DEVELOPMENT OF MIXTURE PREDICTION MODEL FOR OPTIMIZATION OF LATERITE-SAND CEMENT MORTAR

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A THESIS SUBMITTED TO POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGERIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTERS OF TECHNOLOGY (MTECH) IN CONSTRUCTION TECHNOLOGY

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ABSTRACT

The use of conventional cement-sand for the production of mortar for permanent ferro-cement formworks and bedding & jointing sandcrete block walls has been in use for ages. An attempt to substitute partially, with binary mixtures of sand:laterite to introduce both cement and plastic bonds as a property of the composite material was carried out to reduce the cost of cement. This research work is focused on development of a specifications writing procedure for optimizing component mixes. An experimental mixture procedure is introduced using the Central Composite Design (CCD). The physical properties of the constituent materials were determined in accordance with relevant standards. The hardened properties of the composite material were investigated including compressive strength at 7 and 28 days for the control and binary mixtures and found to satisfy basic NIS standards. Models were developed for predicting responses of interest. Lower cement contents with corresponding higher minimum compressive strength are achievable, which is well above the minimum requirement of 2.8 N/mm^2 NIS standards, thus making the replacements suitable for permanent ferro-cement and bedding & jointing masonry works.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

The construction sector is growing rapidly, with new innovations and techniques evolving to create and improve new materials and techniques. Cement-sand mortar mix is widely used for bedding and jointing structural load bearing and non-load bearing block works. Traditionally, cement-sand mortar has been produced from a few well-defined components: cement, water, fine aggregate and admixture (Murali & Kandasamy, 2009; Egbele and Orie, 2016). In cement based composite mix design and quality control, the strength of the mix is regarded as the most important property (Salem & Loubna, 2015).

Production of cement-sand mortar mix over the years has been done either by using prescribed mixes or designed mixes (Dieter, 1983; Okoloekewe & Okafor, 2007). The result of the design process is the predictions of the required proportions of cement, fine aggregates and water required to produce cement-sand mortar mix of a specified compressive strength. Cement-sand mortar production can result in either good quality or poor-quality paste. The constituent materials must be properly proportioned to obtain a good quality mix

Mix design is the process of ascertaining the appropriate quantities of the ingredients of the component mixes required for a specified grade of concrete (Okoloekewe & Okafor, 2007). Over the years a number of standards have been stipulated especially, for concrete mix design. These include: the Department of the Environment (DoE)'s Design of Normal Concrete Mixes method published in 1975 and originated from the long-established Road

Note 4 of the Road Research Laboratory (Okoloekwe & Okafor, 2007). The American Concrete Institute (ACI) method which is similar to the DoE method but differs from it in the method of estimating the relative proportions of fine and coarse aggregate (Reddy & Gupta, 2008). The British Ready Mixed Concrete Association (BRMCA) method developed over many years provides base data on the ideal proportioning for all mix constituents to achieve specified concrete properties enabling preparation of correct batching instructions for the production of all mixes (Neville and Brooks, 1987).

Lateritic soils are naturally occurring, which is a widely used building material across the globe. Laterites are used for masonry walls in rural and urban areas. Mainly, the use of laterite is for making bricks for low-cost building construction. They can be used also as a replacement (partially or fully) with sand in concrete (Ige, 2017; Enaworu *et al*., 2017; Rao & Raju, 2017). In order to utilize eco-friendly materials, investigation needs to be carried out on the properties and behaviour of laterite-cement-mortar mixes (Biju *et al*., 2018; Joseph *et al.*, 2012). Laterite is mainly formed by weathering of rock in hot and wet regions, (Joshua et al., 2008). The color of laterite is generally red or rusty–red, (Amu *et al.*, 2011; Lasisi and Osunade, 1984). Various modes of lateritic formation depend on tropical weathering process in the rocks, (Adeyemi, 2002; Rajeev, 2018). The main advantage is that the composition in its surface does not change according to the time, (Gidigasu, 1972; Mustapha & Alhassan, 2012).

In this research work, laterite-sand cement mortar will be used as a composite material to partially replace sand in conventional cement-sand mixtures using the Central Composite Design (CCD) experimental approach. The use of laterite as a partial replacement of sand in this thesis is to improve the plasticity characteristics of the mixture, thereby introducing both cement and plastic bonds in the composite material. This to obtain high workability characteristics and a cheaper mix at low cement content.

1.2 Statement of the Research Problem

Selection of component mixtures is fundamental for performance of cement based composite materials. The traditional trial mix and methods which uses mixtures based on what has been in use previously is not sustainable (Obam, 2009; Okere *et al*., 2013; Okafor & Egbe, 2017 Anyan & Osadebe, 2015; Makenya & John, 2017). Therefore, there is a need to adopt suitable method for selection of constituent materials for laterite-sand cement mortar mixes. Also, it is necessary to develop a specification writing procedure which will enhance the use and production of laterite-sand cement mortar (Salem & Loubna, 2015; Anyan, 2015; Anyan & Osadebe, 2015). The challenges encountered during batching of the constituent materials and over dependent on cement as a binder for production of concrete and mortar is desired.

1.3 Aim and Objectives of the Study

The aim of this research work is to develop a specifications writing procedure for obtaining the compressive strength of a binary mixture of laterite-sand cement mortar mixtures. The objectives are to:

i) Investigate physical properties of the composite materials.

ii) Determine the proportions of the composite materials using the Central Composite Design experimental method.

iii) Determine the effect of replacements laterite-sand cement on hardened properties of the mortar

iv) Carry out absorption characteristics of the mortar paste

v) Develop specifications writing procedure for the mortar mixes using this composite mortar mixes.

1.4 Scope of the Study

Experiments was conducted on laterite-sand cement mortar mixes with in 0% replacement with laterite as control and binary mixtures consisting of 50% (half) and 67% (one third) partial replacement of sand with laterite. A mixture experimental procedure using the Central Composite Design of the Response Surface Methodology was employed.

1.5 Justification for the Study

Laterite in itself has some cohesive and adhesive properties. Reduction of cement use in laterite-sand cement mortar mixes would reduce overall effect of the cost of bedding and jointing in laying block walls or in ferro-cement permanent formworks. Partial replacement aimed at reducing the quantity of cement without compromising the hardened properties of the mortar would inherently prevent excessive abrasion effect when subjected to eroding rain (Joshua *et al.,* 2014; Matin *et al*., 2017). A specification writing procedure would also enhance getting the composite mixture selection and desired requirements to be arrived at a first attempt thereby eliminating trial mixture process.

Laterite is used in the composite material in this study as an alternative to using only river sand in the production of mortar. Since fine aggregate is a major constituent of mortar, the availability and cost of fine aggregate determines the viability and economy of mortar. This study will further help to reduce environmental problems created by excessive explorations (Awoyera *et al*., 2014). In the present scenario of sustainable infrastructural development demands, the need of alternative cost-effective building material that should satisfy technical requirements of fine aggregate is desired Biju *et al* (2018). The in the utilization of alternative material such as stone dust, laterite that can partly or completely replace sand in the mortar mix and in concrete production which will result to reduction in environmental degradation that do occur at banks of major rivers across Nigeria (Vengadesh & Kirubakaran , 2017; Rajeev, 2018; Festus *et al*., 2006; Joseph & Maurice 2012).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Mortar

Mortar is a composite product primarily consisting of cement, sand and mixing water. When water is added to this product the cement in the mix is activated, thus making the material plastic. Cement-sand mortar is primarily used for bedding and jointing. Apart from bedding and jointing purposes, the composite material is also responsible for creating a uniform stress distribution of dead loads from the block walls. Therefore, the knowledge of both its wet and hardened properties is fundamental (Vladimir *et al.,* 2011). Knowledge of mortar and its application is important for use for a diverse range in project execution (Imrose *et al.,* 2014; Neville, 2012). When water is mixed with Portland cement, it creates a cohesive mixture that is very workable, before setting time starts.

Portland cement products' including use of admixtures however, aids the workability and versatility of the mortar. It likewise gives early quality to the mortar and controls setting. Mollo and Greo (2011) considered it as an anisotropic composite material. Mortar influences the thermo hygrometric behaviour and is responsible for distribution of stress in masonry structure by creating uniform stress distribution and correcting the irregularity of block (Vladimir *et al.,* 2011; Panarese *et al.,* 1991). It also accommodates deformation associated with the thermal expansion and shrinkage (Hendry, 2001; Hacch, 2011). More so, mortar had a high influence on the bond strength and the deformation of masonry and it is found to play a major role in bond strength properties at the brick- mortar interface (Edgell & Haseltine, 2005; Haach *et al*., 2011).

Enenmo (2014) Defines mortar as a paste of a mixture of cement and sand. The basic requirements of mortar should include: solidifying within the required time without crushing and possessing adequate plastic properties for bedding and jointing of blockworks, good permeability properties that must not deteriorate due to action of weathering of ice and rain. The constituent material which is mainly fine aggregate, cement as binder and water influence the mortar qualities. The performance of mortar is also affected by the properties of sand (Vladimir *et al.*, 2011).

2.1.1 Mortar types in current use

The current specifications for mortars for masonry according to the American Society for Testing and Materials ASTM C 270 (2012) recognizes five types of mortar as class M, S, N, O and K as shown in Table 2.1. Mortars are further identified by proportion of constituent materials, and cementitious combination. Portland- cement and masonry cement mortars are identified as Type S, and N mortars respectively (Godbey & Thomson, 2014 & Westerholm *et al.*, 2008). In this method of specification for mortar type, c1assification is dependent solely on their combined strength characteristics determined using standard laboratory test. Building code considers the utilization of a mortar for specific application, for example type M or S mortar is specified for foundation wall design and N and S mortar is specified for glass unit's masonry (ASTM C270: 2012).

Table 2.1 Specification requirement for mortar (ASTM C270: 2012)

Mortar	**Type**	**Average compressive at 28 days (N/mm^2)**
	M	2500 (17.2)

Mortar	S	1800 (12.4)
	N	750 (5.2)
	O	350 (2.4)
	K	75

Source: ASTM C270: 2012

2.2 Constituent Proportions and Properties of Mortar

Constituent proportions selection for Portland-limestone cement-sand mortar is necessary to achieve expected properties. These properties include particle size distribution, specific gravity, shape and surface texture. They influence both the properties of the mortar in both their fresh and hardened states (BS EN 933-1: 2012).

2.2.1 Portland cement

The cement paste is an important part in mortar/concrete and thus mechanical properties of cement paste majorly influenced the compressive strength properties of mortar or concrete (Rosa *et al.,* 2009). It is desired that properties of the binder should be investigated in accordance with required specifications, such as European standard BS EN 196 -1:2016 to confirm its acceptability.

2.2.1.1 Fineness

One of the most important characteristic property that affect the degree of reaction of cement with water and other components of concrete or mortar is the fineness of cement, because the finely ground binder has more readily available surface area for hydration process than a coarsely grounded one. It should be noted that grinding is last step in Portland cement production: which includes grinding of clinker mixed with gypsum (Neville, 2012). Since hydration process start at the surface area of Portland limestone cement particles, the surface area of the solids take care of the material obtainable for hydration. The processes of hydration depend on fineness of the cementing particles and for rapid strength development. High fineness is fundamental to high early rate of hydration which implies a high rate of heat of hydration (Rahhal & Talero, 2012).

2.2.1.2 Chemical composition

The content of certain cement compound in proportion to other may lead to retardation or acceleration of the rate of setting and hardening. These components need to conform to standard specification. The quality of any of this component could affect the rate of hydration. Calcium sulphate (gypsum) and calcium chloride are used as admixture to retard or accelerate the setting time of cement paste.

Portland limestone cement consists of a mixture of compounds formed from a number of oxides at the high temperatures in the kiln. This abbreviated symbols are used which describes each principal oxides present often used: CaO (lime) = C; SiO_2 (silica) = S; Al_2O_3 (alumina) = A; Fe_2O_3 (iron oxide) = F, (Neville & Brooks, 2010). Portland limestone cement is the major constituent of masonry cement, and the performance of cement mortars is largely dependent on the amount of cement in it. Tricalcium silicate and Tricalcium aluminate are the two chemical compounds in Portland cement that contribute to early strength development (Neville 2012). Since water for hydration is of prime importance, cement-mortar requires water to initiate and continue the hydration for setting and hardening. This mixing water is readily available for cement hydration which begins with hydration of the tricalcium aluminate.

