X0	⅓	⅓	⅓	13.249	12.964	12.894	15.453	11.291
X0	⅓	⅓	⅓	11.2104	12.486	10.58	11.954	12.818
X0	⅓	⅓	⅓	10.452	9.725	12.421	10.999	15.368

The prediction equation for water absorption is shown in Equation 8(a) – (e)

$$MX-0; \quad \%\,absorption = -89.6978x_1 - 22.3871x_2 + 45.74561x_3 \quad (8a)$$

$$MX-C1; \quad \%\,absorption = -36.6952x_1 - 18.9585x_2 + 24.02774x_3 \quad (8b)$$

$$MX-F1; \quad \%\,absorption = -93.5172x_1 + 0.98076x_2 + 43.70935x_3 \quad (8c)$$

$$MX-C2; \quad \%\,absorption = -25.8390x_1 - 24.03620x_2 + 20.85438x_3 \quad (8d)$$

$$MX-F2; \quad \%\,absorption = -106.7205x_1 - 20.9823x_2 + 51.7205x_3 \quad (8e)$$

Figure 3 shows the relationship between cement content and percentage absorption. The relationship shows a reduction in water absorption as cement content increases. The requirement of rate of absorption below 10 percent is satisfied using the 10MN/m^2 compactive effort. The percentage absorption for the brick ranges between 3.04 - 7.98% for all blends. The values of the ordinates and the abscissa are derived from Equations 8(a) – (e) and using Example on estimation of component proportions in Appendix B.

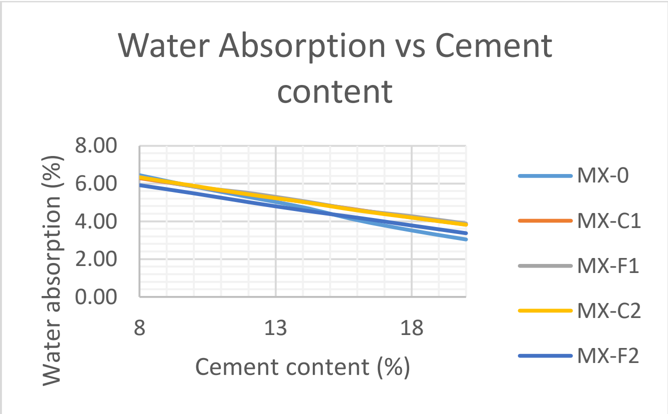

Figure 3: Water Absorption vs cement content

5. Conclusion

The properties of the bricks are not affected while the ‘cement’ and ‘plastic’ bonds can still be maintained within the domain of the component mixture selection. Using this material would enable the production of durable laterite-cement bricks that can withstand agents of deterioration in temperate environments thereby meeting specified requirement of durability.

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APPENDIX A: Table of coefficients

Table A.1: Table of coefficients for second-order prediction equation for 28-day strength

Code	Response	Water Coefficient	Cement Coefficient	Laterite Coefficent	Blend Description
MX-0;	$1/(fc,_{28})$	-3.5472400	0.1034100	1.538650	Laterite
MX-C1;	$1/(fc,_{28})$	-1.1069895	-0.0184988	0.568564	Lat + 10% C-Sand
MX-F1;	$1/(fc,_{28})$	-0.1705730	-0.5641350	0.271676	Lat + 10% F-Sand
MX-C2;	$1/(fc,_{28})$	-5.9289800	1.3079900	2.366790	Lat + 20% C-Sand
MX-F2;	$1/(fc,_{28})$	-0.9498900	-0.6988700	0.579710	Lat + 20% F-Sand

Table A.2: Table of coefficients for laterite quantity

S/NO.	BLEND	$.p_i$	$.-q_i$
1	MX-0	1927	0.7767
2	MX-C1	1956	0.9058
3	MX-F1	1959	0.8697
4	MX-C2	1928	0.7886
5	MX-F2	1907	0.6749

Table A.3: Table of coefficients for quantity of water

S/NO.	BLEND	$.a_i$	$.-b_i$
1	MX-0	269.5	36.93
2	MX-C1	259.8	39.40
3	MX-F1	258.5	18.42
4	MX-C2	269.4	29.77
5	MX-F2	276.6	99.04

APPENDIX B: Example of estimation of component mixture proportions

This method starts as an iterative process by initially selecting an absolute volume on cement content from the within the limits of the component mixes. Absolute volumes of all constituent proportions must sum equal to unity. The actual weights are obtained by multiplying the absolute volumes of each component by their respective unit weights per meter cube. The procedure is stated thus:

i) Select an absolute volume on cement from within the limits for the various blends.
ii) Calculate the corresponding absolute volume of laterite from Equation 4 relating the cement quantity and laterite
iii) Calculate the absolute volume of water from the equation 5 relating water to cement/laterite ratio
iv) Substitute the absolute volumes of the component mixture quantities in Equation 6 relating strength at 28days from Appendix A.1 to obtain the compressive strength at 28 days
v) Calculate the inverse or reciprocal of the value of 28-day strength obtained in (iv)
vi) Calculate the cement:laterite ratio and cement percentage per m^3 of mix

Substitute the values in the problem statement for blend MX-0.

i) Using a value of cement within the suggested limits in Equation 7 (absolute volume = 0.057) represents 179.55kg of cement, that is (0.057 x 3150 = 179.55kg), where unit weight of cement is 3150kg/m^3
ii) The corresponding absolute volume of laterite from equation 4 and coefficients in Appendix A.2 relating the calculated cement quantity is: $laterite = (1927 - 0.7767 * cement)$ which gives (1927-(0.7767*179.55))/2640 = 0.6771 and the weight of laterite is 0.6771*2640 = 1787.54352kg/m^3 where the unit weight of laterite is 2640 kg/m^3
iii) The corresponding quantity of water from Equation 5 and coefficients in Appendix A..3 relating the calculated cement/laterite ratio is: $water = 269.5 - 36.93 * \frac{cement}{laterite}$ This substitution gives =(269.5-(36.93*(179.55/1787.54352))) = 266.55kg/m^3. The absolute volume of water is 266.55/1000 = 0.265791 ≈ 0.266
iv) Substituting the absolute volumes of all the constituent materials in equation 6 and coefficients in
v) Appendix A.1

$$^{1}/_{fc_{28}} = -3.54724 * water + 0.10341 * cement + 1.53865 * laterite =$$

$$^{1}/_{fc_{28}} = -3.54724 * 0.266 + 0.10341 * 0.057 + 1.53865 * 0.6771 = 0.104891$$

vi) The inverse of this expression is 9.5337N/mm^2
vii) The cement laterite ratio is $^{179.55}/_{1787.54352}$ which represents a ratio 1:10