DEVELOPMENT OF AN OPTIMISATION MODEL TO PREDICT THE COMPRESSIVE STRENGTH OF CONCRETE CONTAINING RICE HUSK ASH BASED ON SCHEFFE'S THEORY

BY

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MEng/SIPET/2018/8692

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ABSTRACT

The cost of cement as one of the ingredients for producing concrete has rapidly increased over the years. This has led to the search for it to be possibly replaced with some other materials that possess same, or better property than that of cement. Rice Husk Ash (RHA), being an agricultural waste has played significant role in concrete mix research. It has served as complementary material to some of the ingredients of concrete especially cement. In this study, it served as a fifth ingredient of concrete blend as it replaced 5%, 10%, 15%, 20% and 25% of cement. The other four ingredients were cement, sharp sand (fine aggregates), granite (coarse aggregate) and water. Scheffe's theory was used for five mix ratios in a {5, 2} experimental design, which resulted in additional ten mix ratios. For the optimisation model to be verified and also tested, fifteen additional mix ratios were generated. The thirty mix ratios were subjected to laboratory experimentations to determine the 28 days compressive strengths. The results for the first fifteen compressive strengths were used for calibration of the model constant coefficients, while those from the second fifteen were used for the model verification using Scheffe's simplex lattice design. The model compared favorably with the experimented data and the predictions from the model were tested with statistical Fischer test and found to be adequate at 95% confidence level. A mathematical regression model was derived from the experimented results, with which the compressive strengths were predicted; this ascertained the model to be adequate with an R^2 value of 0. 902.The mathematical model developed in this study can be used to predict mix ratios for any desired compressive strength of RHA concrete within the factor space of the simplex used in the study.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Concrete, a product of aggregates, cement and water is used in various forms to resist and carry load when sufficiently hardened. The cost of ordinary Portland cement as one of concrete ingredients is rapidly rising. Cheaper and replaceable or complimentary substitutes are being developed (Neville, 1995). One of the partially replaced materials for cement is Rice Husk Ash (RHA), obtained from incineration of Rice Husk (RH). RH is the outer layer covering of the rice grains that is obtained during the milling process. This is usually being thrown away to the landfill without further use, thus, contribute to environmental pollution. Rice husk ash (RHA) is a by-product from the burning of rice husk under controlled temperature and burning time. RH has been used as a highly reactive pozzolanic material leading to a significant improvement on strength and durability of normal concretes (Bui, 2001). When burnt under controlled conditions, the RHA is highly pozzolanic and very suitable for use in lime-pozzolana mixes and for Portland cement replacement (Yogenda and Jagadish, 1988). A pozzolana can be defined as silicious or silicious/ aluminious compounds which has no cementitious property, but in the presence of calcium hydroxide or lime, acquires cementitious property (Yogenda and Jagadish, 1988).

RH has a high concentration of silica, generally between range of 80-85% (Oyejobi *et al.*, 2014). Researchers have shown that small amounts of inert filler have always been acceptable as cement replacement. Some of the advantages of using pozzolans in concrete includes improvement in workability of concrete at low replacement levels and with low carbon content, reduced bleeding and segregation, low heat of hydration, lower creep and shrinkage, high resistance to chemical attack at later ages (due to lower permeability and less calcium hydroxide available for reaction) and low diffusion rate of chloride ions resulting in a higher resistance to corrosion of steel in concrete. The chemical analysis of RHA obtained in Malaysia has 96.7% Silicon dioxide (SiO_2) with 0.91% of potassium oxide (K2O), and has some minor oxides such as alkalis, sulphate and calcium oxide. The sum of these oxides i.e. $SiO_2 + Al_2O_3 + Fe_2O_3$ of RHA were 97.8% (ASTM, 1978). Thus, classified as pozzolan in accordance with American Standard for Testing Materials (Anbu and Nordin, 2009) that specify 70% minimum for SiO_2.

Modeling involves setting up mathematical formulations of physical or other systems. Such formulations are constructed for the assessment of the objective function after the hindsight of observed operating variables. Hence or otherwise, model could be constructed for a proper observation of response from the integration of the factors through controlled experimentations followed by schematic design where such simplex lattice approach of thr type of Scheffe (1958), optimisation theory could be employed. Entirely different physical systems may correspond to the same mathematical model so they can be solved by the methods. This is an impressive demonstration of the unifying power of mathematics (Erwin, 2004). This study seeks to develop an optimisation model to predict the compressive strength of concrete when cement is partially replaced with Rice Husk Ash (RHA).

1.2 Statement of the Research Problem

Disposal of rice husks as one of the agro-waste is a big problem and open heap burning is not acceptable on environmental grounds, and so the majority of husk is currently going into landfill. These are utilized as fuel in some regions, while they are regarded as wastes in other regions causing environmental pollution (Rawid *et al.*, 2012). Cement is a crucial contributor to the total carbon dioxide emissions of the world, the importance of infrastructure cannot be undermined. Also, cost of ordinary Portland cement as one of the ingredients of concrete is rapidly rising. The possibility of it been replaced with some other material that has a smaller carbon footprint as well as possessing the same or better properties than cement (Chen *et al.*, 2010). One of the factors that determine the strength of concrete is its mix ratio, having the right mix ratio will provide optimal strength. The mathematical model, from economic view point, aims at selecting the optimal ratio from the component ratios list that can be automatically generated which will provide optimal strength.

1.3 Aim and Objectives of the Study

The aim of this study is to develop an optimisation model to predict the compressive strength of concrete containing rice husk ask based on Scheffe's theory.

Objectives are to:

1. determine physical properties of aggregates;
2. determine the oxide composition of RHA; and
3. develop an optimisation model to predict the compressive strength of concrete when Ordinary Portland Cement (OPC) is partially replaced with Rice Husk Ash (RHA) using Scheffe's theory.

1.4 Justification of the Study

The need to protect environment from hazardous effect is of great concern to mankind, using Rice Husk Ash (RHA) as a pozzolana will be of great help in terms of utilising waste and also reduce environmental pollution to a great extent. Replacing Ordinary Portland Cement (OPC) with RHA will reduce the use of cement in construction thereby leading to a reduction in construction cost. It will also reduce the level of carbon dioxide emission caused by ordinary Portland cement production. The need to optimise concrete strength is of great importance to concrete production because it gives a concrete of high strength with efficient use of the materials available. Hence, developing an optimisation model through Scheffe's approach will help in predicting the mix ratio for optimal strength of concrete.

1.5 Scope of Study

The research work focuses on the development of an optimisation model for predicting the compressive strength of RHA concrete using Scheffe's simplex theory, the routine laboratory tests such as specific gravity, grain size distribution, and bulk density were carried out on all the aggregates. Crushing test was also carried out on the hardened concrete to determine the compressive strength. An optimisation model was developed based on Scheffe's theory to predict the compressive strength of the concrete. Finally, the results from the predictive model and experimental results were compared and check for adequacy of the model done.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Preamble

The problem of affordable housing and construction economy continue to remain a topic of discussion for researchers. Concrete is one of the most popular construction materials worldwide and its use has witnessed tremendous increase over the years. Concrete is a mixture of cement, fine aggregate and coarse aggregate and water and when sufficiently hardened is used in supporting various structural loads. The cost of production of concrete heavily impacts on construction cost. Most of the engineering characteristics of concrete depend on proportions of the constituent materials (Ephraim and Rowland,2015). Ordinary Portland Cement (OPC) which is commonly used in the production of concrete is rising in cost and this poses a problem in the production of concrete. This emphasises the need to find alternatives for cement and also optimise the use of cement with a view to reducing the cost of its production.

2.2 Concrete Constituents

The materials used in the production of concrete are cement, fine aggregates(sand), coarse aggregates(grits) and water. For a concrete to attain higher strength, admixtures can also be used. Pozzolana is another material used in concrete production, it enhances the cost of concrete production (Chao-Lung *et al.*, 2011).

2.2.1 Cement

Babylonians and Assyrians were probably the first to use clay as cementing material. Stones have been used invariably as a construction material with lime as the binder in ancient monuments such as forts, places of worship and defense structures. Calcareous cements used by the Romans were either composed of mixtures of lime and pozzolanic materials (volcanic ash, tuff) or suitable limestone burned in kiln. In 1824, Joseph Aspedin of Yorshikre (United Kingdom) was the first to introduce Portland cement by heating the mixture of limestone and finely divided clay in a furnace to a temperature high enough to drive off the carbonic acid gas (Shetty, 1982).

In general sense, cements are adhesive and cohesive materials which are capable of bonding together particles of solid matter into a compact durable mass. For general engineering works, they are restricted to calcareous cements containing compounds of lime as their chief constituents. The main function of cement is to bind fine (sand) and coarse (grits) aggregates together. In the construction industry, cement may be classified as hydraulic and non-hydraulic. Hydraulic cement set and hardens in water and gives a product that is stable, Portland cement is one of such. Non- hydraulic cement does not set and harden in water and are also unstable in water (Duggal, 2008).

Cement can either be manufactured from natural cement stones or by using calcareous and argillaceous materials. Today, cement finds extensive use in all types of construction works; in large structures such as bridges, silos, chimneys and structures where high strength is required, for example, bridge piers, light houses, lofty towers. Cement mortar, concrete, reinforced brick work, artificial stones, plastering, pointing and partition walls are routinely used in buildings.

Portland cement is a cementing material resembling a natural stone quarried from Portland in United Kingdom. It can be defined as a product obtained by finely pulverizing clinker produced by calcining to incipient fusion, an intimate and properly proportioned mixture of argillaceous and calcareous materials. Care must be taken in proportioning the raw materials so that the clinker of proper constitution is obtained after burning.