2.2.2 Fine aggregate

Fine aggregate is an important ingredient for mortar and concrete production. The most popular fine aggregate used for normal mortar/concrete production being sand and are generally referred to as particles passing sieve 4.75 mm (No. 40) aperture size but are retained on sieve 0.075 mm (No. 200), (ASTM C125, 2015). They improve the flowing ability and segregation resistance when mixed in appropriate proportions (Gidigasu 1976; Su *et al.*, 2002; Bhattacharya *et al.,* 2008). A well graded fine aggregate according to Hu and Wang, (2005) and Benabed *et al.,* (2012) improve the flow ability of mortar (Tasi *et al*., 2006; Chore & Josh, 2015). It improves the compacted density as well as increase in strength development and durability of concrete. Major sources of fine aggregate are from river banks and pits but when used in mortal mix it should be properly washed to ascertain that total percentage of clay silt , salts and other organic matter do not exceed specified limits (Asiedu & Agbenyga, 2014; Subramanian & Kannan, 2013; Sheety, 2006;Castro *et al* ., 2011).

2.2.2.1 Specific Gravity (GS) of fine aggregates

It indicates the suitability of an aggregate, a measure of unit weight when compared with the weight of an equal volume of water. A very low specific gravity frequently indicates an aggregate that is porous, friable or absorptive (Roberts *et al.*, 1996; El-Sayed 2013).

2.2.2.2 Textural characteristics

Fine aggregates textural characteristics have an important effect on both properties of fresh mortar (workability) and hardened mortar (strength and durability). Spherical particles have less specific surface area than flat and elongated particles, and consequently require less cement paste and less water for workability (Shilstone, 1999). An angular and rough particle requires more water as they possess larger void content than flaky and elongated particles. They produce very harsh mixture while that of spherical particles produce better workability (Veer Reddy, 2017; Shilstone, 1999; Connell, 2002). These particles tend to increase the water demand for a given workability. Ganesh *et al.* (2017) compares the shape of crushed sand and river sand and found that crushed sand is better in terms of strength than river sand.

2.2.2.3 Grain size distribution

Grain size distribution affects significantly some characteristics of mortar like; packing density, voids content which has effect on workability, segregation and durability. Many authors (Johansson, 1979; Johansen and Andersen 1989; Glavind *et al.*, 1993; Golterman *et al.*, 1997) claim that uniformly distributed mixtures produce better workability.

2.3 Laterite

Laterites are a soil or rock types which is the residual product of weathering (Irabor and Okolo, 2010). It is rich in oxide and hydroxides of iron and aluminum and is commonly considered to have been formed in hot and wet tropics area (Asiedu and Agbenyega, 2014). According to Joseph *et al*. (2012); Ukpata *et al*. (2012) and Awoyera *et al*. (2015), laterite is nearly devoid of base and primary silicates but may contain huge number of quartz and kaolinite. (Aguwa, 2009; Adebisi *et al.,* 2013) also viewed laterite as class of pedogenics in which the cementing materials are the sesquioxides and constitute not less than 50% of its constituents when the sample is chemically analyzed. Laterite has been used for wall construction around the world. It is cheap, environmentally friendly and an abundantly available building material in the tropical region (Olugbenga *et al*., 2007).

2.3.1 Physical properties of laterite

A soil sample may be confirmed to be laterite by observing some of the physical properties. Laterite is a product with red, reddish brown and dark brown colour, with or without nodules, ability to self-harden, concretions, and generally gravelly in texture (Amu *et al*., 2011). The reddish color becomes predominant when wet while the brown color becomes distinct or dirty-brown when sun dried. Some of the particles sticks to the palm of the hand when wet and they can easily be dusted off when dry (Aguwa, 2009). Also, some laboratory index property tests may be used to classify laterite. Such tests are the Atterberg limit, grain size distribution, compaction, specific gravity and linear shrinkage (Sabarish *et al.,* 2015; Tsado *et al.*, 2017).

2.3.2 The formation of laterites

Chemical composition of laterite soil/gravel varies widely based on genesis, climate conditions, and age of laterization (Irabor & Okolo 2010; Renuka *et al.,* 2018). Laterization process which involve chemical and physico-chemical transformation of the parent rock-forming minerals that are rich in secondary oxides of iron, aluminum or both. Laterite constituents and clay minerals are different in mineralogical composition (Asiedu & Agbenyega, 2014; Awoyera *et al.,* 2015). Weathering process in the rocks can be categorized into three major stages namely; decomposition, leaching and dehydration/desiccation. The first stage in decomposition is usually characterized by physical and chemical break down of primary minerals and the release of major constituent of material elements. The second stage which involves leaching, under appropriate drainage conditions of combined silica and bases and the relative accumulation or enrichment from outside sources (absolute accumulation) of oxides and hydroxides of sesquioxides mainly: Al_2O_3, and Fe_2O_3. The third stage called dehydration or desiccation involves partial or complete dehydration (Agbede & Manasseh, 2015; Udeyo *et al.,* 2006; Rajeev, 2017).

2.3.3 Chemical properties of laterite

At ordinary temperatures and pressure below 100mm mercury, potassium peroxide combines with oxygen to give the sesquioxides, K_2O_3, an oxide with three atoms of oxygen and metal atoms (Ige *et al*., 2014; Joshua *et al.,* 2014). The iron presence determines the characteristic color produced by the soils. The aluminum is generally in the form $Al_2O_3H_2O$, are called bauxite, an ore of aluminum. The chemical analysis of lateritic soil by Renuka *et al*. (2018) shows that it contains more than 60% Fe_20_3 and little of Al_20_3. Indian soils show soils rich in iron and aluminum but poor in nitrogen, potassium, lime and organic matter (Joshua *et al.,* 2014). The degree of laterization is estimated by the silica: sesquioxides ratio

(SiO_2/ (Fe_2O_3 + Al_2O_3). Silica-Sesquioxide (S-S) ratio less than 1.33 are indicative of laterites; those between 1.33 and 2.00 are lateritic soils and those greater than 2.00 are non-lateritic (Joshua *et al.,* 2014).

2.4 Differences Between Laterite and Clay

Laterite soil consists of clay and iron particles, and characterized by its hardening properties, chemical content and structural evolution (Gidigasu, 1977; Whitlow, 1995; Olubisi, 2017). It is porous and soft at high humidity, when exposed continuously to high ambient temperatures would cause it to harden (Punmia *et al.,* 2005; Jain *et al.,* 2011) In contrast, clay comprises small pores of air and solid particles with no void spaces. It is also soft at high humidity and will quickly harden if continuously exposed to high ambient temperatures. It has a low shear strength and high compressibility level (Udoeyo *et al.,* 2006; Zivica 2009).

2.5 Properties of Fresh and Hardened Mortar

Mortar is responsible for the distribution of stresses in masonry structures (El-Sayed, 2013). The knowledge about the fresh and hardened properties of mortar is fundamental to ensure a good performance of masonry walls (Vladimir *et al*., 2011). The basic properties of fresh and hardened mortar are workability, density, compressive strength and water absorption.

2.5.1 Workability

Workability of mortar plays an important role in the construction of masonry structures. Workability may be considered one of the most important properties of mortar because it influences directly the mason's work. The quality of the workmanship can be influenced considerably by the mechanical properties of masonry (Vladimir *et al.,* 2011). The workability is an assembly of several properties such as consistency, plasticity and cohesion (Panarese *et al.,* 2010). Workability of mortar mixes without adding super plasticizer increases with increasing water/cement ratio. The water content of the mix is the main factor affecting workability of concrete and mortar thereby increasing water content and will result in higher workability of mix (Cheah *et al*., 2010). Singh *et al*. (2014) observed that increase in w/c ratio of mortar has adverse effect on reduction in the value of mechanical properties and increases the workability. Aggregate shapes such as round, smooth require less water cement ratio in mortar and produces more strength at equal cement mortar content on basis of lower water /cement ratio that can be used (Roces & Elicas, 2009). Angular shapes requires more water but it may not be workable enough for its application in a cement mortar mix (El-Sayed, 2013).

2.5.2 Bleeding

Bleeding occurs when mixing water gains at top surface of concrete in place or when certain amount of water in the mix has tendency to float to the surface of freshly place mortar. Bleeding is caused by failures of the solid constituent of the blended material not to hold all of majority of the mixing water when it settles downward (Neville & Brooks, 2010). It can be quantitatively being expressed as the total settlement (reduction in height) per unit height of concrete or mortar. ASTM C232-04 explained experimental test to determined bleeding capacity as well as the rate of bleeding in concrete.

2.6 Water Cement Ratio

There is a general knowledge in cement production that excessive water content will result to compressive strength reduction of cement mortar, while the lower water content results in poor workability. Therefore, influence of water/cement ratio and determination of optimum water contents on cement is of utmost important (Singh *et al.,* 2015; Haach *et al.,* 2011; Kim *et al.,* 2014; Zhou *et al.,* 2011). Increase in water cement ratio for cement mortar or even polymer modified mortar has reduced the compressive strength of mortar. In all these cases, it results into an increase in workability. Low water cement ratio mortar results in brittle products (Ji-Kai & Li-Mei, 2015) while high water cement ratio doubles the rate of porosity of the mortar (Kim *et al* ., 2014). Lower fineness modulus of sand requires a higher water cement ratio to attain equivalent workability (Lim *et al.,* 2013). Mortar with coarse fine aggregate has higher compressive strength than those of the finer aggregate when the w/c ratio is lower. Influence of grading therefore affects the properties of mortar (Singh *et al.,* 2015).

2.7 Grading and Sources of Sand for Cement-Sand Mortar

Fine aggregates often referred to as sand is generally described as aggregates passing 4.75 mm aperture size openings and retained on 75 microns sieve openings irrespective of their source. The requirement is that it should generally be free from silt, clay and all deleterious substances. It can be sourced from River bed or erosion sand, crushed stones or naturally deposited (Neville, 2012).The result of sieve analysis describes the distribution of the particle sizes usually represented on a log-linear graph. When plotted on a two-dimensional graph, the vertical scale, called the ordinate represents the percentage passing, and the horizontal scale called the abscissa on a log scale, represents the size. A continuous curve represents a well-graded deposit with all the size ranges present in the deposit.

BS 812 (1990) classification uses four grading bandwidths called grading zones over which a grading curve should lie within it. The zones are called 1, 2, 3 and 4. Plaster sand called Zone 4 is almost naturally occurring while others can be sourced from river beds or as erosion soil (Neville, 1996). In contrast, BS EN 933-1: 2012 classifies sand into. These include coarse sand with grain size within 2 to 4.75 mm range, medium sand with grain size within 0.425 to 2 mm range and fine sand with a grain size up to maximum of 0.425 mm aperture size.

2.8 Density

According to Neville (2012), density is known as unit weight per volume. Density of mortar can be determined in the laboratory through the procedure described in BS EN 12390-7:2009. Hypothetically, density is the quantity of constituents of mortar divided by the volume occupied by the mortar. Mortar with higher density than 2000 kg/m3 are known as normal weight mortar as prescribed by ASTM C 140, 2003.

2.9 Water Absorption

Absorption is defined as a process through which liquid penetrates into and fill porous medium within a solid body in mortar or concrete, (ASTM C125, 2015. Fine aggregates with very low absorption generally develop higher bond strength and produce durable mortars than those with a slightly higher absorption (Alawode & Idowu, 2011). Also, water absorption property of a mortar specimen is a test carried out on mortar cubes to determine the rate at which mortar specimens absorb water through its pores when completely immersed in water (Dodoo *et al.,* 2013). This test deals with change in weight of the specimen as it showed an information on a measure of durability and strength of mortar (Omopariola, 2014).