Ordinary Portland Cement (OPC) has been classified as 33 Grade (IS269:1989), 43 Grade (IS 8112: 1989), and 53 Grade (IS 12669 – 1987). The physical requirements of all the three grades of cement are almost same except for compressive strength (Duggal,2008).

Various components combine in burning to form cement clinker which results in the formation of compounds. These compounds are known as Bogue compounds. They are represented in Table

Table 2.1: Composition of cement clinker

	Principal mineral compounds in Portland cement	Formula	Name	Symbol
1.	Tricalcium silicate	$3CaO.SiO_2$	Alite	C_3S
2.	Dicalcium silicate	$2CaO. SiO_2$	Belite	C_2S
3.	Tricalcium silicate	$3CaO. Al_2O_3$	Celite	C_3A
4.	Tetracalcalcium alumino ferrite	$4CaO.Al_2O_3.Fe_2O_3$	Felite	C_4AF

The proportions of the four compounds above reflects substantial difference between the individual behavior of the properties of Portland Cement.

2.2.2 Aggregates

Aggregates are the most important constituents in concrete. They provide body to the concrete, effect economy and reduce shrinkage. Some aggregates are chemically active and exhibit chemical bond at the interface of aggregate and paste. Aggregates occupies 70-80 percent concrete volume, this makes their impact on various characteristics and properties of concrete undoubtedly considerable. Aggregates are classified as normal, light and heavy weight aggregates. Normal weight aggregates are also classified as natural aggregates and artificial aggregate. Aggregates can also be classified on the basis of the size of the aggregates as coarse aggregate and fine aggregate (Shetty, 1982).

2.2.3 Fine Aggregates

Sharp sand or sand (> 0.07mm) is normally used as fine aggregates in mortar and concrete. It is usually a granular form of silica. Sand used for design mix is known as standard sand (IS: 650). It should pass through 2-mm IS sieve and should be retained on 90- micron IS sieve with the following distribution in Table 2.2.

Table 2.2: Particle Size Distribution

Particle Size	Per cent
Smaller than 2mm and greater than 1mm	33.33
Smaller than 1mm and greater than 500mm micron	33.33
Smaller than 500 micron but greater than 90 micron	33.33

Sand used for construction purposes should possess at least 85 percent of strength of standard sand mortars of like proportions and consistency (Duggal, 2008).

Sand is classified based on its size as coarse sand – Fine modulus (FM) 2.90-3.20: Medium sand – FM.: 2.60-2.90 fine sand – FM.: 2.60-2.60. Sand can also be classified based on its particle size distribution. Table 2.3 shows the grading of fine aggregates.

Table 2.3: Grading of Fine Aggregates (IS: 383)

Sieve Designation	Percentage Passing For			
	Grading Zone 1	Grading Zone II	Grading Zone III	Grading Zone IV
10mm	100	100	100	100
4.75mm	90-100	90-100	90-100	95-100
2.36mm	60-65	75-100	85-100	95-100
1.18mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0.10	0-10	0-10	0.15

2.2.4 Coarse Aggregates

Coarse aggregates are either uncrushed, crushed or partially crushed gravel or stones most of which is retained on 4.75mm sieve. They are usually strong, dense, hard, durable, clear and free from veins and adherent coatings: free from injurious amounts of disintegrated pieces, alkali organic matter and other deleterious substances. Coarse aggregates have same function as that of fine aggregates (Duggal, 2008).

2.2.5 Water

The primary purpose of using water with cement is to cause hydration of the cement. Excess water required for hydration acts as a lubricant between coarse and fine aggregates and produces a workable and economical concrete. Water in excess may leak through the form work, resulting in honeycombed concrete and on evaporation makes the concrete porous. Lesser water makes it difficult to work with concrete and because of non-uniform mixing, the resultant concrete is weaker in strength. The amount of water to be used in concrete production should be limited to produce a concrete with quality. Water can also be used to wash aggregates and for curing purposes (Shetty, 1982).

Any natural potable water that has no pronounced taste or odour is acceptable for a concrete mix. Many sources of water which is unsuitable for drinking can also be used. However, excessive impurities may affect setting time, durability, strength and may cause efflorescence, surface discoloration, and corrosion of steel. The effects impurities have on water are mainly expressed in terms of setting time of Portland cement. The initial setting time of the mixes with impure and pure water are obtained and the difference in the initial setting time is ± 30 minutes. The 7 day and 28 day compressive strengths of cube/cylinder specimens prepared with impure water should not differ by 10 percent from cubes/cylinders prepared with pure water (Duggal, 2008). The tolerable concentrations of some water impurities are given in Table 2.4.

Table 2.4 Tolerance Concentration of Impurities in Mixing Water

S/N	Impurity	Tolerable Concentration
1.	Silt and suspended particles	2,000 ppm
2. i)	Carbonates and bicarbonates of Na or K	1,000 ppm
ii)	Bicarbonates of Mg	400 ppm
3.	Chlorides	10,000 ppm
4.	Sulphates	20,000ppm
5.	Sulphuric anhydride	3,000 ppm
6.	Calcium chloride	2 percent by weight of cement
7.	Sodium Sulphide	< 100 ppm
8.	Sodium hydroxide	0.5 percent by weight of cement provided quick set is not induced
9.	Dissolved salts	15,000 ppm
10.	Organic matter	3,000 ppm
11.	Ph	6-8
12.	Iron salts	40,000 ppm
13.	Acids (HCL, H_2SO_4)	10, 000 ppm
14.	Sugar	500 ppm

2.3 Pozzolana

Pozzolana may be defined as a siliceous material which whilst itself possessing no cementitious properties, processed or unprocessed and in finely divided form, reacts in the presence of water with lime at normal temperatures to form compounds of low solubility having cementitious properties. It may be natural or artificial, fly ash being the most known in the latter category. Pozzolanas were used with lime in the production of concrete before the invention of cement. Currently, its principal used is to replace a proportion of cement when producing concrete. The advantages gained in using pozzolana are economy, improvement in workability of concrete mix with reduction of bleeding and segregation. It also helps in providing greater imperviousness, to freezing and thawing and to attack by sulphates and natural waters. It is generally held that the addition of natural pozzolanas reduce the leaching of soluble compounds from concrete and contributes to the impermeability of the concrete at the later ages (Yogenda and Jagadish, 1988).

Pozzolanas are mainly justified by the possible reduction in cost while producing concrete. They must be obtained locally if they are to reduced cost and it is for this reason that they have not so far been in used. Pozzolanas are classified as natural and artificial. Natural pozzolanas are rich in silica and aluminium and contain only a small quantity of alkalis. The following are some examples of naturally occurring pozzolanas:

1. Dlatomaceous earth and opaline cherts and shales which may or may not need calcination.
2. Clay and shales which must be calcined to become active.
3. Rhenish and Bavarian trass
4. Volcanic tuffs and pumicites.

Some of the examples of artificial pozzolanas are:

1. Rice husk ash
2. Fly ash
3. Ground blast – furnace slag

4. Silica fume
5. Surkhi

2.3.1 Activities of Pozzolana in Concrete Production

When pozzolana mixes with Ordinary Portland Cement (OPC), the silica of the pozzolana combines with free lime released during the hydration of cement, this is known as pozzolanic action. The pozzolanic activity is due to the presence of finely divided glassy silica and lime which produces calcium silicate hydrate similar to as produced during hydration of Portland cement. The lime produced during hydration of Portland cement reacts with the silica in the pozzolana and contributes to development of strength. Gradually, additional silicate hydrate is formed which is a binder and fills up the space, gives impermeability, durability and ever increasing (Duggal, 2008). Silica of amorphous form react with lime readily than those of crystalline form and its constitutes the difference between active pozzolanas and materials of similar chemical composition which exhibit little pozzolanic activity.

It is usually thought that lime – silica reaction is the main or the only one that takes place, but recent information indicates that alumina and iron if present also take part in the chemical reaction. Pozzolana can serve as a replacement for cement within the range of 10-30 percent and be as low as 4-6 percent for natural pozzolanas (Oyejobi *et al.*, 2014).

2.4 Effect of Rice Husk Ash (RHA) on Concrete

RHA, produced after burning of Rice husks (RH) has high reactivity and pozzolanic property. Indian Standard code of practice for plain and reinforced concrete, IS 456–2000, recommends use of RHA in concrete but does not specify quantities. Chemical compositions of RHA are affected due to burning process and temperature. Silica content in the ash increases with higher the burning temperature. As per study by Saurabha *et al.* (2015), RHA produced by burning rice husk between 600 and 700°C temperatures for 2 hours, contains 90-95% SiO_2, 1-3% K_2O and < 5% unburnt carbon. Under controlled burning condition in industrial furnace, conducted by Mehta, P. K. (1992), RHA contains silica in amorphous and highly cellular form, with 50-1000 m_2/g surface area. So use of RHA with cement improves workability and stability, reduces heat evolution, thermal cracking and plastic shrinkage. This increases strength development, impermeability and durability by strengthening transition zone, modifying the pore-structure, blocking the large voids in the hydrated cement paste through pozzolanic reaction. RHA minimizes alkali-aggregate reaction, reduces expansion, refines pore structure and hinders diffusion of alkali ions to the surface of aggregate by micro porous structure. Portland cement contains 60 to 65% CaO and, upon hydration, a considerable portion of lime is released as free $Ca(OH)_2$, which is primarily responsible for the poor performance of Portland cement concretes in acidic environments.

Ameri *et al.* (2019), conducted a research on concrete containing RHA. It was found that concrete containing RHA showed a vigorous increase in early compressive strength. However, by increasing the RHA content by more than 15 percent, the compressive strength was decreased. This is attributed to the excess amount of silica present in RHA which remains unreacted. The compressive strength of concrete with RHA as a Secondary Cementious Materials was 9, 12, 13, and 16 percent higher than that of control mix.