2.10 Compressive strength of mortar

Compressive strength of cement mortar is the most common performance measurement to prescribe quality of mortars and concrete. The strength of cement mortar is assumed to depend primarily on two factors: the water: cement ratio and the degree of compaction. Although the shape of aggregates has an influence on the cement mortar strength (Rocco and Elices 2009; Vladimir *et al*., 2011), compressive strengths of mortar seem to depend on shape of the aggregate. In other words, surface texture has a significant effect on strength, as rough surfaces enhance the bond between particles and paste, thereby increasing strength. Neville and brooks, (2012) and El-Sayed, (2013) stated that the compressive strength of a concrete or mortar is a major property that is directly related to many further features in concrete or mortar production. Strength of mortar and concrete can also determine the comparative quality of materials that is made up of the composite material (Graba, 2008). Basic factors influencing the compressive strength of mortar therefore are: the quality and quantities of binders, age, water /cement ratio, rate of compaction and method of curing (El- Sayed *et al*., 2013).

2.11 Sustainability

The incorporations of eco-friendly building material will be of greater benefit to the environment by means of reduction in the amount of cement used in building, decrease the amount of CO_2 emitted and reduce energy consumption. Notable sources of emission with huge amounts of carbon emissions are from electricity generation, industries transport, and building operations (Marinković *et al*., 2010; Rathod & Pitroda, 2013). Production of Ordinary Portland cement or Portland Limestone cement results from the calcinations of limestone (calcium carbonate) and silico-aluminous materials. The production process of about 1 ton of cement generates about 0.55 - 0.65 tons of CO_2 into the air and it requires the combustion of carbon-fuel into 0.40 tons of CO_2, (Adedeji, 2005; Oshike, 2015). Therefore, the need for reduction of cement through the use of ecologically-friendly building materials like laterite can be useful to protect our environment by the reduction of energy consumption and CO_2 emissions to the atmosphere (Adam, & Agib 2001; Daniel *et al*.,2014). Cement price in Nigeria is usually on an incremental scale, due to supply and demand inequalities. The demand and supply gap has not been able to narrow down due to the increasing demand for home ownership, and government's efforts towards controlling the inequality have so far proved abortive (Enenmo, 2014). With a population of over 180 million people and a growth rate of approximately 3% per annum, the demand for and consumption of cement in Nigeria is expected to be on the increase (Amadi & Amadi, 2013). As a result of the increase in price of cement, seeking for alternative and eco-friendly material to reduce the demand is vital (Alolote & Amadi, 2018; Olubisi, 2017; Biju *et al.,* 2018). Due to increase in building construction, new infrastructures, remodeling and expansion of existing ones, the construction industries and even researchers in developing countries are compelled to look for alternative materials in order to reduce cost (Olugbenga *et al.,* 2007 ; Ukpata *et al* 2011; Imrose *et al.,* 2014; Ige 2016; Biju *et al.,* 2017; Mathew *et al.,*2018). Laterite, quarry dust and some other materials that have been identified as suitable alternatives are now being used either partially or wholly in block, mortar and concrete production.

2.12 Mix design

Mortar mix design is a procedure aimed at selecting proportions of component mixes. There are various methods of mix design available. Mix design is the process of ascertaining the appropriate quantities of the ingredients of concrete or mortar required for a specified grade (Okoloekwe & Okafor, 2007).These mix design methods include: use of trial mixes using absolute volume method of proportioning and use of mixture experimental design which use factorial designs approach such as the Taguchi's Mixture method, Scheffe's Mixture method and the Response Surface Methodology (Okere *et al*., 2013; Alao & Ogunbode, 2019). The basic consideration for mortar mix proportioning should include: the ability of specimen sample to meet specifications requirement which include: durability, strength and economy (Makenya & John 2017).

2.13 The response surface methodology

Response surface methodology (RSM) consists of a set of statistical, factorial experimental techniques that can be used in proportioning of mixture. It is used to either improve or optimize a particular product, (Myers & Montgomery, 1995). RSM are specifically used in a situation where there many factors called variables and responses of interest. Influence of one or more performance characteristic or responses (such as hardened properties of mortar) may be used to optimize one or more response. In other words RSM are commonly used in statistical and mathematical techniques to analyze and develop models between one or more independent variables and responses (Montgomery 2008; Adamu *et al.*, 2017). Also, RSM can also be used to model multi-objective optimization by setting defined desirable goals based on either responses or variables (Mohammed *et al*., 2012; Montgomery, 2008). RSM comprise of three major general steps: experiment design, modeling and optimization (Simon, 2003). This procedure and its application had been used to solve many real life problem in fields such as: Medicine, Pharmacy, Food, Agriculture, Engineering and in Detergents industries to optimize the performances of their products (Babatunde, 2016; Okafor & Egbe, 2017; Osadebe *et al* ., 2014). Optimization features of RSM are useful for most complicated experimental design and it has been used to optimize mixture proportion and develop mathematical models for compressive strength of concrete, to meet a given set of specification requirements (Ettu *et al*., 2013 & Mtarfi *et al.,* 2016). Factorial application and modern experimental design have outstanding contribution in optimizing experimental procedures and this lessens the number of experimental studies and the response is easy to interprete (Rhea & Andres, 2013). In "factorial design", the phrase or the word 'factorial' refers to 'factor' which is a synonym to the word 'design variable'. These factorial designs are employed to fit response surfaces. RSM presents a better way of showing the relationship between different experimental variables and their responses graphically. In obtaining a second order quadratic model of the form in Equation (2.1), (Miličević *et al.,* 2015; Montgomery, 2005).

$$y = \beta_0 + \sum_i^k \beta_i x_i + \sum\sum_{i<j} \beta_{ij} x_i x_j + \sum_i^k \beta_{ii} x_i^2 \qquad (2.1)$$

for a $\boldsymbol{k = 3}$ independent variable components, the full quadratic model is of the form in Equation (2.2):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + e \qquad (2.2)$$

The response *"$\boldsymbol{y}$"* is the measured property of the mixture. The values $\boldsymbol{x_i}$ are the component variables and the parameters β_i and β_{ij} are usually calculated as the linear and quadratic coefficients fitting the experimental data for linear and interactive terms respectively. The response *"**y**"*could further be optimized using the multi-criteria decision process by overlying contour plots produced based on these second order models of the responses (Design Expert, 2000). Whenever a valid polynomial model which contains quadratic terms has been identified, it can be interpreted graphically using 'response trace plots' and 'contour plots' which are used to identify conditions that give the extremum, (Montgomery, 2005). According to Babatunde (2016), Response Surface Methodology can basically be categorized into 4 groups namely:

i) Mixture response surface methodology

ii) Box-Behnken Design

iii) Central Composite Design (CCD)

iv) Dohlert design

A major advantage in the use of the CCD design is its characteristic "*rotatability*" which implies that the method estimates the responses with equal precision at all points in the factor space that are equidistant from the centre point of a cube.

2.14 Absolute volume of constituent proportions

This is an experimental proportioning method where the constituent proportions being investigated and made up of several components or ingredients and summed up to unity, representing the absolute volume (Okarfor & Egbe, 2017; Godfrey *et al.*, 2018). The responses are dependent on constituent materials called the variables. The variables must also be non-negative as shown in Equations (2.3) and (2.4).

$$x_1 + x_2 + \cdots x_q = 1 \quad (2.3)$$

The constraint can be written out in general term as:

$$\sum_{i=1}^{q} x_i = 1 \quad (2.4)$$

and $\quad x_i \geq 0$

In equations (2.3) and (2.4), q is the number of mixture components, and unity representing total absolute volume of components in the mixture.

2.15 Factorial design

This is a factorial experimental design in which combinations of level of factors are set as the run (Milicevic & Tanja 2017). Factorial design can be categorized as full factorial design or fractional factorial design with both of them with two levels of each factor and are commonly used in process screening design for economical consideration (Okafor ,2001; Vera-candioti *et al.*, 2010; Florentinus, 2019). It is possible to combine every factor at the design level using full factorial design. It should be noted that the fractional factorial design can reduce the number of experimental runs but does not estimate all major and interactive effects separately (Brereton, 2017 & Hibbert, 2012). Table 2.2 shows the factorial design for 2, 3, and 4 experimental variables at two-levels including the signs. Similarly, in building up the matrix involving 5 and 6 variables, it would give 32 and 64 experimental runs respectively which imply the exponential increment of (2^n), as the number of variables increase.

Table 2.2: Signs tables for calculating the main effects from a Factorial design for two, three and four Variables.

Two variables			**Three variables**				**Four variables**				
Exp. No.	x1	x2	Exp. No.	x1	x2	x3	Exp. No	x1	x2	x3	x4
1	-	-	**1**	-	-	-	**1**	-	-	-	-
2	+	+	**2**	+	-	-	**2**	+	-	-	-
3	-	+	**3**	-	+	-	**3**	-	+	-	-
4	+	+	**4**	+	+	-	**4**	+	+	-	-
			5	-	-	+	**5**	-	-	+	-
			6	+	-	+	**6**	+	-	+	-
	2^2		**7**	-	+	+	**7**	-	+	+	-
			8	+	+	+	**8**	+	+	+	-
							9	-	-	-	+
							10	+	-	-	+
					2^3		**11**	-	+	-	+
							12	+	+	-	+
							13	-	-	+	+
							14	+	-	+	+
							15	-	+	+	+
							16	+	+	+	+
										2^4	

Source: Lundstedt *et al*, (1998).

2.16 The central composite design (CCD)

This is a methodology in factorial experimental design and was a useful tool in response surface methodology. It is a response model generally used for building a second order (quadratic) model for measuring responses from variable components input without needing to use a complete three-level full factorial experiment (Montgomery, 2005). The CCD is an augmented factorial design, used in product optimization and generally can be used to reduce the numbers of experiment to close to two-level full factorial design (Okumu *et al.,* 2017; Revathi & Baskara 2018; Salem & Loubna, 2015). A CCD experimental design procedure consists of three distinct sets of experimental runs (Montgomery, 2013; Coruh & Elevli, 2015 ; Barbuta, *et al.*, 2015), namely:

i) A factorial design or "cube points" consisting of a 2^n cube points which are generated from a full factorial design.

ii) Axial points which consisting of 2n axial points.

iii) A "centre point" experimental run which is a single point in the centre which is created by a "*nominal design"*.

Centre points are often repeated so that the accuracy of the experiments can be further improved. CCD therefore, can then be considered as consisting of a factorial design (corners of a cube) together with the axial and centre points at two levels for a three-component variable (Montgomery, 2005). This makes CCD more advantageous by reducing the number of experimental runs. It also creates a more perfect prediction of linear and quadratic interaction effects of parameters affecting a particular process, (Babatunde, 2016). CCD therefore specifies $2^n + 2n + 1$ design points for a full quadratic model consisting of n factors or variables. The ranges of "minimum and maximum" values of the control parameters are usually scaled to [-1, +1] (Barbuta *et al.*, 2015; Okumu *et al.*, 2017; Miličević & Kalman, 2017). The graphical illustration in a three-dimensional form and plan of the Central Composite in three variables are shown in Figure 2.1: (a) - (c).