Similarly, Chao-Lung *et al.* (2011), incorporated RHA in concrete and concluded that concrete containing RHA showed strength 1.2 to 1.5 times greater than that of the control mix. Chindaprasirt *et al.* (2007), tested the concrete containing RHA for sulphate attack resistance and reported that concrete containing RHA proved to be highly effective against sulphate attack. It was reported by Thomas and Green (*2*018) in a review paper that concrete containing RHA has a dense microstructure, so it can be used to reduce the water absorption of concrete by up to 30 percent.

Habeebh (2009), reported that the investigation on the behaviour of concrete produced from ordinary Portland cement with RHA. The properties of fresh concrete and the effect of replacing 5%, 10%, 15%, and 20% of cement with RHA on the compressive strength were investigated. Incorporation of RHA in concrete resulted in increased water demand, for the hardened properties, RHA concrete gave excellent improvement in strength for 10% replacement, and up to 20% of cement could be valuably replaced with RHA without adversely affecting the strength.

Ephrain (2012), reported the investigation on the use of rice husk ash as a partial substitute for cement in construction. The results show that at 5% partial replacement of cement with rice husk ash can be used for structural concrete and at 15% replacement or more it can be used for non - structural construction works or light weight concrete construction. The cost analysis shows substantial amount of savings for the country.

Oyejobi *et al.* (2014), in a study on the investigation of Rice Husk Ash (RHA) cementitious constituent in concrete reported that there is an increase in setting time of paste having rice husk ash. This shows low level of hydration for rice husk ash concrete which result from the reaction between cement and water, and consequently, liberate calcium hydroxide $Ca(OH)_2$. It was recommended that RHA as a pozzolana should be used as partial replacement for cement in concrete production at a percentage up to 20% and RHA can also be utilized for the production of lightweight, durable and cheap concrete because of its availability in significant quantities across the country. Table 2.5 shows the chemical composition of rice husk ash.

Table 2.5: Chemical Composition of Rice Husk Ash (Oyejobi *et al.*, 2014)

Constituents	Weight (%)
Silica (S_iO_2)	77.267
Aluminum Oxide (Al_2O_3)	3.592
Ferrous Oxide (Fe_2O_3)	9.846
Calcium Oxide (CaO)	8.947
Magnesium Oxide (MgO)	5.849
Potassium Oxide (K_2O)	4.084
Sodium Oxide (Na_2O)	2.898
Copper Oxide (CuO)	1.184
Loss of Ignition (L.O.I)	4.084

2.5 Science Models

Science models are simplified representations of a system. Models attempt to reduce the world to a fundamental set of elements and laws and on this basic hope to better understand and predict key aspect of the world. Models captures the structure and dynamics of scientific endeavor are expected to provide insights into inner workings of science.

Structure can be defined as a normal platform in the behavior of elementary parts of a system based on observations of repeated processes of interaction. Dynamics refers to the processes and behaviours that lead to changes in the structural units of science or their interlinkages (Katy *et al.,* 2012). Model designs typically involves the formulation of a scientific hypothesis or identification of a specific structure or dynamics. Often this hypothesis is based on analysis of patterns found in empirical data. If the hypothesis is based in data or in theory, an empirical dataset needs to be available to test model results (Akhanarova and Kafarov, 1982).

There are two major types of models :

1. Qualitative models: These are often used for verbal descriptions of general behaviour.
2. Quantitative model: These express units of analysis, their interrelations and dynamics using properties susceptible of measurements (Katy *et al.,* 2012).

Quantitative models can be divided into two: descriptive and process models. The two can be used to make predictions. Descriptive models aim to describe the major features of typically static data set. Results are usually communicated through tables, charts, or maps. Process models aim to stimulate, statistically describe, or formally reproduce statistical characteristics of interest, typically by means of formulas or implemented algorithms. Formal mathematical approaches to process modelling work best for static, homogeneous worlds. However, computational models allow thorough investigation to be done for dynamic environments with greater fidelity. Respective models are interested in explaining the dynamic nature of science.

2.5.1 Concrete Optimisation

Optimisation is one of the oldest sciences or practices. Mankind from onset have strived for perfection when it came to its creations, products, gains or self-improvements. Many phenomenon preceding the human race aimed at achieving optimum states. Optimisation of concrete mixes involves the determination of the proportions of the constituents of concrete required to optimize (minimize or maximize) certain desirable properties of fresh or hardened concrete. The selection of mix proportions is the process of choosing suitable ingredients of concrete and determining their relevant quantities with the object of producing as economically as possible concrete of certain minimum properties, notably strength, durability, and a required consistency, because the ingredients used are essentially variable and many of the material properties cannot be assessed truly quantitatively, the selection properties of concrete can also be defined as the finding the optimum combinations of this ingredients on the basis of some empirical data as stated in relevant standards and experience (Ravi and Rajakumara, 2018).

2.5.2 Optimisation Model Approaches

Considering a concrete mix which consist of q components materials (where q is the number of component materials). Two model approaches can be applied to concrete mixture optimisation.

1. Classic mixture approach: In this approach, the total number of the product is fixed, and the settings of each of the q components are proportions. Since the total amount is constrained to sum to one, only q-1 of the factors (component variables) can be chosen independently. A simple (hypothetical) example of a mixture experiment, consider concrete as a mixture of three components: water (X_1), cement (X_2), and

aggregate (X_3), where X_i represents the volume fraction of the component. Assuming that the coarse to fine aggregate ratio is held constant. The fractional volume of the component sum to one, and the region defined by this constraint is the regular triangle or simplex shown in Figure 2.1. The axis for each component Xi extends from the vertex it labels {$X_i = 1$) to the midpoint of the opposite side of the triangle (Xi = 0). The vertex represents pure component (Scheffe, 1958).

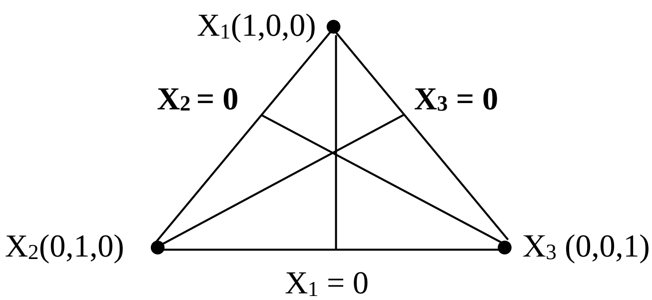

Figure 2.1: Triangular simplex region for three components

All the responses (properties) of interest will be measured for each mixture in the design and modeled as a function of the components. Typically, polynomial functions are used for modeling, but other functional forms can also be used. For three components, the linear polynomial model for a response Y is given in equation (2.1).

Where the bi * are constant and e, the random error term, represents the combined effects of all variables not included in the model. For a mixture experiment, $X_1 + X_2 + X_3 = 1$; therefore, the model be written in the form:

Using,

Equation (2.3) takes a form called Scheffe linear mixture polynomial (Scheffe, 1958).

2. Mathematical independent variable (MIV) approach: This is the approach where q mixture components are transformed into q-1 independent mixture – related variables. In the classic mixture approach, the MIV approach, with the variables independent, permits the use of classical factorial and response surface design, but has the undesirable feature that the experimental region changes depending on how q mixture components are reduced to q-1 independent factors. The MIV approach is referred to as the factorial approach because factorial experiment designs form the basis of the approach (Ravi and Rajakumara, 2018).

   The factorial approach, the q components of a mixture are reduced to q-1 independent variables using the ratio of two components as an independent. In case of concrete, w/c is a natural choice for this ratio variable. For the situation with q-1 independent variables, a 2q-1 factorial design forms the backbone of the experiment. The design consists of several factors (variables) set at two different levels. Consider a simple example of a concrete mixture composed of four components: water, cement, fine aggregate, and coarse aggregate. Three independent factors, of variables xk, that can be selscted to describe this system are X1 = w/c (by mass), X2 = fine aggregate (volume fraction), and X3 = coarse aggregate (volume fraction). Reasonable ranges for those valuables might be:

   The levels for this example would be 0.40 and 0.50 for X1, 0.25 and 0.30 for X2, and 0.40 and 0.45 for X3. To simplify calculations and analysis, the actual variable ranges are usually transformed to dimensionless codded variables with ranges of .

For the example above, the general equation used to translate from coded to uncoded is presented in equation (2.4)

Where xactual is the uncoded value, xmin and xmax are the uncoded minimum and maximum values (corresponding to 1 and +1 coded values), and xcoded is the coded value to be translated (Ravi and Rajakumara, 2018).

2.6 The Scheffe's Lattice Design Theory

This is a theory where a polynomial expression of any degrees, is used to characterize a simplex lattice mixture component. In the theory, only a single phase mixture is covered. The theory lends path to a unifying equation model capable of taking varying component ratios to fix approximately equal mixture properties. The optimisation, from economic view point, aims at selecting the optimal ratio from the component ratios list that can be automatically generated. Scheffe (1958) developed a model in which the response surfaces of the physical and chemical characteristics of a mixture can be approximated by a polynomial of the second and higher degrees.

Using the approach, Akhnazarova and Kafarov (1982), predicted the variations of reactivity and porosity of coke with the charges of four process groups of coal in a mixture. The approach could be adapted to predict the desired strength of concrete where the essential factors lies on the adequate proportioning of ingredients needed to make the concrete where with the compressive strength desired specified, possible combinations of needed ingredients to achieve the compressive strength can easily be predicted by the aid of computer, and if proportions are specified, the compressive strength can easily be fixed.

2.7 Model Predictions Based on Scheffe's Theory

Onuamah (2014), concluded from the study "Compressive strength of Hollow Sandcrete Block with Rice Husk Ash Admixture" that Scheffe's simplex design proved that the modulus of laterictic concrete is a function of the proportion of the ingredients (cement, Aggregates, RHA, water), but not the qualities of the materials. The researcher also concluded that the maximum values achievable, within experimental errors, is quite below that of obtainable using only cement. This is due to the low binding strength of RHA. It was however recommended that the accuracy of the model can be model can be improved by taking higher order polynomials of the simplex.

Ephraim *et al.* (2019) in "Optimization Model for Predicting of Compressive Strength of Concrete containing fly Ash and Quarry Dust Based on Scheffe's Simplex Theory" considered an extension of Scheffe's optimization techniques from fifth to sixth dimensions, to cover six component mix ratios of concrete containing fly ash and quarry dust and obtained mathematical model for the optimization of the compressive strength. This mathematical model can predict the compressive strength of a six component concrete when the mix ratios are known. The prediction from the model was tested for 95% accuracy level using Fischer (F) test and regression statistic and found to be adequate with r^2 of 0.84. The maximum strength predicted by the model was 43.01N/mm2 derived from a mix ratio of 0.91:0.094:0.868:0.138:2.18:0.40. (i.e., cement: fly ash: sand: quarry dust: granite: water).

Oba *et al.* (2019) in "Development of Scheffe's Model to Predict the Compressive Strength of Concrete using SDA as Partial Replacement for Fine Aggregate" replaced fine aggregate with 5% SDA which resulted in acceptable 28 days' compressive strengths (between 22 and 36N/mm^2) with concrete mix ratios resulting from different design methods. A regression model has been generated from the resulting laboratory experiments using Scheffe's simplex theory. A two-tailed t-test was carried out, which confirmed the adequacy of the derived model with an R^2 value of 0.8336. The results also confirmed that SDA is a suitable material to replace a small fraction of fine aggregate in a bid to promote sustainability.

Kalyan *et al.* (2019), in "Regression Analysis and Optimization of Rice Husk Ash Based Concrete Mixes" concluded that the regression analysis and optimization of RHA based concrete mixes is presented. The statistical regression analysis has been found to be a highly useful technique in finding the correlation between response and predictors. The regression equation obtained is near perfect to correlate response and predictors in which compressive strength is considered as response whereas.

In "Optimization of Compressive Strength of Fly Ash Blended Cement Concrete using Scheffe's Simplex Theory", Anyaogu and Ezeh (2013) used Scheffe's (5, 2) polynomial equation, mix design mathematical model for a five component fly ash blended cement concrete was developed. The model was used to predict the compressive strength of fly ash blended concrete when the mix ratios re known and vice versa. The predictions from the model were tested at 95% accuracy level using statistical Fisher test and found to be adequate. The maximum strength predicted by this model was 43.152 N/mm^2 derived from a mix ratio of 0.549:0.935:0.065:1.760:3.52 for water: cement: fly ash: sand: granite respectively.

Edidiong *et al.* (2021) in "Scheffe's Models for Optimization of Tensile and Flexural Strength of Recycled Ceramic Tile Aggregate Concrete" developed a mathematical model for predicting and optimizing the tensile and flexural strength of concrete incorporating RCT as fine aggregates. This was achieved using augmented Scheffe's simplex lattice theory. Results of preliminary tests show that RCT is suitable for use as a fine aggregate in concrete production. The quality of the model was also reflected in their high R^2 value, adjusted R^2 and predicted R^2 values. Maximum and minimum predictable tensile strengths were 3.560 N/mm^2 and 2.049 N/mm^2, while the corresponding values for the flexural strength were 4.534 and 3.045 N/mm^2.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used to achieve the aim of this study include the following;

a. Rice Husk Ash (ASH) was gotten from a local grinding mill in Kuta, Shiroro Local Government Area, Niger state as seen in Plate I.

b. Ordinary Portland Cement (OPC) of Dangote Brand that conforms to BS 12 (1991) was used as the binder in the concrete mixes investigated.

c. Coarse Aggregates obtained from a quarry in Maikunkele, Bosso Local Government Area, and Niger State, grading of the aggregate was carried out to BS 882 (1992).

d. Fine Aggregates was obtained from a river behind the boy's hostel Gidan Kwano Campus, Federal University of Technology Minna. The grading of the aggregate was carried out to BS 812: 103: Part 1, 1975.

e. Potable Water used was obtained from the University water mains free from impurities.

Plate I: Rice Husk Ash (RHA)

3.2 Methods

3.2.1 Scheffe's Simplex Theory

This is a theory where a polynomial expression of any degrees, is used to characterize a simplex lattice mixture component. In the theory, only a single phase mixture is covered. The theory lends path to a unifying equation model capable of taking varying component ratios to fix approximately equal mixture properties (Scheffe, 1958).

Scheffe's model is based on the simplex lattice and simplex theory or approach (Scheffe, 1958). A lattice is purely an abstract space to achieve the desired strength of concrete. The major factor lies on the adequate proportioning of ingredients needed to make concrete. The simplex approach considers a number of components, *q*, and a degree of polynomial, *m*. The sum of all the *ith* components is not greater than 1. Hence,

$$+ + \ldots\ldots + = 1 \qquad (3.2)$$

with $0 \leq x \leq 1$. The factor space becomes S_{q-1}. According to (Scheffe, 1958), the $\{q,m\}$ simplex lattice design is a symmetrical arrangement of points within the experimental region in a suitable polynomial equation representing the response surface in the simplex region. The number of points has (m+1) equally spaced values of X_i = 0, , ,…. . For a 3-component mixture with degree of polynomial 2, the corresponding number of points with degree of polynomial 2, the corresponding number of points will be which gives 6 (equation (3.3) or equation (3.4) below) with number of spaced values, 2+1 = 3, that is X_i = 0, , and 1 as a design points of (1, 0, 0), (0, 1, 0), (0, 0, 1), (1/2, 1/2, 0), (1/2, 0, 1/2), and (0, 1/2, 1/2). Similarly, for a $\{5, 2\}$ simplex, there will be 15 points with X_i = 0, , and 1 as spaced values.

The 15 design points are (1,0,0,0,0), (0,1,0,0,0), (0,0,1,0,0), (0,0,0,1,0), (0,0,0,0,1), (1/2,1/2,0,0,0),(1/2,0,1/2,0,0),(1/2,0,0,1/2,0), (1/2,0,0,0,1/2), (0,1/2,1/2,0,0), (0,0,1/2,1/2,0), (0,0,0,1/2,1/2), (0,1/2,0,1/2,0), (0,0,1/2,0,1/2), (0,1/2,0,0,1/2).

Simplifying equation (3.3) further gives:

For a polynomial of elements N, degree *m* with *q* component variables where equation (3. 2) holds, the general form is:

Y = b_0 + + + + …. +3.5)

Where $1 \le i \le q$, $1 \le i \le j \le q$, $1 \le i \le j \le k \le q$, and b_0 is the constant coefficient.

x is the pseudo component for constituents *i*, *j*, and *k*.

When $\{q,m\} = \{5,2\}$,equation(3.5) becomes:

And equation. (3.2) becomes

Multiplying equation (3.7) by b_0 gives

Multiplying equation (3.7) successively by x_1, x_2, x_3, x_4, and x_5 and making x_1, x_2, x_3, x_4, and x_5 the subjects of the respective formulas:

Substituting equation (3.8) and equation (3.9) into equation (3.6) we have:

Further simplifying the equation above gives:

Let

Substituting equation (3.11) into equation (3.10) gives

Where the response, Y is a dependent variable (compressive strength of concrete). Eqn. (3.12) is the general equation for a {*5*, *2*} polynomial, and it has 15 terms, which conforms to Scheffe's theory in equation (3.3)

Let Y_i denote response to pure components, and Y_{ij} denote response to mixture components in *i* and *j*. If $x_i = 1$ and $x_j = 0$, since $j \neq i$, then.

This means that;

Hence, from equation. (3.14)

According to Scheffe (1958),

Substituting equation (3.14) into equation (3.17)

3.2.2 Concrete mix design

The Department of Environment (DoE, 1988) mix design will be adopted for the preparation of the concrete due to its versatility and applications in different concrete structures such as buildings, roads and bridges.

a. Collected data

   Grade Designation = M25 (specified characteristic strength)

   Type of Cement = OPC – 43 grade

   Specific Gravity of Cement = 3.15

   Specific Gravity of Fine Aggregate = 2.61

   Specific Gravity of Coarse Aggregate = 2.65

b. Target mean strength

   Target mean strength = specified characteristic strength + standard deviation x risk factor.

   Allow 8% risk factor

c. Water/cement ratio

   Using Table 11.11 (Approximate Compressive strength of concrete made with a free water/cement ratio) and Table 11.3 according to the 1988 British Method, the water/cement ratio for mean strength of 39Mpa is 0.58. Checking the W/C ratio from durability consideration from table 9.20 (Requirements of BS 8110 part 1: Ensure Durability under Specified Exposure Conditions of Reinforced and

Prestressed Concrete made with Normal Weight Aggregate) the maximum W/C ratio permitted is 0.50. Adopt the lower of the two, therefore adopt W/C ratio of 0.50.

d. Calculation of Water Content

From Table 11.12 (Approximate Free Water Contents required to give Various Levels of workability), according to 1988 British Method, for coarse (crushed) aggregate of 20mm maximum size and assumed slump of 75mm, the water demand for fine aggregate is 195 litres and 225 litres for coarse aggregate.

W_f =Water demand for natural fine aggregate = 195l

W_{ca} = Water demand for crushed coarse 20mm aggregate = 225l

= 205 $kg\ m^3$

e. Cement Content

Cement Content =

Cement Content = 410.0 $kg\ m^3$

This is more than 350 kg (As per table No. 9.2 of BS 8110: part I: 1985). Hence ok.

f. Weight of Total Aggregate

From Table 11.4 (Approximate water content and specific gravity of aggregate), according to 1988 British Method, for a water content of 205 $kg\ m^3$, 20mm crushed aggregate of specific gravity 2.65, the total weight density is 2375 $kg\ m^3$.