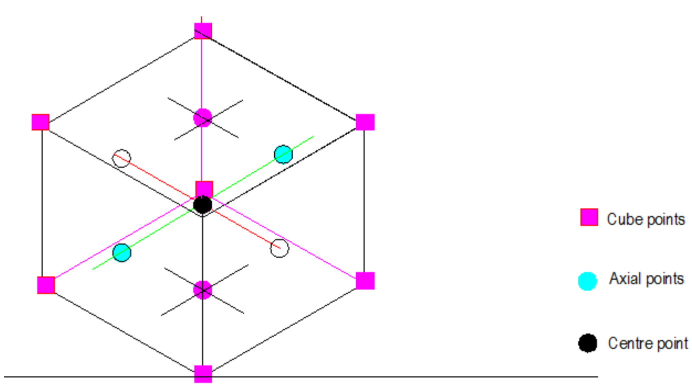

Figure 2.1 (a): Graphic Image of a Central Composite Design (Isometric)

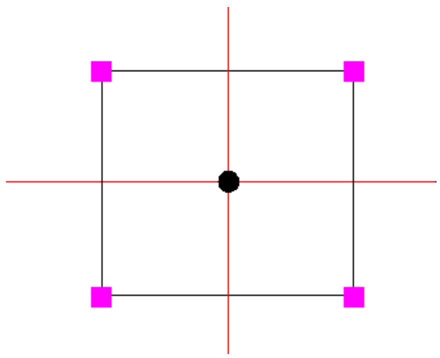

Figure 2.1 (b): Graphic Image of a Central Composite Design (Plan)

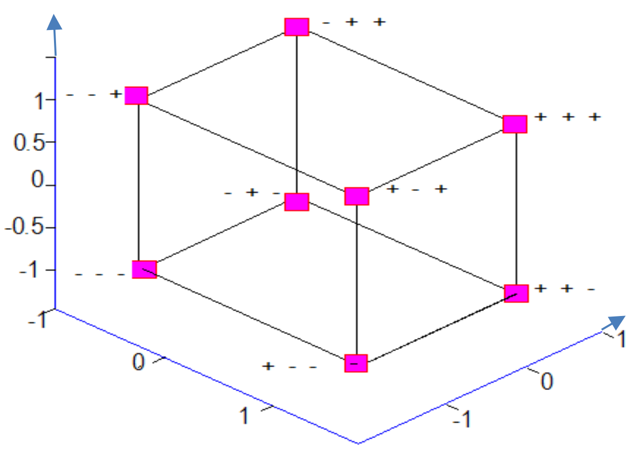

Figure 2.1 (c): The signs of the factorial points in a design with three variables

Table 2.3: Construction of vectors of Central Composite Design matrices for two and three variables

Two component variables		**Three component variables**		
X_1	X_2	X_1	X_2	X_3
-1	-1	-1	-1	-1
1	-1	1	-1	-1
-1	1Factorial point	-1	1	0 Factorial point
1	1	1	1	-1
		-1	-1	1
0	0 Central point	1	-1	1

		-1	1	1
-α	0	1	1	1
-α	0 Axial point			
0	-α	0	0	0 Central point
0	A			
		α	0	0
		-α	0	0
		0	-α	0 Axial point
		0	A	0
		0	0	-α
		0	0	α

Source: Lundstedt *et al.*, (1998).

2.17 related work of blending of sand with laterite

Okafor and Egbe (2017) used mixture experiment to design a model to predict compressive strength and water absorption of a laterite-Quarry dust cement block. The research work concentrated on the use of laterite, quarry dust for the replacement for sand in sandcrete block production using Scheffe"s simplex lattice design. The statistical model developed was used to predict the mix proportions that produced a good result of a *p* value of less than 0.05. This model was found to be adequate when tested for lack of fit.

Cement-sand mortar for bedding and jointing was introduced to reduce total cost of block wall per square metre. It was confirmed that cement-sand blended with laterite was capable for creating a uniform stress distribution of dead loads from the block (Vladimir *et al*., 2011). The uniqueness in the use of laterite as a partial replacement of sand is its plasticity characteristics, thereby introducing both cement and plastic bonds in the composite material. It enables the mixture to produce a high workability, plastic and cheaper mix at low cement content. Cement-sand-laterite mortars are also used as a basic finishing material both on block walls such as plastering, rendering and/or on screeded beds and as a ferro-cement material (Kolapo *et al.,* 2007; Joshua *et al.,* 2014).

Egbele and Orie, (2016) worked on Optimization of the Compressive Strength of Termite Mound Soil-Cement Blended Concrete using Design Expert 7.0. The experiment focused on analysis of a mix proportion of concrete containing coarse aggregate, fine aggregate, cement, termite mound soil using 2-Level factorial design method to optimize its compressive strength. The experimental design obtained values of responses (compressive strength at 7 and 28 days). A mathematical model which predicts the compressive strength of termite mound soil-cement blended concrete was obtained. The optimal compressive strength value of 32.36 N/mm^2 compared favourably with unblended material with a value of 33.78N/mm^2. The predictions from the model were found to be adequate at 95% confidence level. The mix value of 8.24kg of cement, 21.96kg of sand, 43.73kg of granite,0.55kg of termite mound and 5.57kg of water: corresponding to a mix ratio 1:2.5:5:0.07:0.6 produced the optimum mix. That corresponds to optimum compressive strength of concrete at 28days and was found to be 32.36N/mm^2 and concluded that termite mound soil can be used as a construction material.

Olubisi (2017) examined the performances of concrete under harsh environmental condition. The work concentrated on ascertaining the suitability of laterite as fine aggregate replacement for sand at 0, 10, 20, 30 and 40% replacement. The laterized concrete cubes were subjected to varying temperatures and immersion in chemicals such as magnesium sulphate (Mg_2SO_4) and alternate wetting and drying to simulate wet and dry seasons. The result showed that compressive strength of laterized concrete with laterite-fine aggregate ratio decreases when subjected to alternate wetting and drying and increases when subjected to magnesium sulphate (Mg_2SO_4). It observed that a laterized-concrete with a laterite-fine aggregate percentage of 20% at 100^oC attained optimum compressive strength of 12.90N/mm^2.

Biju Mathew *et al.* (2018) examined the suitability of laterite sand as fine aggregate in mortar. The experimental work concentrated on preparing a cement mortar using river sand for different cement mortar ratios from 1:3, 1:2 and 1:6. Replacing the natural sand by laterite for the replacement levels of 20, 40 and 60 % by weight of sand at ambient temperature were tested in accordance with IS:2250- 1981. Water absorption and durability tests (sulphate attack, chloride attack and acid attack) were also conducted after the initial curing of the laterized mortar cubes. The test result shows that up to 40 % of replacement of laterite in river sand and crushed granite dust sand are suitable for bedding and jointing in masonry construction.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The following are the materials used for this study: Portland cement (PLC), laterite, fine aggregate and water.

3.1.1 Portland limestone cement (PLC)

The cement used for this research is Portland Limestone brand of cement. The cement used was Dangote brand 5X cement obtained in Minna. Necessary precaution was taken to ensure that the cement was current supply was free of adulteration. It is stated by the manufacturer as complying with BS EN 196 -1:2016.

3.1.2 Laterite

Laterite fines with specific gravity of 2.65 as shown in Appendix B.2, reddish- brown in colour and non- granular was obtained from borrow pit of Federal University of Technology, Minna, Niger State conforming to BS EN 196-1:2016 as shown in Appendix A.2.

3.1.4 Mixing and curing water

The water used for mixing and curing of mortar cubes samples for this experiment is a clean potable water.

3.2 Experimental Plan

The experimental plan is designed in order to be able to achieve the stated objectives.

3.2.1 Work plan one

The work plan one to achieve objective one which centered on investigation of the physical properties of the main constituent materials (cement, sand and laterite). The results are shown in Appendix A.1-A.2, B.1-B.3,

a. Sample materials were examined in laboratory for specific gravity, bulk density and other physical properties.
b. Fine aggregate and laterite samples were examined in the laboratory for particle size distributions (P.S.D).

3.2.2 Work plan two

Work plan two was to achieve the objective two which is the determination of appropriate proportions of the constituent material for mortar and determine the fresh properties of mortar made with the cement sand and laterite.

a. Then making requisite combination of sand and laterite for the control, binary mixtures (½. sand and` ½. of laterite; and 1/3. of laterite and 2/3. of sand). The mix without the laterite combination serves as the control.
b. Determination of quantities of materials / mix ratio and establishing limits for lower and upper bounds for the mix ratios.
c. This involves the use of central composite design (CCD) mixture experimental plan. to generate the design mix for the proportions of the constituent materials.

3.2.3 Work plan three

Work plan three was designed to achieve objective three and four which dealt with examining the effect of laterite and sand on hardened properties of mortar produced from the composite material and absorption characteristics. The properties investigated here were examined using the following test and sample sizes as shown in Appendix C.1: appendix E

a. Compressive strength of 50mm mortar cubes at curing age of 7 and 28 days
b. Water absorption – 50mm mortar cubes at curing age of 7 and 28 days

3.2.4 Work plan four

Work plan four was designed to achieve objective five which dealt with developing specification writing procedure for the mortar mix which is achievable using Design Expert Statistical Software (Design Expert, 2000). These were done by imputing the variables and the responses (the result) obtained from experimental work to D-Expert software for evaluation of influence of interaction of constituent materials on hardened properties of the composite mortar mix. This enables specification writing to be carried out.

3.3 Method

This describes the method employed to conduct the experiment in accordance to relevant standard.

3.3.1 Estimation of constituent proportions

The absolute volume method was used for estimating the mixture proportions for the lower and upper bounds using equation 5, (Neville, 1996) as:

$$\frac{water}{Gs_{water} \times 1000} + \frac{cement}{Gs_{cement} \times 1000} + \frac{sand}{Gs_{sand} \times 1000} = 1 \qquad (3.1)$$

$\boldsymbol{w}here\ Gs$

$= specific\ gravity\ of\ 1.0, 3.15\ and\ 2.62\ for\ water, cement\ and\ sand\ respectively$

For this research work, the sand /cement ratio selected were between the ratios 1:6 and 1:10 for upper limits and lower limits and water cement ratio of 0.5 was initially used as a starting estimate and was used to estimate the quantities of proportions for the mortar mix. The equations 3.1 was re-written to represent the conditions in Equations 3.2 and equation 3.3 as shown below for the control and the binary mixtures below.

$$\frac{0.5}{1 \times 1000} + \frac{C}{3.15 \times 1000} + \frac{6C}{2.62 \times 1000} = 1 \qquad (3.2)$$

$$\frac{0.5}{1 \times 1000} + \frac{C}{3.15 \times 1000} + \frac{10C}{2.62 \times 1000} = 1 \qquad (3.3)$$

These quantities were later revised to reflect water mix requirement to obtain a reasonable workability requirement for the mix with the aid of a flow meter apparatus. Then the required water quantity was used to re-calculate the resulting component proportions for lower limits and upper limits for cement, sand and aggregate as shown in Tables 3.1 and 3.2

Table 3.1: Summary of Mix Design

Mix ratio	W/C ratio	Water(kg)	Cement(kg)	Sand(kg)
1:10	0.50	107.89	215.78	2157.84
1: 60	0.50	160.90	321.80	1930.79

Table 3.2: Mix design with new water ratio for various proportions mix

	mix ratio	Water(kg)	Cement(kg)	Sand(kg)
Control	1:10	276.50	175.00	1750.01

	1:60	262.89	282.68	1696.10
⅔ : ⅓	1:10	303.32	168.51	1685.13
	1:60	339.99	357.89	1431.55
½ : ½	1:10	340.02	159.63	1596.64
	1:60	377.31	238.80	1432.82

3.3.2 Experimental design

Design expert 2000 software was used in generating the design mix matrix with upper bound of ratio 1: 6 and lower bound of ratio 1:10 of cement sand mortar mix. as shown in Table 3.2. Equations 3.4 and 3.5 represents coding and decoding of the variable components for all design points in the variable space, (Montgomery, 2000). These are the equations used by the Design Expert software for converting variable quantities from actual to coded variables respectively.

$$x_i = \frac{2x_i' - x_{il} - x_{iu}}{x_{iu} - x_{il}} \tag{3.4}$$

and the normalized variable are now bonded within the cube as:

$$-1 \leq x_i \leq 1$$

The transformation into actual variables is carried out using the expression:

$$x_{\boldsymbol{actual}} = x_{min} + \frac{(x_{coded} + 1)}{2} * (x_{max} - x_{min}) \tag{3.5}$$

Where x_{actual} is the uncoded value and x_{min} and x_{max} are the uncoded minimum and maximum values corresponding to **±1** coded values respectively and x_{coded} is the coded value to be translated.

3.3.4 Preparation of test specimen

The mortar cubes were prepared using a cube sizes 50 x 50 x 50mm cube sizes for different proportions of mixes for the control and binary (⅔ : ⅓ and ½ : ½) mixes. Three mix design constituent were mixed, placed and compacted in the cube for each mix. A total of 360 cubes were caste and cured for varied curing ages of 7 and 28 days. Compressive strength, water absorption tests were carried out in the experimental investigation for various mix control for the control and binary mixtures respectively.

3.4 Particle Size Distribution

Particle size distribution of the natural sand was conducted using the dry-sieving approach in accordance with BS EN 196-1:2016 for a classification of the natural sand. Sieve sizes of 4.75mm, 2.36mm, 1.18mm, 300µmm, 150µmm, 75µmm pan sieves, brush, scoop, stopwatch, and weighing balance. The reference sand required for the production for strength determination test specification using BS EN 196-1:2016.