Weight of Total Aggregate = Total wet density – (Weight of cement + Weight of free water) (3.22)

Weight of Total Aggregate = 2375 – (410 + 205) = 1760 kg $/m^3$

g. Weight of Fine Aggregate

i. The proportion of fine aggregate is determined in the total aggregate is determined in the total aggregate using figures available, (a) is for 10mm size, 11.5 (b) is for 20mm size and (c) is for 40mm size coarse aggregate, according to the 1988 British Method.

ii. For 20mm aggregate size, W/C ratio of 0.50, Slump of 75mm for 50% fines passing through 600 μ sieve, the percentage of

$$\% \ Fine\ Aggregate = 41\ \%$$

h. Proportions

Table 3.1 shows mix proportions gotten from the design technique.

Table 3.1: Mix proportions

Ingredients	Water	Cement	Fine Aggregate	Coarse Aggregate
Quantity ($kg\ m^3$)	205.0	410.0	721.6	1038.4
Ratio	0.50	1	1.76	2.54
1 Bag of Cement	25.0	50.0	88.0	127.0

i. Adjustment for Field Condition

1. The proportions are required to be adjusted for the field conditions. Field Aggregate has surface moisture of 2%

2. Coarse Aggregate absorbs 1% water

j. Final Design Proportions

Table 3.2 shows the final design mix proportions

Table 3.2: Final Design Mix proportions

Ingredients	Water	Cement	Fine Aggregate	Coarse Aggregate
Quantity (*kg m*^{3})	205.0	410.0	728.0	1029.1
Ratio	0.50	1	1.80	2.51
1 Bag of Cement	25.0	50.0	90.00	125.5

Steps g to j is repeated for four other mix proportions and cement replaced with Rice Husk Ash (RHA) from 5 to 25% respectively. The following results in Table 3.3 were obtained.

Table 3.3: Mix Design Ratios for a (5, 2) Component system

Sample points	Water	Cement	RHA	Fine Aggregate (F.A)	Coarse Aggregate (C.A)
N1	0.50	0.95	0.05	1.50	2.51

N2	0.51	0.90	0.10	1.88	2.43
N3	0.52	0.85	0.15	1.97	2.34
N4	0.49	0.80	0.20	1.71	2.59
N5	0.51	0.75	0.25	1.93	2.37

3.3 Simplex Lattice Design Formulation for (5, 2) System

Scheffe's model can be adapted to represent a five-component concrete mix containing water, cement, Rice Husk Ask (RHA), fine aggregate and coarse aggregate, by the pentahedron simplex matrix shown in Figure 3.1. The modal coordinates are the pseudo components of the matrix (Scheffe, 1958).

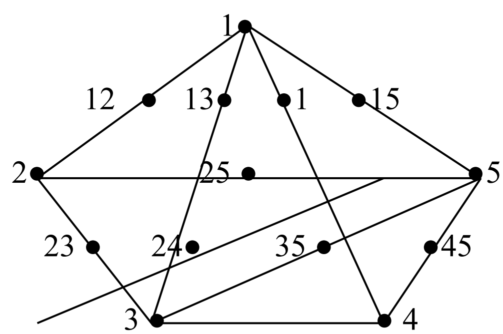

Figure 3.1: A (5, 2) Pentahedron Simplex Lattice, representing Five-Component Mix

3.3.1 The Simplex Lattice Method

In mathematical terms, a simplex lattice is a space of constituents' variables of and which obeys equation (3.1). Lattice is an abstract space to achieve the desired strength of concrete, the essential factors lies on the adequate proportioning of ingredients needed to make the concrete. In designing experiment to attack mixture problems involving component property diagrams Akhnazaroma and Kafarov, (1982) suggested that the property studied is assumed to be a continuous function of certain arguments and with a sufficient accuracy it was approximated with a polynomial. A polynomial of degree n in q variables has C^{th}_{q+n} coefficients. If a mixture has a total of q the components and be the proportion of the i[th] component in the mixture, (equation 3.2).

3.3.2 Actual and Pseudo Components

The requirements of the simplex are in line Eqn. (3.1) which makes it impossible to use the normal mix ratios such as 1:3, 1:5, at a given water/cement ratio. Hence a transformation of the actual components (Ingredients Proportions) to meet the above criterion is unavoidable. Such transformed ratios say x^i_1, x^i_2, and x^i_3. For the i[th] experimental point, the transformation computations are to be done by some multiplicative operations between the pseudo and the initially arbitrarily assumed actual variables.

The relationship between the actual components and the pseudo components is according to Osadebe and Ibearuegbulem (2009) defined by the following equation:

Where S, A and X, represent the actual mix ratios, coefficient of relation matrix, and pseudo mix ratios respectively. S and X are five component vectors and A is 5 x 5 matrix of coefficients. The value of matrix A was obtained from the first five mix ratios comprising the designed and modified mix ratios, (see Table 3.3).

In order to satisfy the requirement of a 5, 2 Scheffe's model, the following five mix ratios of Water: Cement: RHA: FA: CA were generated from a five mix design in 3.3.2:

$$A_1 = [0.50, 0.95, 0.05, 1.80, 2.51]$$

A_2 = [0.51, 0.90, 0.10, 1.88, 2.43]

A_3 = [0.52, 0.85, 0.15, 1.97, 2.34] (3.24)

A_4 = [0.49, 0.80, 0.20, 1.71, 2.59]

A_5 = [0.51, 0.75, 0.25, 1.93, 2.37]

The corresponding pseudo components are:

$$\left.\begin{array}{l} X_1 = [1, 0, 0, 0, 0] \\ X_2 = [0, 1, 0, 0, 0] \\ X_3 = [0, 0, 1, 0, 0] \\ X_4 = [0, 0, 0, 1, 0] \\ X_5 = [0, 0, 0, 0, 1] \end{array}\right\} \quad (3.25)$$

Substituting X_i and S_i into equation (3.23) and transposing the values of A matrix were obtained as:

$$[S] = \begin{bmatrix} 0.50 & 0.51 & 0.52 & 0.49 & 0.51 \\ 0.95 & 0.90 & 0.85 & 0.80 & 0.75 \\ 0.05 & 0.10 & 0.15 & 0.20 & 0,25 \\ 1.80 & 1.88 & 1.97 & 1.71 & 1.93 \\ 2.51 & 2.43 & 2.34 & 2.59 & 2.37 \end{bmatrix} \quad (3.26)$$

With centre points,

$$\left.\begin{array}{l} X_{12} = [0.5, 0.5, 0, 0, 0] \\ X_{13} = [0.5, 0, 0.5, 0, 0] \\ X_{14} = [0.5, 0, 0, 0.5, 0] \\ X_{15} = [0.5, 0, 0, 0, 0.5] \end{array}\right\}$$

$$X_{23} = [0, 0.5, 0.5, 0, 0]$$

$$X_{24} = [0, 0.5, 0, 0.5, 0] \qquad (3.27)$$

$$X_{25} = [0, 0.5, 0, 0, 0.5]$$

$$X_{34} = [0, 0, 0.5, 0.5, 0]$$

$$X_{35} = [0, 0, 0.5, 0, 0.5]$$

$$X_{45} = [0, 0, 0, 0.5, 0.5]$$

According to Scheffe (1958),

Where X, and represent the actual mix ratios, pseudo mix ratios and coefficient of relation matrix respectively

Substituting,

$$\begin{bmatrix} S_{12} \\ S_{13} \\ S_{14} \\ S_{15} \\ S_{23} \end{bmatrix} = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0 & 0.5 & 0 & 0 \\ 0.5 & 0 & 0 & 0.5 & 0 \\ 0.5 & 0 & 0 & 0 & 0.5 \\ 0 & 0.5 & 0.5 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0.50 \\ 0.51 \\ 0.52 \\ 0.49 \\ 0.51 \end{bmatrix} \qquad (3.29)$$

This process is repeated for S_{24}, S_{25}, S_{34}, S_{35} and S_{45}. Similarly, this process is repeated for an additional 15 control points that will be used for the verification of the formulated model. The results from the repeated process are presented in Table 3.4 and Table 3.5.

Table 3.4: Actual and Pseudo Mix Ratios of the Model

Sample Points	Actual Components					Response	Pseudo Components				
	Water	Cement	RHA	F.A	C.A		Water	Cement	RHA	F.A	C.A
	S_1	S_2	S_3	S_4	S_5	Y_{exp}	X_1	X_2	X_3	X_4	X_5

N_1	0.50	0.95	0.05	1.80	2.51	Y_1	1	0	0	0	0
N_2	0.51	0.90	0.10	1.88	2.43	Y_2	0	1	0	0	0
N_3	0.52	0.85	0.15	1.97	2.34	Y_3	0	0	1	0	0
N_4	0.49	0.80	0.20	1.71	2.59	Y_4	0	0	0	1	0
N_5	0.51	0.75	0.25	1.93	2.37	Y_5	0	0	0	0	1
N_{12}	0.505	0.925	0.075	1.84	2,47	Y_{12}	0.5	0.5	0	0	0
N_{13}	0.51	0.90	0.10	1.885	2.425	Y_{13}	0.5	0	0.5	0	0
N_{14}	0.495	0.875	0.125	1.755	2.55	Y_{14}	0.5	0	0	0.5	0
N_{15}	0.505	0.85	0.15	1.865	2.44	Y_{15}	0.5	0	0	0	0.5
N_{23}	0.515	0.875	0.125	1.925	2.345	Y_{23}	0	0.5	0.5	0	0
N_{24}	0.50	0.85	0.15	1.795	2.51	Y_{24}	0	0.5	0	0.5	0
N_{25}	0.51	0.825	0.175	1.905	2.40	Y_{25}	0	0.5	0	0	0.5
N_{34}	0.505	0.825	0.175	1.84	2.465	Y_{34}	0	0	0.5	0.5	0
N_{35}	0.515	0.80	0.20	1.95	2.355	Y_{35}	0	0	0.5	0	0.5
N_{45}	0.50	0.775	0.225	1.82	2.48	Y_{45}	0	0	0	0.5	0.5