The data obtained from particle size distribution of the sample were plotted on semi-log graph with sieve particle diameter size on horizontal X-axis using logarithmic scale and the vertical Y-axis indicating the percentage passing. Other analysis obtained is the coefficient of uniformity (C_u) and the coefficient of curvature in Equations 3.6 and 3.7 respectively for the natural deposit without sieving.

Uniformity Coefficient

$$C_u = \frac{D60}{D10} \qquad (3.6)$$

Coefficient of curvature

$$C_c = \frac{D30^2}{D10\ x\ D60} \tag{3.7}$$

Well graded requirement using the C_u and C_c were represented by as $C_u \geq 4$ for gravel; $C_u \geq 6$ for sand and C_c =1 and 3 for all type of soil having a $C_u < 2$ are classified as uniformed graded.

3.5 Bulk Density of Materials

The bulk density of the fine aggregate was calculated in compliance with BS EN 12390:2009. The apparatus used was density cube (wooden), trowel, rammer and weighing balance. The bulk density for aggregate sample was computed using Equation 3.8

$$D = \frac{M}{V} \tag{3.8}$$

Where; D is the density of the aggregate sample in kg/m^3

M is the mass of the aggregate sample in kg

V is the volume of the aggregate sample in m^3

3.6 Specific Gravity of Materials

The specific gravity of the test materials was determined as specified by BS EN 1097:2003. The apparatus used in carrying the test include a funnel, weighing balance, density bottle, spatula and stopper.

The specific gravity (Gs) of the materials was calculated using Equation 3.9

Specific gravity

$$Gs = \frac{(w2 - w1)}{(w2 - w1) - (w3 - w2)} \quad (3.9)$$

w_1 is the weight of bottle

w_2 is the weight of the bottle + dry sample

w_3 is the weight of the bottle + sample + water

3.7 Atterberg's Limit Test

The Atterberg's limit test classifies the laterite sample to determine the level of cohesiveness of the sample or otherwise the percentage of clay content. Tests covered include: plastic limit, liquid limit and plasticity index tests.

3.7.1 Liquid limit test (cassangrande method).

A weighted air-dried sample passing sieve was placed on a flat plastic smooth plate and then mixed with water using the spatula until it attained homogeneous paste. The soil sample is then transferred into Casagrande's cup and then smoothened. The sample is scoped at the middle using a plastic groove. Blows which must not be greater than 50 blows and the least below must not be less than 10 were applied to the sample. Water was further added to the sample and the procedure was repeated. At each stage small quantity of the paste is obtained for the determination of moisture content.

3.7.2 Plastic limit

A known weight soil sample passing sieve No. 40 sieve size was mixed with water to obtain a homogeneous paste that was plastic enough to be rolled into ball. The ball of the soil was then rolled between the hand and the flat plastic smooth plate. The rolling is continuous, until a thread of about 3mm diameter was obtained. At this stage, the thread crumbled. The portion of the crumbled soil was packed into moisture content can with known weight for moisture content determination.

3.7.3 Moisture content

According to Neville and Brooks, (2010), moisture content is the presences of excess water in the saturated state of the surface-dried material. Two samples of sand labeled A, B, will be weighed and placed in the oven and dried for 24 hours at about 100°C and is calculated on as a percentage. According to BS EN 13139:2013, The moisture content is the ratio of the mass of water in the sand sample to the mass of the dried sand sample in percentage expressed as in Equation 3.10

Moisture content

$$mc(\%) = \frac{weight\ of\ the\ water\ in\ the\ sand\ ssample}{weight\ of\ dried\ sand\ sample} \times 100 \tag{3.10}$$

3.6 Compressive strength

The test for the determination of compressive strength of cement – laterite mortar cubes were carried out according to methods specified by the European Standard BS EN 196-1:2016. The cubes were cast and were tested for compressive strength by loading the sides of the cubes uniformly with a compressive strength testing machine until fracture occured. The maximum load in KN at which fracture occurred was recorded and used to calculate the compressive strength as expressed in Equation 3.11

Compressive strength,

$$F = \frac{P}{A} \tag{3.11}$$

Where; F is the compressive strength in N/mm^2

P is the maximum load at failure, in N

A is the cross-sectional area, in mm^2.

3.7 Water Absorption Test

The mortar samples (cubes) were removed from the curing tank and allowed to dry and then placed in the electrical oven to dry at 105^0 C for 24 hours. The mortar samples were removed from the oven and allowed to cool at room temperature then weighed to define the initial weights and the values were recorded as w1. The final weights were determined after immersing the mortar samples in the curing medium for 30 minutes then removed with a cloth, dried and re-weighed again and the value was recorded as w2. The values obtained were recorded and the results were calculated to assess the rate of absorption of the mortar sample in accordance with BS 1881-122 (2011) and shown in Equation 3.12.

Water Absorption

$$W = \frac{w2-w1}{w1}\; x\; 100 \tag{3.12}$$

3.8 Absolute Volume (V)

The absolute volume of a granular material is the volume of the solid matter in the particles; it does not include the volume of the voids between the particles. The absolute volume of a material is computed in Equation 3.13:

Absolute Volume

$$V = \frac{weight\ of\ material}{specific\ gravity\ of\ material\ x\ unit\ weight\ of\ water} \qquad (3.13)$$

3.9 Fitting of the Central Composite Design Variable Components

After estimation of material quantities for the upper and lower bounds with aids of absolute volume method, a mixture experimental design is employed for modelling responses of interest as a second order quadratic model.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physical Properties of Materials

Physical properties of the materials influence the strength and durability of the mortar. Hence, the effect of the component mixtures on the hardened properties were determined.

4.1.1 Lateritic soil characteristic test results.

Tables A.1, B.1, B.2 and C.1 show the physical properties of the lateritic soil which shows the Sieve Analysis, Atterberg's limits, specific gravity and densities of the lateritic soils. These properties are used in classifying the soils and the implications of their characteristic values are discussed in proceeding properties below.

4.1.2 Grain size analysis result (gradation).

Figures 4.1and 4.2 show the result of particle size distribution (PSD) of the laterite and fine aggregate for the experiment. The grading curve for the laterite fines revealed a coefficient of curvature (Cc) of 2.401 and coefficient of uniformity (Cu) of 15.56 in its natural deposit form without sieving, with sizes ranging from 0.063mm to 10mm. The natural soil was thus classified as intermediate plasticity. The laterite soils have liquid limit between 35% and 50%. The linear shrinkage limit of 14.07% on the other hand fell within the range of 4 - 25%. Fine aggregate in figure 4.2 shows the grading curve with coefficient of curvature of C_c 2.26 and coefficient of uniformity (Cu) of 1.03

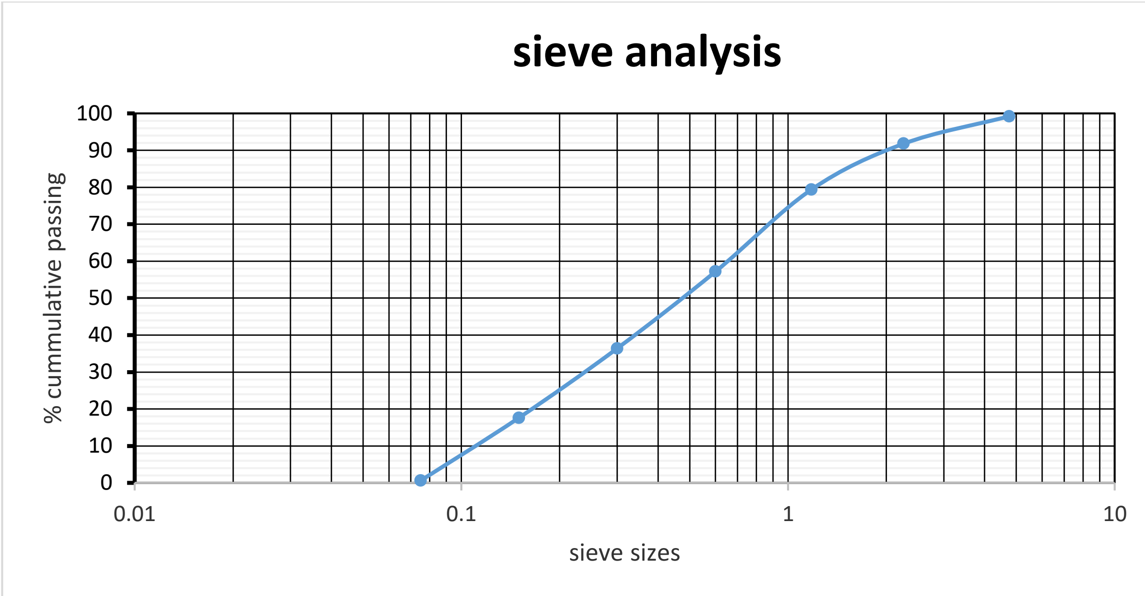

Figure 4.1: Sieve analysis laterite

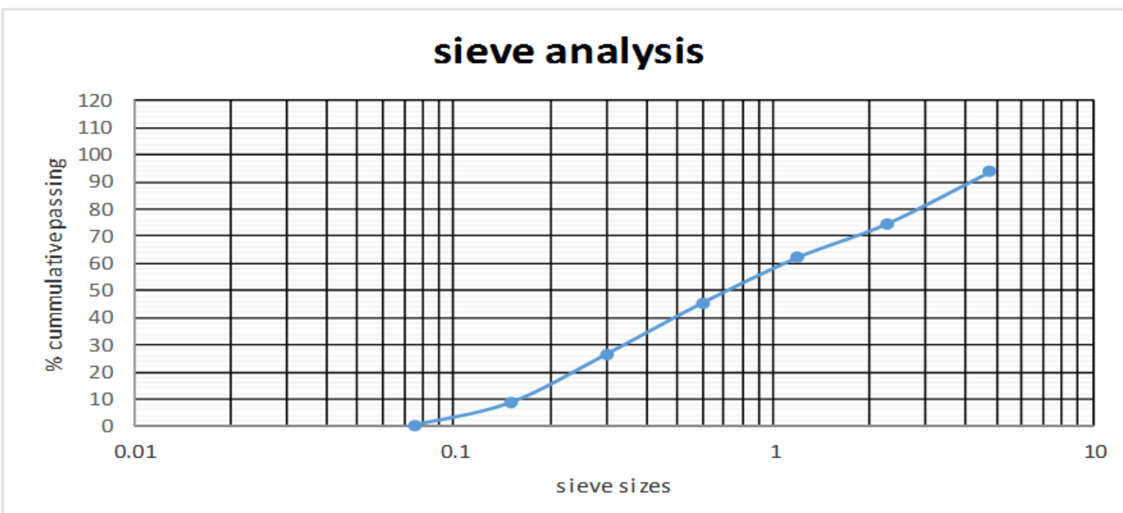

Figure 4.2: Sieve analysis sand

4.1.3 Atterberg limits test

The laterite liquid limit (LL) is 42.16 and plastic limit (PL) is 24.49 in Table B.1 was used to generate the plasticity index (PI) whose value is 17.67. The liquid limits and the plasticity index on the Casagrande's plasticity chat shows that they are on the A-line and above the hatch zone on the chat signifying that all samples are clay of high plasticity.

4.1.4 Specific gravity

Tables B.2 and B.3 show the specific gravity for laterite and sand which is 2.65 and 2.62 respectively. The specific gravity of laterite falls within the range of 2.55 and 4.6 which was recommended by and is suitable for masonry units. while that of the sand falls within the specified value by Neville and Brooks (1987) for natural aggregates.

4.1.5 Moisture content

The natural Moisture Content of the fine aggregate was observed to be 0.46%.