Table 3.5: Actual and Pseudo Components of Control Observation Points

Sample point	**Actual Components**					**Response**	**Pseudo Components**				
	Water	Cement	RHA	F.A	C.A		Water	Cement	RHA	F.A	C.A

ts	S_1	S_2	S_3	S_4	S_5	**Y_{exp}**	X_1	X_2	X_3	X_4	X_5
C_1	0.502	0.86	0.14	1.812	2.494	Yc_1	0	0.6	0	0.4	0
C_2	0.504	0.93	0.07	1.834	2.476	Yc_2	0.8	0	0.2	0	0
C_3	0.51	0.87	0.13	1.894	2.414	Yc_3	0.4	0	0.4	0	0.2
C_4	0.508	0.79	0.21	1.904	2.398	Yc_4	0.2	0	0	0	0.8
C_5	0.514	0.84	0.16	1.918	2.39	Yc_5	0	0	0.8	0.2	0
C_{12}	0.504	0.87	0.13	1.852	2.454	Yc_{12}	0.6	0	0	0	0.4
C_{13}	0.506	0.79	0.21	1.876	2.426	Yc_{13}	0	0.2	0	0.2	0.6
C_{14}	0.512	0.89	0.11	1.892	2.412	Yc_{14}	0	0.8	0.2	0	0
C_{15}	0.51	0.83	0.17	1.892	2.414	Yc_{15}	0	0.2	0.4	0.2	0.2
C_{23}	0.514	0.85	0.15	1.928	2.38	Yc_{23}	0.2	0	0.6	0	0.2
C_{24}	0.502	0.83	0.17	1.822	2.482	Yc_{24}	0	0.4	0	0.4	0.2
C_{25}	0.504	0.90	0.10	1.842	2.466	Yc_{25}	0.6	0.2	0	0	0.2
C_{34}	0.506	0.85	0.15	1.858	2.448	Yc_{34}	0.2	0.2	0.2	0.2	0.2
C_{35}	0.514	0.81	0.19	1.918	2.39	Yc_{35}	0	0	0.2	0.8	0
C_{45}	0.502	0.91	0.09	1.826	2.482	Yc_{45}	0.8	0	0	0	0.2

3.4 Determination of the Physical Properties of Aggregates

The test carried out to determine the physical properties include;

1. **Sieve Analysis Test**

This talks of fraction consisting particles of the same shape. In normal practice, each of these fractions consists of particles between the openings of the standard test sieves. The test sieves normally used for aggregates have square openings and usually described by the size of the openings in millimeter (mm). Coarser test sieves (4.0mm and larger) are made with wire cloth. It has a screening which varies between 34-53% of the gross area of the sieve.

Sieve analysis in simple terms can be defined as the process of partitioning aggregates sample into fractions of the same particle sizes. It is used to determine the grinding effect of the aggregate.

Test procedures

Coarse aggregates are aggregates retained at the 12mm BS Sieve. For the purpose of this research work, the coarse aggregates to be used are is granite. Fine aggregates are aggregates mainly passing the 4.75mm sieve. Sharp sand is the fine aggregate used here.

The sieve was thoroughly cleaned and weighed on an electronic weighing balance, the set of sieve were arranged in descending order according to their sizes from a maximum mesh opening to the minimum opening with a pan at the bottom. The sample was poured gradually into the topmost sieve of the set of the sieves. The set of sieve with the sample were shaken manually due to the absence of the mechanical shaker in the lab. The sieve was then removed from the shake and weighed. The weight of the samples retained on them after it was shaken was determined by subtracting the weight of sieves from the weight of sieve plus sample retained on the sieve.

2. **Bulk Density Test**

This is defined as the weight of the aggregates needed to fill a given space of a given unit volume where the aggregates are said to be fully packed according to volume. Bulk density of a material depends on the packing of the material. The material can either be loosely packed or well compacted. This test is being carried out to know the degree of void that an aggregate will have.

Test Procedures for Compacted Bulk Density

a) Measure the volume of the mould
b) Fill the mould to about one-third with the sample and tamp it for 25 times using the tamping rod.
c) Again, add one third of the sample and tamp it again with the tamping rod for 25 times.
d) Fill the mould with the sample for the final time and tamp it for another 25 times.
e) Use the tamping rod as a straight edge to remove the surplus aggregates
f) Measure the weight of the material and record it as 'W' in Kg.
g) Determine the bulk density by

Test Procedures for Uncompacted Bulk Density

a) Measure the volume of the mould
b) Fill the mould with the sample to overflowing by means of a scoop
c) Level top surface of the aggregate.

d) Measure the aggregate weight and record as ‘W’ in Kg.

3. Specific Gravity Test

According to the BS standard provided; the ratio of the mass of the material, to the mass of the same volume of free distilled water at a taken stated temperature is defined as specific gravity. The objective of carrying out this test is so as to determine specific gravities of both the fine and coarse aggregates been specified.

Test Procedures for Uncompacted Bulk Density

a) An empty cylinder was weighed and mass recorded.

b) Aggregates were introduced into the cylinder, weighed and mass recorded.

c) The cylinder in (2) above is then filled with water to gauge level, weighed and mass recorded.

d) The cylinder was then emptied, filled with water to gauge level, weighed and mass recorded.

e) The procedures were repeated for two more tests.

Where,

W_1 = Weight of empty cylinder

W_2 = Weight of empty cylinder + sample

W_3 = Weight of empty cylinder + sample + water

W_4 = Weight of empty cylinder + water

4. Water Absorption Test

Water absorption test is used in determining the amount of water absorbed by a material under specified conditions. The factors that affect water absorption include additives used, type of plastics, length and temperature of exposure.

Test Procedures for Water Absorption

a) The sample is dried in the oven for a specific period of time (24 hours) and then placed in the desiccator to cool
b) After cooling the sample is then weighed.
c) The material is merged in water at a particular condition often 23˚c for 24 hours. The specimen is then removed, patted dry and the weighed.

5. Aggregate Impact Value (AIV) Test

This test is carried out so as to evaluate the resistance of a material to mechanical degradation. Degradation may take place if the aggregate is weak and this leads to a change in grading, or production of excessive, and undesired fines.

Test Procedures for AIV

a) The material used is the aggregate passing through the 28mm sieve and retained on the 20mm sieve. The mould is then cleaned.
b) Place sample in the mould, and compact by a single tamping of 25 strokes.
c) Subject the sample to 15 blows of the hammer dropping each being delivered at an interval not less than a second.
d) The aggregate crushed is then sieved using the 2.36mm sieve. The portion passing through the 2.36mm sieve is then weighed

3.5 Compressive Strength of Concrete

Two replicate concrete cubes were made for each of the thirty mix ratios using 150 x 150 x 150mm moulds. The cubes were removed after 24 hours from the mould and were soaked in water to cure for 28 days. The cubes were removed on the 28th day and subjected to crushing with the help of a uniaxial compressive strength machine. The compressive strength was determined with equation (3.36).

Where

F_c = compressive strength of concrete

P = the applied compressive load at failure (KN)

A = the cross sectional area of the specimen (mm^2)

Progress photograph on how the compressive strength test was carried out is presented in Plate II.

Plate II: Progress Photograph of Compressive Strength Test

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Sieve Analysis

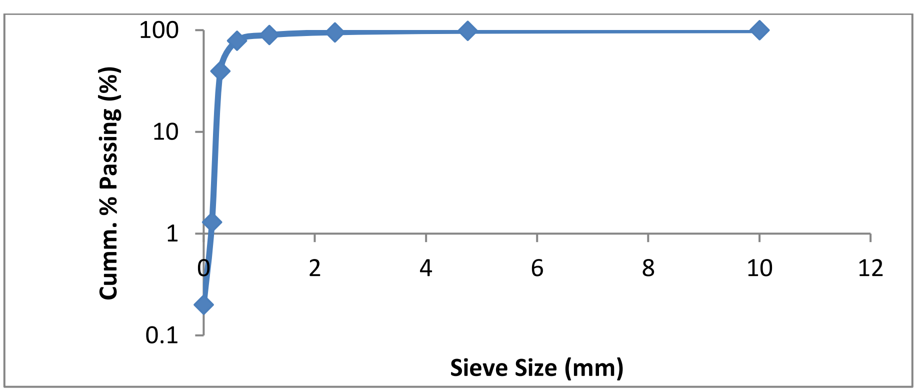

Figure 4.1: Sieve Analysis Graph for Fine Aggregate

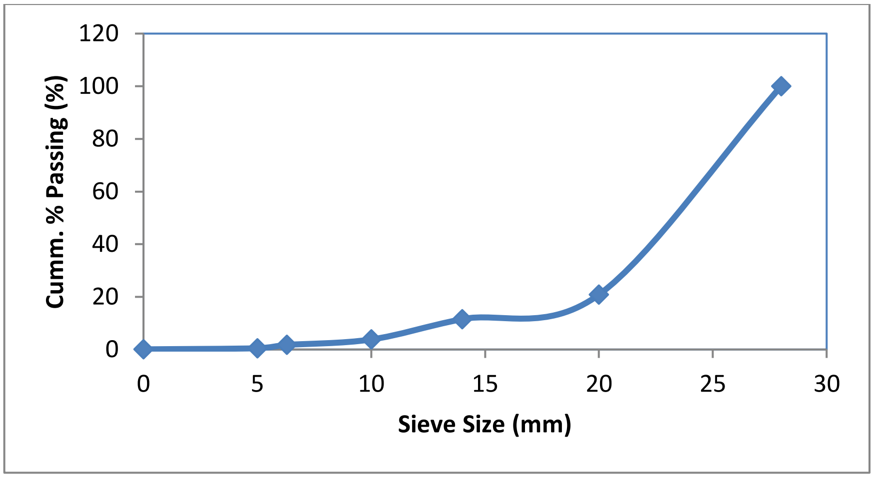

Figure 4.2: Sieve Analysis Graph for Coarse Aggregates

The sieve analysis results show 2.0 and 1.85 as C_u for Fine and Coarse aggregates respectively. According to AASHTO soil classification system, the values show that the aggregates were uniformly graded ($1< C_u < 2$).