4.2 Density

The Figures 4.3 and 4.4 illustrate the variation of the density of specimen with different percentage replacement of natural sand by laterite fines. Mortar cubes produced had densities above the minimum of 1600kg/m^3. Generally, there was a gradual decrease in the densities of the mortar cubes as the laterite content increases. The highest density was 2253kg/m^3 which was recorded by the control mortar (no laterite fines) whiles those of binary replacements recorded an average density of 2148kg/m^3, 2079kg/m^3, and 1847kg/m^3 respectively. Obviously, this signifies that mortar with high amount of laterite fines were less dense or lighter than those with only conventional sand. This is attributed to the lower specific density of the laterite fines when compared to that of the natural sand as presented in Appendix. C.1

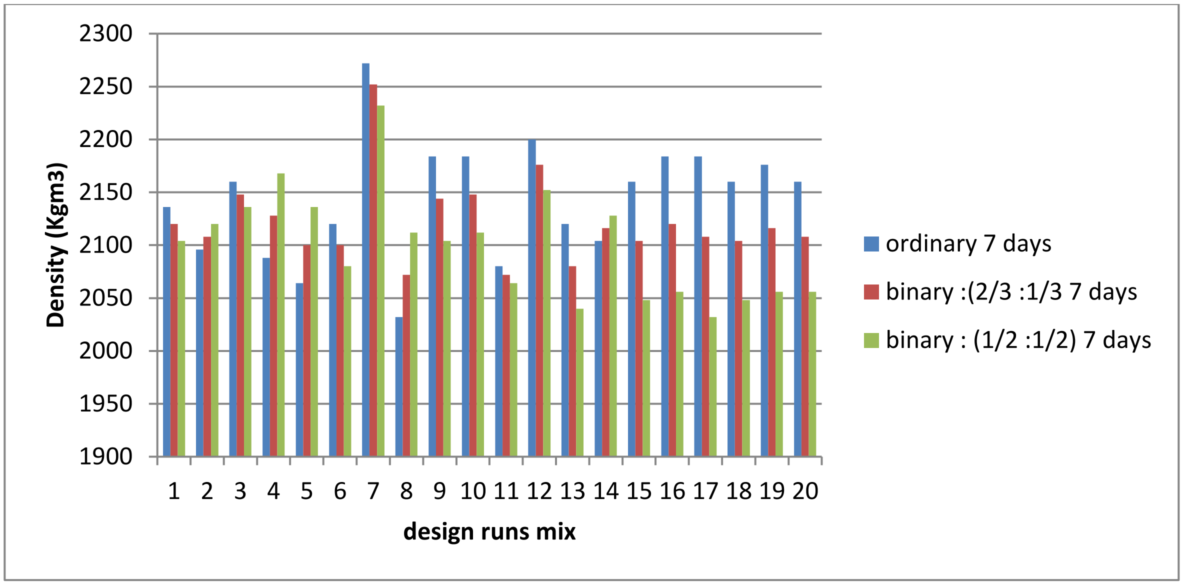

Figure 4.3: Average Density of control, binary (⅔ : ⅓ and ½ : ½) mortar sample for 7 days .

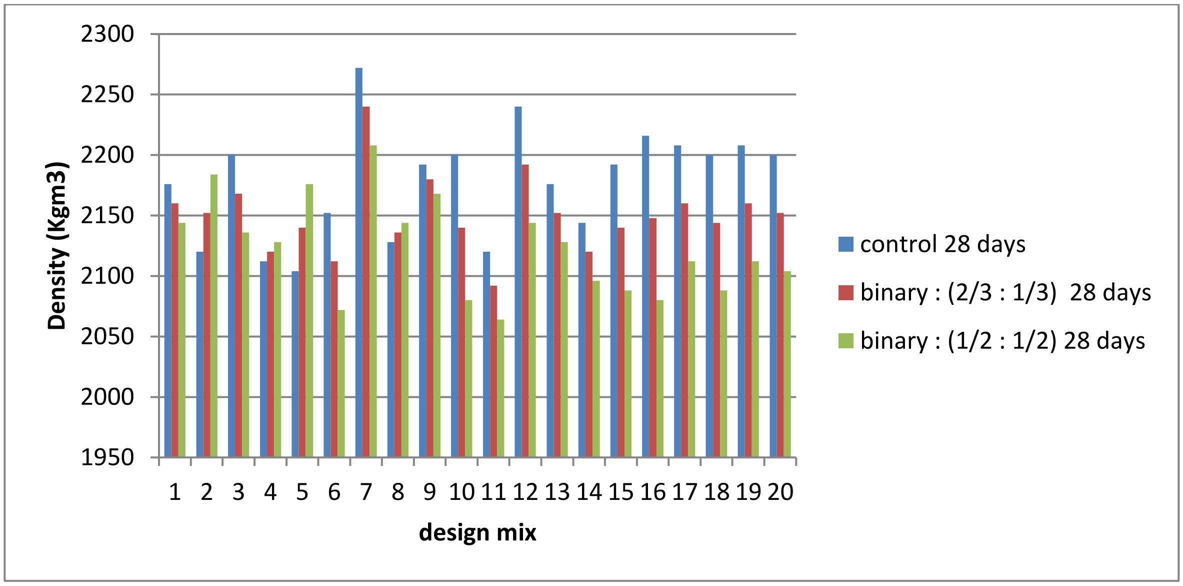

Figure 4.4: Average Density of control, binary (⅔ : ⅓ and ½ : ½) mortar sample for 28 days

4.3 Compressive strength

A summarized experimental design which consists of three different mortar mix designs and three various mix variables. It also includes their various range of constituent mixture rof values obtained from mix design and the responses (compressive strength at 7 and 28 days). The variables obtained are presented in Tables 4.1, 4.2 and 4.3 representing control mix, binary **(⅔ : ⅓ and ½ : ½)** mixes respectively.

Table 4.1: Actual and coded variable for mixture proportion for cement sand for control mixture.

(1)	(2)	(3)			(4)			(5)	(6)
The design matrix		x_1=water; x_2=cement		x_3=sand (control)				$Y_1=f_{c7}$	$Y_2=f_{c28}$
		Variables							Response
		coded			actual (kg)			N/mm^2	N/mm^2
Experiment no.	Point	x_1	x_2	x_3	x_1	x_2	x_3	Y_1	Y_2
1	Factorial	-1	-1	-1	262.89	175.00	1696.10	6.88	7.47
2	Factorial	1	-1	-1	276.50	175.00	1696.10	3.31	4.96
3	Factorial	-1	1	-1	262.89	282.68	1696.10	6.51	8.56
4	Factorial	1	1	-1	276.50	282.68	1696.10	6.44	7.92
5	Factorial	-1	-1	1	262.89	175.00	1750.01	2.93	4.59
6	Factorial	1	-1	1	276.50	175.00	1750.01	3.84	6.16
7	Factorial	-1	1	1	262.89	282.68	1750.01	9.00	10.41
8	Factorial	1	1	1	276.50	282.68	1750.01	9.29	11.32
9	Axial	-1.682	0	0	258.25	228.84	1723.05	5.00	7.52
10	Axial	1.682	0	0	281.14	228.84	1723.05	4.41	9.36
11	Axial	0	-1.682	0	269.70	138.28	1723.05	2.93	4.48
12	Axial	0	1.682	0	269.70	319.40	1723.05	11.61	15.76
13	Axial	0	0	-1.682	269.70	228.84	1677.71	7.56	12.00
14	Axial	0	0	1.682	269.70	228.84	1768.39	5.87	7.77
15	Centre	0	0	0	269.70	228.84	1723.05	5.21	8.37
16	Centre	0	0	0	269.70	228.84	1723.05	5.23	8.36
17	Centre	0	0	0	269.70	228.84	1723.05	5.37	8.36
18	Centre	0	0	0	269.70	228.84	1723.05	5.32	8.37
19	Centre	0	0	0	269.70	228.84	1723.05	5.37	8.37
20	Centre	0	0	0	269.70	228.84	1723.05	5.32	8.37

Column 3 represents coded variables. Column 4 represents actual variables and columns 5 and 6 represent responses at 7 and 28 days respectively

Table 4.2: Actual and coded variable for mixture proportion for binary (½ : ½) cement sand : laterite mixture.

(1)	(2)	(3)			(4)			(5)	(6)
The ccd design matrix		x_1=water; x_2=cement		x_3=sand + laterite (binary ½ : ½)				$Y_1=f_{c7}$	$Y_2=f_{c28}$
		Variables							Response
		coded			actual (kg)			N/mm^2	N/mm^2
Experiment no.	Point	x_1	x_2	x_3	x_1	x_2	x_3	Y_1	Y_2
1	Factorial	-1	-1	-1	340.03	159.64	1432.82	3.76	6.68
2	Factorial	1	-1	-1	377.31	159.64	1432.82	3.36	6.15
3	Factorial	-1	1	-1	340.03	238.80	1432.82	4.44	6.75
4	Factorial	1	1	-1	377.31	238.80	1432.82	5.04	7.33
5	Factorial	-1	-1	1	340.03	159.64	1596.36	3.77	6.07
6	Factorial	1	-1	1	377.31	159.64	1596.36	3.44	5.97
7	Factorial	-1	1	1	340.03	238.80	1596.36	5.47	8.36
8	Factorial	1	1	1	377.31	238.80	1596.36	4.96	8.19
9	Axial	-1.682	0	0	327.31	199.22	1514.59	4.32	7.80
10	Axial	1.682	0	0	390.02	199.22	1514.59	3.72	7.15
11	Axial	0	-1.682	0	358.67	132.64	1514.59	2.72	5.84
12	Axial	0	1.682	0	358.67	265.80	1514.59	5.16	7.80
13	Axial	0	0	-1.682	358.67	199.22	1377.06	3.67	6.44
14	Axial	0	0	1.682	358.67	199.22	1652.12	4.00	6.21
15	Centre	0	0	0	358.67	199.22	1514.59	4.04	7.05
16	Centre	0	0	0	358.67	199.22	1514.59	4.05	7.03
17	Centre	0	0	0	358.67	199.22	1514.59	4.05	6.97
18	Centre	0	0	0	358.67	199.22	1514.59	4.05	7.03
19	Centre	0	0	0	358.67	199.22	1514.59	4.05	7.15
20	Centre	0	0	0	358.67	199.22	1514.59	4.04	7.04

Column 3 represents coded variables. Column 4 represents actual variables and columns 5 and 6 represent responses at 7 and 28 days respectively

Table 4.3: **Actual and coded mixture proportion for binary (⅔ : ⅓) mix for cement sand : laterite mixture**

1	2	3			4			5	6
The CCD design matrix		x_1=water; x_2=cement		x_3=sand +	Laterite(binary (⅔ : ⅓)			$Y=f_{c7}$	$y=f_{c28}$
		Variables							Response
		coded			actual (kg)			N/mm^2	N/mm^2
Experiment	Point	x_1	x_2	x_3	x_1	x_2	x_3	Y	Y
1	Factorial	-1	-1	-1	252.97	180.69	1710.6	5.32	7.07
2	Factorial	1	-1	-1	325.79	180.69	1710.6	3.33	5.55
3	Factorial	-1	1	-1	252.97	258.56	1710.6	5.47	7.65
4	Factorial	1	1	-1	325.79	258.56	1710.6	5.74	7.63
5	Factorial	-1	-1	1	252.97	180.69	1806.93	3.35	5.33
6	Factorial	1	-1	1	325.79	180.69	1806.93	3.64	6.07
7	Factorial	-1	1	1	252.97	258.56	1806.93	7.23	9.39
8	Factorial	1	1	1	325.79	258.56	1806.93	7.13	9.75
9	Axial	-1.682	0	0	228.14	219.63	1758.77	4.66	7.66
10	Axial	1.682	0	0	350.62	219.63	1758.77	3.33	8.25
11	Axial	0	-1.682	0	289.38	154.14	1758.77	2.83	5.16
12	Axial	0	1.682	0	289.38	285.12	1758.77	8.39	11.78
13	Axial	0	0	-1.682	289.38	219.63	1677.76	5.61	9.22
14	Axial	0	0	1.682	289.38	219.63	1839.78	4.93	6.99
15	Centre	0	0	0	289.38	219.63	1758.77	4.63	7.71
16	Centre	0	0	0	289.38	219.63	1758.77	4.64	7.69
17	Centre	0	0	0	289.38	219.63	1758.77	4.71	7.67
18	Centre	0	0	0	289.38	219.63	1758.77	4.69	7.7
19	Centre	0	0	0	289.38	219.63	1758.77	4.71	7.76
20	Centre	0	0	0	289.38	219.63	1758.77	4.68	7.71

Column 3 represents coded variables. Column 4 represents actual variables and columns 5 and 6 represent responses at 7 and 28 days respectively

4.4 The Model

The model reveals the prediction equations from the factor variables, their coefficients including the mean and standard deviation derived from Tables 4.1, 4.2 and 4.3. The model is of the quadratic type. However, the elimination of insignificant terms to achieve a probability $p \leq 0.05$ have eliminated all insignificant interaction terms in the model. The method is essentially, a factorial design of n-factors. Compressive strength at 7 and 28 days varied according to the blends including the control mix.

4.5 The Limits on Constituent Materials

A starting water-cement ratio of 0.5 was used during the estimation of the constituents of water, cement,and sand/laterite. This was later revised to reflect the mixing water required to obtain the needed workable mix using the flow metre apparatus. This mixing water was used to re-calculate the mix proportions using the same absolute volume method. The resulting mixtures for the lower and upper limits on water, cement and fine aggregates are shown in Equation 4.1, 4.2 and 4.3

$$\left.\begin{array}{l} 0.263 \leq x_1 \leq 0.277 \\ 0.056 \leq x_2 \leq 0.090 \\ 0.647 \leq x_3 \leq 0.668 \end{array}\right\} \quad CCD_{CONTROL} \qquad (4.1)$$

$$\left.\begin{array}{l} 0.340 \leq x_1 \leq 0.377 \\ 0.051 \leq x_2 \leq 0.076 \\ 0.547 \leq x_3 \leq 0.609 \end{array}\right\} \quad CCD_{BINARY(½:\,½)} \qquad (4.2)$$

$$\left.\begin{array}{l} 0.253 \leq x_1 \leq 0.326 \\ 0.057 \leq x_2 \leq 0.082 \\ 0.653 \leq x_3 \leq 0.689 \end{array}\right\} \quad CCD_{BINARY\,(⅔:\,⅓)} \qquad (4.3)$$

4.6 The Model Equations

The models that explain the fitted data are as shown in Equations 4.4 – 4.9, which represent the response predictions for mortar strength at 7 and 28 days for cement sand mortar, binary and tenary mixtures of sand/laterite mixtures. By default, the CCD model consists of a constant term and a coefficient of the variable term which describes the responses from input variable data. This model represents the statistical significance with a low probability value of $p \leq 0.05$ and should show that both the model, the coefficient and the intercept are significant and should be included in the model.

$$fcontrol; \qquad fc7 = -3.11682 + 0.039274 * Cement \qquad (4.4)$$

$f control;$ $fc28 = -2.16033 + 0.046255 * Cement$ (4.5)

$f binary(½ : ½);$ $fc7 = 0.54007 + 0.017899 * Cement$ (4.6)

$f binary(½ : ½);$ $fc28 = 3.61276 + 0.016751 * Cement$ (4.7)

$f binary(⅔ : ⅓);$ $fc7 = -3.01066 + 0.036254 * Cement$ (4.8)

$f binary(⅔ : ⅓);$ $fc28 = -1.20983 + 0.040497 * Cement$ (4.9)

4.7 The Correlation and Significance of the Factor Variables

A close study of the correlation and significance effects of each of the factors (cement, fine aggregate, sand/laterite and water) on the compressive strength at 7 and 28 days for the mix designs are shown in Appendix D. Sample contour plots of some selected factors against the compressive strength at 28 days are presented in the Figures 4.3 (a) and (b). The statistical significance with probability ≤ 0.05 between the fine aggregate, water and the compressive strength after twenty days of curing are shown in Appendix D.1(a) – D.1(f)

4.8 Mixing Water Requirement and Cement Quantity

A simple linear relationship can be written for mixing water requirement and the quantity of aggregate for the composite mix. The limits in equations 4.1– 4.3 was used to generate the points within an augmented [3,2] Simplex lattice design representing 10 design points. By multiplying the relative absolute volumes of the component mixes by their densities, the proportions can be obtained for all the selected design points. This method also enables fitting points that can yield a second order-quadratic polynomial expression, (Montgomery, 2005) and thus obtain a linear mathematical relationship between water requirement and the cement sand/ laterite ratio per one cubic meter of the mix. Similarly, the fine aggregate quantity can be regressed in a similar manner thus yielding the linear expression in Equations 4.10 – 4.11 and 4.12 – 4.13 using a probability $p < 0.05$ statistical significance,

$$Water_{control}\ ; \qquad W_{control} = 291.267 - 159.860 * \left(\frac{Cement}{sand}\right) \qquad (4.10)$$

$$Water_{binary}\ ; \qquad W_{binary}\,Y = 335.063 + 166.076 * \left(\frac{Cement}{sand{:}\,Laterite}\right) \qquad (4.11)$$

$$Aggregate_{control}\ ; \qquad A_{control} = 1849.236 - 0.555 * Cement \qquad (4.12)$$

$$Aggregate_{binary}\ ; \qquad A_{binary} = 1717.380 - 0.992 * Cement \qquad (4.13)$$

4.9 Example of Component Mix Selection

This method starts as an iterative process by selecting a cement quantity within the limits to obtain the desired strength. The procedure is stated thus:

i) Calculate the quantity of cement from within the limits suggested

ii) Substitute the cement quantity in the equation expressing the compressive strength of mortar cube

iii) Estimate the quantity of fine aggregates from the equation relating the calculated cement quantity

iv) Estimate the quantity of water from the equation relating the ratio of cement/fine

v) Calculate cement: laterite ratio

Using the same problem statement:

i) Starting with the lowest limit of cement in Equation 4.1 (absolute volume = 0.056) represents 176.4 kg of cement, that is (0.056 x 3150 = 176.4 kg), where unit weight of cement is 3150 kg/m^3.

ii) Substituting the cement quantity in Equation 4.5, $fc = -2.16033 + 0.046255 * 176.4$

iii) This yields a compressive strength value of 6.0 N/mm^2.

iv) The corresponding quantity of fine aggregates from equation 4.12 relating the calculated cement quantity is: $.e = 1849.236 - 0.555 * cement$; gives (1849.236 -(0.555*176.4)) = 1751.334 kg/m^3.

v) The corresponding quantity of water from equation 4.10 relating the calculated cement/laterite ratio is: $water = 291.267 - 159.860 * \frac{cement}{sand}$. This substitution gives = (291.267 - (159.267*(176.4/1751.334))) = 275.23 kg/m^3

vi) The cement sand ratio is 176.4/1751.334 ≈ 1:6

At the same cement content and substituting the values in the example, the compressive strength of binary mixture yields higher strength i.e, 6.6 N/mm^2 > 6.0 N/mm^2.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on this research work, the following conclusions were drawn;

i) The physical properties, such as specific gravity, moisture content, bulk density, PSD were found suitable in accordance BS EN 133-1: (2012): Atterberg's Limit test results such as [PL, LL, PI] were found suitable for the laterite sample used.

ii) Hardened properties of the test samples for the various blends show that replacement of silica sand with laterite can be designed to meet a specification requirements using the Central Composite Design method.

iii) The study also show that mortar samples produced from binary mixtures possess density higher than that of control mix. Similarly, absorption properties of the mortar conform with requirements of basic standards such as ASTM C 642: 2006.

5.2 Contribution to knowledge

The study developed mix models using a computational approach for a composite material using sand:laterite replacement for binary mixtures . It has contributed to the body of knowledge in the following area areas:

i) Developed a mixture with a higher plasticity at a lower cement content

ii) Developed a procedure capable of meeting a specification writing process

5.3 Recommendation

The proposed technique can be used to design mortar of high compressive strength that can be employed for a wider range of use.

Suggestions in area of further research include:

i) Studies on early strength development and effect of additives

ii) Durability studies

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APPENDIX A: Material Characterization

Table A.1: Sieve Analysis for laterite

Sieve Size (mm)	**Weight of Sieve (g)**	Weight of sieve+ retain **(g)**	Weight of **Retained (g)**	% of **Retained**	Cumulative % **Retained**	% **Passing**
4.75	376	376	0	0	0	100
2.36	397	433	36	7.2	7.2	92.8
1.18	367	414	47	9.4	16.6	83.4
0.6	381	492	111	22.2	38.8	61.2

0.3	366	470	104	20.8	59.6	40.4
0.15	335	429	94	18.8	78.4	21.6
0.075	369	464	95	19	97.4	2.6
Pan	310	323	13	2.6	100	0

Fineness modulus= $\frac{\%\ cumulative\ passsing}{total\ \%\ ratained} = \frac{296}{100}$ =2.96

From the sieve analysis graph for laterite in Table A.2

D_{60} = 0.59mm, D_{30} = 0.25mm, D_{10} = 0.08mm

Coefficient of uniformity (C_u) $= \frac{D60}{D10} =$ 7.34

Coefficient of Curvature (Cc)$= \frac{D30}{D10(D60)} =$ 1.39

Table A.2: Sieve analysis (Fine aggregate)

Sieve Size(mm)	Weight of Sieve (g)	Sample + Sieve (g)	Mass Retained (g)	% Mass Retained	Cumulative % retained	% passing
4.75	376	376	0	0	0	100
2.36	397	402	5	1	1	99
1.18	367	373	6	1.2	2.2	97.8
0.6	381	420	39	7.8	10	90
0.3	364	535	171	34.2	44.2	55.8

0.15	335	573	238	47.6	91.8	8.2
0.075	372	405	33	6.6	98.4	1.6
Pan	311	319	8	1.6	100	0

Fineness modulus= $\frac{\%\ cumulative\ passsing}{total\ \%\ ratained} = \frac{247.6}{100}$ =2.48

From the sieve analysis graph for sand (fine aggregate) in Table A.1

D_{60} = 0.35mm, D_{30} = 0.28mm, D_{10} = 0.16mm

Coefficient of uniformity (C_u) = $\frac{D60}{D10}$ = 2.26

Coefficient of Curvature (Cc)= $\frac{D30}{D10(D60)}$ = 1.03

APPENDIX B: Properties of the Laterite

Table B.1: Atterberg Limit Test results

	LIQUID LIMIT						PLASTIC LIMIT	
Description	**1**	**2**	**3**	**4**	**5**	**6**	**Sample 1**	**Sample 2**
Numbers of blows	37	34	25	22	20	14		
Can numbers	**A**	**B**	**C**	**D**	**E**	**F**	**1**	**2**
Weight of empty can (M_1)	1.7	2.1	1.88	1.75	1.9	1.92	2.05	1.72

Weight of can + wet soil (M_2)	7.26	7.07	7.15	5.06	5.99	6.52	2.61	2.38
Weight of can + dry soil (M_3)	5.7	5.64	5.46	4.11	4.84	5.05	2.5	2.25
Water content =	39.00	40.40	47.21	40.25	39.12	46.96	24.44	24.53
Average moisture content (%)				42.16				24.49

PL = 42.16%, LL = 24.49 %,

P I = LL-PL

PI = 42.16 – 24.49

PI = 17.67

Table B.2: Specific gravity of laterite and fine aggregate

	Specific gravity for laterite		Specific gravity for Fine aggregate	
Description	Sample 1	Sample 2	Sample 1	Sample2
Mass of empty beaker (M_1)	79	79	79	79
Mass of beaker + sample (M_2)	114	113	111	115
Mass of beaker + sample + water (M_3)	174	173	172	173
Mass of beaker + water (M_4)	152	152	152	151
Specific gravity	2.69	2.62	2.67	2.5
Average specific gravity	2.65		2.62	

Table B.3: Summary of properties of materials

Properties	Laterite	Fine aggregate (sand)
Sieve analysis (fineness modulus)	2.96	2.48
Specific gravity	2.65	2.62
Moisture content (%)		0.46
Coefficient of Curvature (Cu)	7.34	2.26
Coefficient of Uniformity (Cc)	1.40	1.03
Atterberg limits		
Liquid limit (%) LL	42.16	
Plasticity index (%) PL	24.49	
Plasticity index (%) PI	17.67	
Optimum Moisture Content	17.5	
Conditions of samples	Air dry	
color	Reddish-brown	

APPENDIX C: Hardened properties

Table C.1: Average density (kg/m^3) of mortar samples

	Average density (kg/m^3) of mortar samples					
	control		tenary		binary	
Runs	7days	28 days	7 days	28 days	7 days	28 days
1	2136	2176	2120	2160	2104	2144
2	2096	2120	2108	2152	2120	2184
3	2160	2200	2148	2168	2136	2136