4.2 Bulk Density

The bulk density results for the aggregates are presented in Tables 4.1 and 4.2

Table 4.1: Bulk Density Results Fine Aggregates

Measurements	Uncompacted			Compacted		
No. of Trials	1	2	3	1	2	3
Volume of Mould(m^3)	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017
Weight of Mould (Kg)	1.10	1.10	1.10	1.10	1.10	1.10
Weight of Mould + Sample (Kg)	3.87	3.80	3.82	3.93	3.88	3.95
Weight of Sample (Kg)	2.77	2.70	2.72	2.83	2.78	2.85

Bulk Density(Kg/m^3)	1629.41	1588.24	1600	1664.71	1635.29	1676.47
Average (Kg/m^3)		1605.88			1658.62	

Table 4.2 Bulk Density Results Coarse Aggregates

Measurements	Uncompacted			Compacted		
No. of Trials	1	2	3	1	2	3
Volume of Mould(m^3)	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017
Weight of Mould (Kg)	1.10	1.10	1.10	1.10	1.10	1.10
Weight of Mould + Sample (Kg)	3.97	4.04	3.99	4.02	4.06	4.03
Weight of Sample (Kg)	2.87	2.94	2.89	2.92	2.96	2.93
Bulk Density(Kg/m^3)	1688.24	1729.41	1700	1717.65	1741.18	1723.53
Average (Kg/m^3)		1705.88			1727.45	

The bulk density result shows 1705.88Kg/m^3 uncompacted and 1727.45Kg/m^3 compacted for the granite, which classifies the granite as a normal weight aggregate.

4.3 Specific Gravity

The specific gravity results for the aggregates are presented in Tables 4.3 and 4.4

Table 4.3: Specific Gravity Results for Fine Aggregates

Cylinder No.	W_1 (g)	W_2 (g)	W_3 (g)	W_4 (g)	Specific Gravity	Average
1	56.51	73.78	165.48	154.67	2.65	
2	69.30	83.86	171.21	162.68	2.41	2.61
3	56.14	71.05	163.46	153.95	2.76	

Table 4.4: Specific Gravity Results for Coarse Aggregates

Cylinder No.	W_1 (g)	W_2 (g)	W_3 (g)	W_4 (g)	Specific Gravity	Average
1	92.48	221.70	434.25	353.05	2.69	
2	80.35	217.40	428.75	341.62	2.75	2.65
3	92.46	222.75	430.55	351.94	2.52	

The specific gravity result shows 2.61, and 2.65 for fine aggregates (sharp sand) and coarse aggregate (granite) respectively. This value classifies the granite as a coarse aggregate that can be used in producing a normal weight concrete or a concrete that has less strength.

4.4 Water Absorption

The water absorption test for the aggregates are presented in Tables 4.5 and 4.6

Table 4.5: Water Absorption Results for Fine Aggregates

No. of Trials	**1**	**2**	**3**
Weight of Can (g)	24.60	25.02	24.86
Weight of Can + Dry Sample (g)	160.48	160.57	160.65
Weight of Can + Wet Sample (g)	160.89	160.75	160.97
Dry weight (g)	135.88	135.55	135.79
Wet Weight (g)	136.02	135.73	136.11

Water Absorption (%)	0.10	0.13	0.24
Average (%)		0.16	

Table 4.6: Water Absorption Results for Coarse Aggregates

No. of Trials	**1**	**2**	**3**
Weight of Can (g)	24.60	24.92	24.74
Weight of Can + Dry Sample (g)	160.58	160.72	160.45
Weight of Can + Wet Sample (g)	161.00	161.20	160.88
Dry weight (g)	135.98	135.80	135.71
Wet Weight (g)	136.39	136.28	136.09
Water Absorption (%)	0.30	0.35	0.28
Average (%)		0.31	

The result shows that the granite has a low water absorption value which is a good property of a material that can be used in the production of concrete, because less water absorption helps in preventing void and making the concrete have high strength.

4.5 Aggregate Impact Value

Table 4.7: Aggregates Impact Value Results for Coarse Aggregates

No. of Trials	1	2	3
Initial Mass of Dried Sample (g)	500.00	500.00	500.00
Mass Passing 2.36mm Sieve (g)	103.42	102.65	104.14
AIV (%)	20.68	20.53	20.83
Average		20.68	

The aggregate impact value shows 20.68%. This value is less than 30%, which by standard of practice means that the materials can withstand degradation and can be used in concrete production.

4.6 Compressive Strength Test

The compressive strength test results for the thirty mix ratios are presented in Table 4.10a and Table 4.10b. The compressive strength of concrete decreased when more of the cement was replaced with the Rice Husk Ash. The strength increased with a reduction in the water/cement ratio. It was however noticed that the compressive strength of concrete was high in mix ratios where there is a higher percentage of the granite (coarse aggregate) to the fine aggregate.

Some mix ratios with low water/cement ratio also had low compressive strength values, this is because the concrete was not workable while the casting process was on-going, this created pore spaces within the concrete structure and lead to failure of the concrete. The test shows the highest strength at 27.98 N/mm^2 for 5 percent cement replacement with Rice Husk Ash (RHA) after 28 days of curing.

Table 4.8a: Axial Compressive Strength of Concrete after 28 days curing

Sample points	Failure Load (kN)			Area (mm^2)	Compressive Strength(N/mm^2)			
	A	B	C		A	B	C	Average
N_1	628.51	626.60	633.70	22500	27.93	27.85	28.16	27.98
N_2	580.00	585.20	586.3	22500	25.78	26.01	22.16	25.95
N_3	493.61	505.80	498.71	22500	21.94	22.48	22.16	22.19
N_4	387.50	381.23	370.40	22500	17.22	16.94	16.46	16.87

N_5	325.20	310.81	287.83	22500	14.45	13.81	12.88	13.71
N_{12}	617.18	608.25	615.30	22500	27.43	27.03	27.35	27.27
N_{13}	604.60	591.33	600.21	22500	26.87	26.28	26.68	26.61
N_{14}	520.61	515.23	511.25	22500	23.14	22.90	22.72	22.92
N_{15}	535.48	493.40	501.64	22500	23.80	21.93	22.30	22.68
N_{23}	487.91	540.61	512.63	22500	21.68	24.03	22.78	22.83
N_{24}	528.43	551.64	540.84	22500	23.49	25.52	24.04	24.35
N_{25}	506.64	501.76	496.51	22500	22.52	22.30	22.07	22.30
N_{34}	464.52	438.41	453.23	22500	20.65	19.48	20.14	20.09
N_{35}	366.24	357.41	346.80	22500	16.28	15.88	15.41	15.86
N_{45}	340.81	319.21	338.57	22500	15.15	14.19	15.05	14.80

Table 4.8b: Axial Compressive Strength of Concrete after 28 days curing

Sample	Failure Load (kN)			Area	Compressive Strength(N/mm^2)			
points	A	B	C	(mm^2)	A	B	C	Average
C_1	528.61	519.61	535.78	22500	23.49	23.09	23.81	23.46
C_2	634.25	615.11	623.48	22500	28.19	27.33	27.71	27.74
C_3	518.31	507.61	511.18	22500	23.04	22.56	22.72	22.77
C_4	351.78	365.28	342.15	22500	15.63	16.23	15.21	15.69
C_5	468.75	480.88	472.15	22500	20.83	21.37	20.98	21.06
C_{12}	499.12	520.72	508.43	22500	22.18	23.14	22.60	22.64
C_{13}	364.46	375.64	370.81	22500	16.20	16.70	16.48	16.46
C_{14}	571.23	567.81	576.01	22500	25.39	25.34	25.60	25.44

C_{15}	463.81	456.25	479.18	22500	20.61	20.28	21.30	20.73
C_{23}	510.47	531.61	523.25	22500	22.69	23.63	23.26	23.19
C_{24}	500.61	489.84	495.12	22500	22.25	21.77	22.00	22.01
C_{25}	589.21	598.60	590.41	22500	26.19	26.47	26.24	26.30
C_{34}	526.81	501.23	512.67	22500	23.41	22.28	22.79	22.83
C_{35}	367.35	372.89	361.25	22500	16.33	16.57	16.06	16.32
C_{45}	593.48	578.61	586.27	22500	26.60	25.72	26.06	26.13

4.7 Optimisation Model for 28 days Compressive Strength

The coefficients of polynomials from Table 4.10, equation (3.16) and equation (3.18) are:

Recall from equation (3.18) that,

Similarly,

Substituting the above coefficients into equation (3.12)

Equation (4.1) above is the optimisation model to predict the 28 days' compressive strength of concrete using RHA to replace 5-25% of cement.

The predicted compressive strength is gotten when the Pseudo points from table 3.4 are substituted into equation (4.1).

Similarly,

The experimental and predicted values of the 28 days compressive strength for the model and control points are presented in Table 4.9a and Table 4.9b respectively.