4	2088	2112	2128	2120	2168	2128
5	2064	2104	2100	2140	2136	2176
6	2120	2152	2100	2112	2080	2072
7	2272	2272	2252	2240	2232	2208
8	2032	2128	2072	2136	2112	2144
9	2184	2192	2144	2180	2104	2168
10	2184	2200	2148	2140	2112	2080
11	2080	2120	2072	2092	2064	2064
12	2200	2240	2176	2192	2152	2144
13	2120	2176	2080	2152	2040	2128
14	2104	2144	2116	2120	2128	2096
15	2160	2192	2104	2140	2048	2088
16	2184	2216	2112	2148	2056	2080
17	2184	2208	2108	2160	2032	2112
18	2160	2200	2104	2144	2048	2088
19	2176	2208	2110	2160	2056	2112
20	2160	2200	2108	2152	2056	2104

APPENDIX D: Correlation and Significance of the Coefficients of the Factor variables

Control

Strength fc28 (control) =
-2.16033
+0.046255 Cement

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	84.70	1	84.70	33.90	< 0.0001	significant
B-Cement	84.70	1	84.70	33.90	< 0.0001	
Residual	44.98	18	2.50			
Lack of Fit	44.98	13	3.46	72982.82	< 0.0001	significant
Pure Error	0.0002	5	0.0000			
Cor Total	129.68	19				

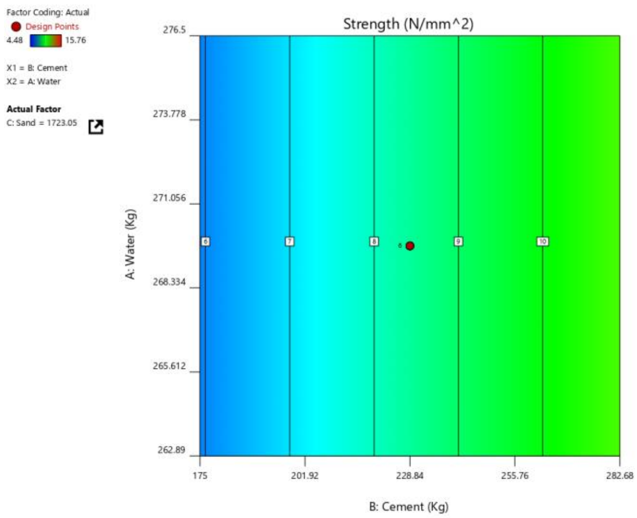

Figure D.1(a): Contour plot for compressive strength at 28 days (control)

Strength fc7 (control) =

-3.11682

+0.039274 Cement

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	61.06	1	61.06	35.68	< 0.0001	significant
B-Cement	61.06	1	61.06	35.68	< 0.0001	
Residual	30.81	18	1.71			
Lack of Fit	30.78	13	2.37	486.70	< 0.0001	significant

Pure Error	0.0243	5	0.0049
Cor Total	91.87	19	

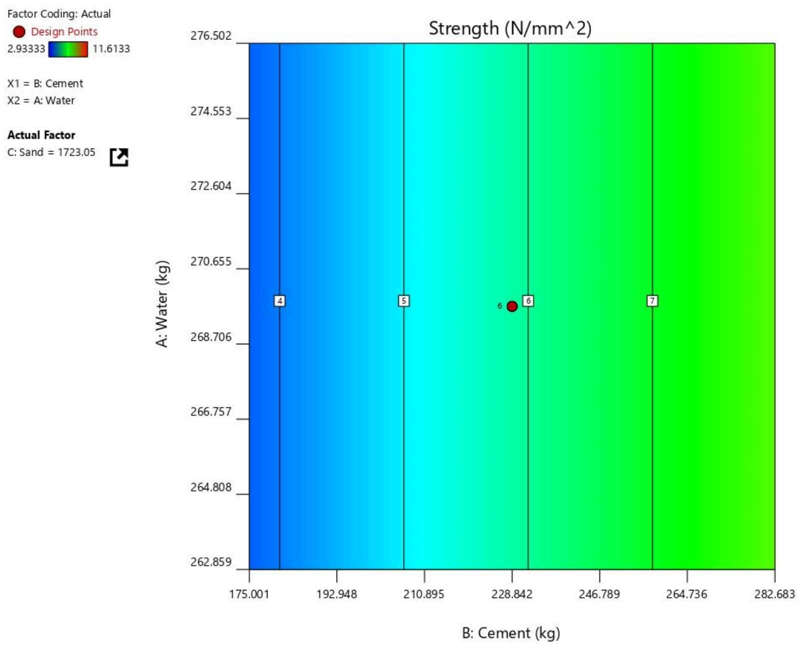

Figure D.1(b): Contour plot for compressive strength at 7 days (control)

Binary

Strength fc28 (binary)=
+3.61276
+0.016751 Cement

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	6.01	1	6.01	28.90	< 0.0001	significant
B-Cement	6.01	1	6.01	28.90	< 0.0001	
Residual	3.74	18	0.2078			
Lack of Fit	3.72	13	0.2865	88.23	< 0.0001	significant
Pure Error	0.0162	5	0.0032			
Cor Total	9.75	19				

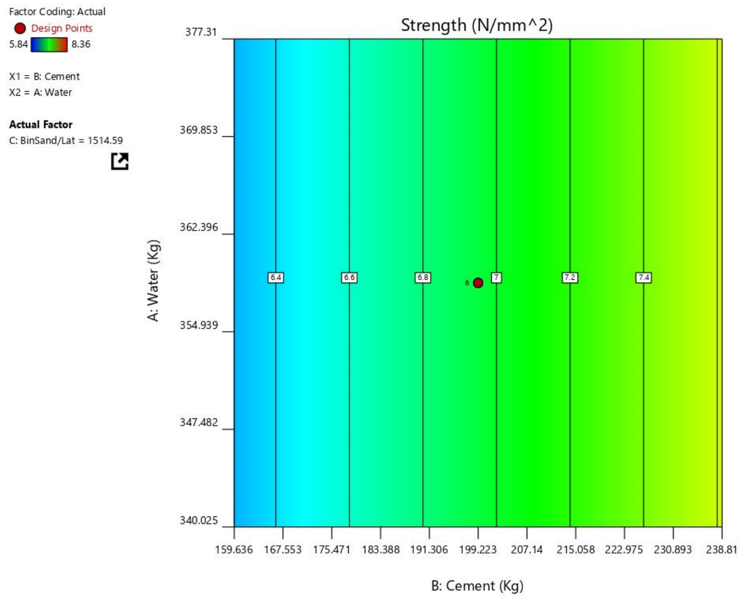

Figure D.1(c): Contour plot for compressive strength at 28 days (binary**, ½ : ½)**

Strength fc7 (binary)=
+0.540070
+0.017899 Cement

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	6.86	1	6.86	88.85	< 0.0001	significant
B-Cement	6.86	1	6.86	88.85	< 0.0001	
Residual	1.39	18	0.0772			
Lack of Fit	1.39	13	0.1068	2253.47	< 0.0001	significant
Pure Error	0.0002	5	0.0000			
Cor Total	8.25	19				

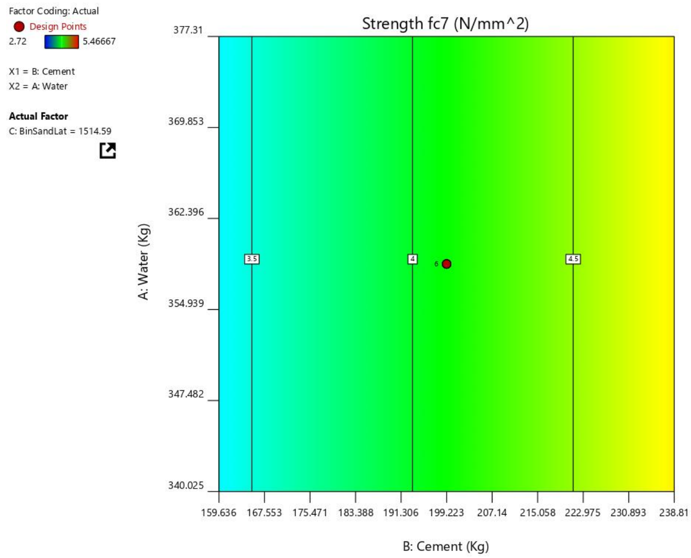

Figure D.1(d): Contour plot for compressive strength at 7 days (binary, **½ : ½)**

Binary (⅔ : ⅓)

fc28 (binary, **⅔ : ⅓)** =

-1.20983

+0.040497 Cement

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	33.95	1	33.95	48.35	< 0.0001	significant
B-Cement	33.95	1	33.95	48.35	< 0.0001	
Residual	12.64	18	0.7023			
Lack of Fit	12.64	13	0.9720	1031.63	< 0.0001	significant
Pure Error	0.0047	5	0.0009			
Cor Total	46.59	19				

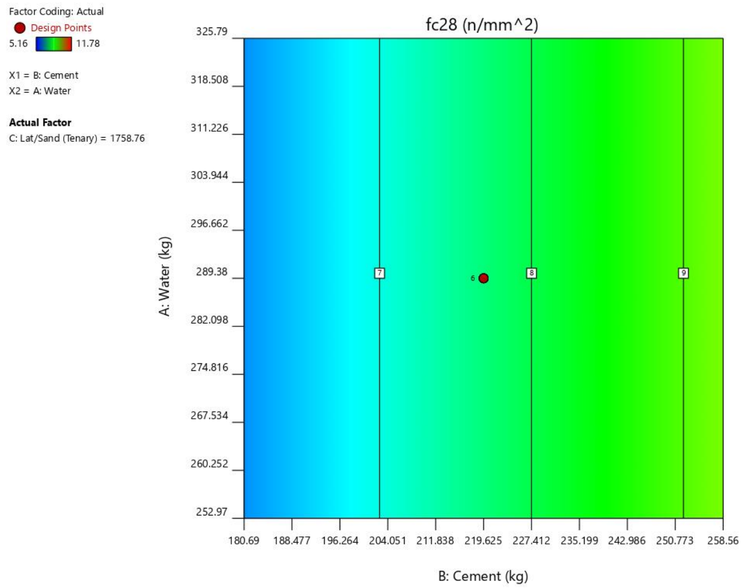

Figure D.1(e): Contour plot for compressive strength at 28 days (binary, **⅔ : ⅓)**

fc7 (binary, **⅔ : ⅓)** =

-3.01066

+0.036254 Cement

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	27.21	1	27.21	46.36	< 0.0001	significant
B-Cement	27.21	1	27.21	46.36	< 0.0001	
Residual	10.57	18	0.5870			
Lack of Fit	10.56	13	0.8123	611.25	< 0.0001	significant
Pure Error	0.0066	5	0.0013			
Cor Total	37.78	19				

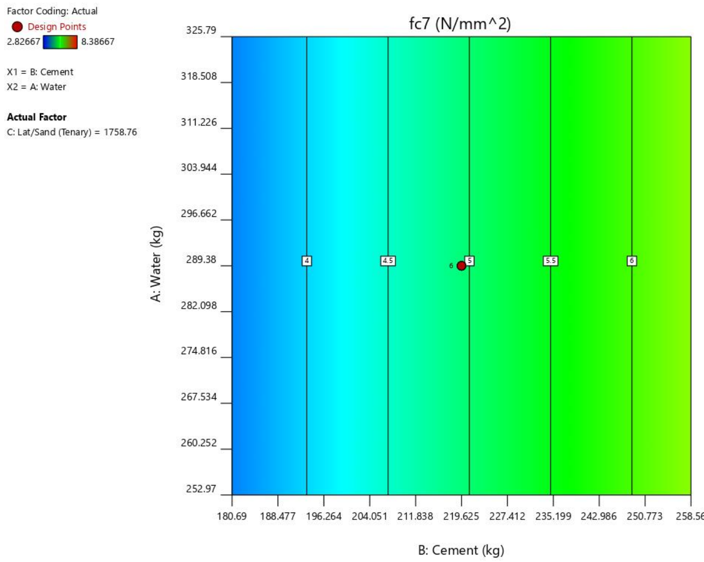

Figure D.1(f): Contour plot for compressive strength at 7 days (binary, **⅔ : ⅓)**