Table 4.9a: Experimental and Predicted Values of 28 days Compressive Strength for the Model

Sample Points	Response Y	Pseudo Components					Comp. Strength $Y_{exp}(N/mm^2)$	Comp. Strength $Y_{pred}(N/mm^2)$
		Water X_1	Cement X_2	RHA X_3	F.A X_4	C.A X_5		
N_1	Y_1	1	0	0	0	0	27.98	27.98
N_2	Y_2	0	1	0	0	0	25.95	25.95
N_3	Y_3	0	0	1	0	0	22.19	22.19
N_4	Y_4	0	0	0	1	0	16.87	16.87
N_5	Y_5	0	0	0	0	1	13.71	13.71
N_{12}	Y_{12}	0.5	0.5	0	0	0	27.27	27.27
N_{13}	Y_{13}	0.5	0	0.5	0	0	26.61	26.61
N_{14}	Y_{14}	0.5	0	0	0.5	0	22.92	22.92

N_{15}	Y_{15}	0.5	0	0	0	0.5	22.68	22.68
N_{23}	Y_{23}	0	0.5	0.5	0	0	22.83	22.83
N_{24}	Y_{24}	0	0.5	0	0.5	0	24.35	24.35
N_{25}	Y_{25}	0	0.5	0	0	0.5	22.30	22.30
N_{34}	Y_{34}	0	0	0.5	0.5	0	20.09	20.09
N_{35}	Y_{35}	0	0	0.5	0	0.5	15.86	15.86
N_{45}	Y_{45}	0	0	0	0.5	0.5	14.80	14.80

Table 4.9b: Experimental and Predicted Values of 28 days Compressive Strength for the Control Points

Sample Points	Response Y	Pseudo Components					Comp. Strength Y_{exp}(N/mm^2)	Comp. Strength Y_{pred}(N/mm^2)
		W-C ratio X_1	Cement X_2	RHA X_3	F.A X_4	C.A X_5		
C_1	Yc_1	0	0.6	0	0.4	0	23.46	25.14
C_2	Yc_2	0.8	0	0.2	0	0	27.74	27.78
C_3	Yc_3	0.4	0	0.4	0	0.2	22.77	23.70
C_4	Yc_4	0.2	0	0	0	0.8	15.69	17.74
C_5	Yc_5	0	0	0.8	0.2	0	21.06	21.48
C_{12}	Yc_{12}	0.6	0	0	0	0.4	22.64	24.03
C_{13}	Yc_{13}	0	0.2	0	0.2	0.6	16.46	18.21
C_{14}	Yc_{14}	0	0.8	0.2	0	0	25.44	24.40
C_{15}	Yc_{15}	0	0.2	0.4	0.2	0.2	20.73	20.08

C_{23}	Yc_{23}	0.2	0	0.6	0	0.2	23.19	21.67
C_{24}	Yc_{24}	0	0.4	0	0.4	0.2	22.01	22.38
C_{25}	Yc_{25}	0.6	0.2	0	0	0.2	26.30	26.14
C_{34}	Yc_{34}	0.2	0.2	0.2	0.2	0.2	22.83	24.55
C_{35}	Yc_{35}	0	0	0.2	0.8	0	16.32	16.60
C_{45}	Yc_{45}	0.8	0	0	0	0.2	26.13	24.81

4.8 Test of Adequacy for the Model

To the test for the adequacy of the model, the Fischer test (Fischer, 1938) at 95% confidence level on the compressive strength at control points (C_1, C_2, C_3, C_4, C_5, C_{12}, C_{13}, C_{14}, C_{15}, C_{23}, C_{24}, C_{25}, C_{34}, C_{35}, and C_{45}) was used. Two hypotheses were formulated from the test.

a. **Null Hypothesis**

   This is when there is no difference between the laboratory compressive strength of cube test results and model predicted compressive strength results.

b. **Alternative Hypothesis**

   There is a significant difference between the laboratory compressive strength cube test results and model predicted compressive results. The hypothesis test was carried out as shown in Table 4.10.

Table 4.10: Fischer Statistical Test Computations for the Model

Control Points	y_{exp}	y_{pred}	$y_{exp} - \bar{y}_{exp}$	$Y_{pred} - \bar{y}_{pred}$	$(y_{exp} - \bar{y}_{exp})^2$	$(y_{pred} - \bar{y}_{pred})^2$
C_1	23.46	25.14	1.28	2.56	1.64	6.55
C_2	27.74	27.78	5.56	5.20	30.91	27.04
C_3	22.77	23.70	0.56	1.12	0.35	1.25
C_4	15.69	17.74	-6.49	-4.84	42.12	23.43
C_5	21.06	21.48	-1.2	-1.10	1.25	1.21
C_{12}	22.64	24.03	0.46	1.45	0.21	2.10
C_{13}	16.46	18.21	-5.72	-4.37	32.72	19.10
C_{14}	25.44	24.40	3.26	1.82	10.63	3.31
C_{15}	20.73	20.08	-1.45	-2.50	2.10	6.25
C_{23}	23.19	21.67	1.01	-0.91	1.02	0.83
C_{24}	22.01	22.38	-0.17	-0.20	0.03	0.04
C_{25}	26.30	26.14	4.12	3.56	16.97	12.67
C_{34}	22.83	24.55	0.65	1.97	0.42	3.88

C_{35}	16.32	16.60	-5.86	-5.98	32.34	35.67
C_{45}	26.13	24.81	3.95	2.23	15.60	4.97
Sum	332.77	338.71			188.31	148.39
Mean	22.18	22.58				

Note: y_{exp} = Experimental Compressive strength from Laboratory

Y_{pred} = Predicted Compressive strength from the model

$\bar{y}_{exp}$ (Mean) =

$\bar{y}_{pred}$ (Mean) =

Where is the greater of while is the smaller of the two

Hence,   and

The model is acceptable at 95% confidence level if

Where, significant level,

Degree of freedom,

From Standard F-statistic table, and

Therefore, the null hypothesis which says there is no significant difference between the experimental results and the model expected result is acceptable. This means that the compressive strength model equation for 28 days is adequate for the prediction of compressive strength of concrete containing water, cement, RHA, fine aggregates (sharp sand) and coarse aggregate(granite).

4.9 Statistical Regression

The graphical relationship between the experimental and predicted values of 28 days' compressive strength of the concrete mix considered in this study is shown in this study is shown in Figure 4.3. The closeness of the data points to the trend line shows that the values of the predicted strength are in agreement with the experimental values.

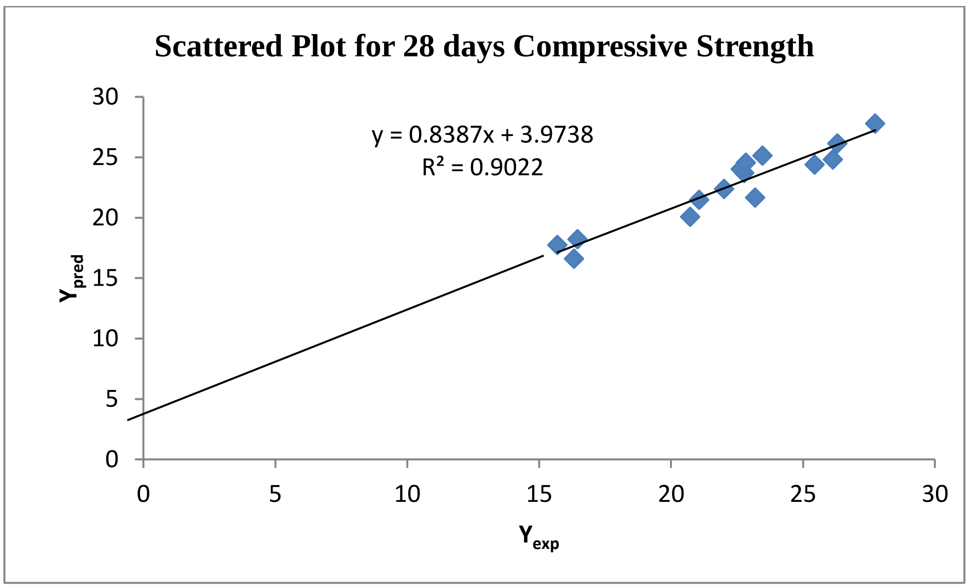

Figure 4.3: Correlation of Experimental and Predicted 28 days Compressive Strength

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Results of this research work have been collected within the limits of experimental accuracy, upon which various deductions have been made, these deductions include;

The compressive strength of concrete decreases on the progressive replacement of cement with Rice Husk Ash (RHA).

Using Scheffe's (5, 2) polynomial equation, mix design optimisation model for a five component RHA blended cement concrete was developed. The model could predict the compressive strength of RHA blended concrete when the mix ratios are known and vice versa.

The predictions from the model were tested at 95% accuracy level using statistical Fischer test and found to be adequate. The maximum strength predicted by this model was 27.78 N/mm^2 derived from a mix ratio of 0.504:0.93:0.07:1.834:2.476 for Water: Cement: RHA: FA (Sharp sand): CA (Granite) respectively.

5. 2 Recommendations

From the results obtained in this research, with the conclusion made on the model developed, the following are hereby recommended

1. The replacement of cement with RHA should not exceed 15%, this is because the compressive strength reduced drastically after it exceeded 15% from this research.

2. A higher polynomial equation can be used in other research so as to get perfect model.

5. 3 Contribution to Knowledge

Two critical problems have been identified by this research, these includes the rising cost in cement which is a fundamental material for the production of concrete and concrete failure which is as a result of poor mix ratio. In solving these problems, this research has been able to provide a partial replacement for cement in concrete production using rice husk ash, and it showed that a replacement of about 5 – 7 percent could still provide the needed strength, also reduces the use of cement. In solving the mix ratio problem, an optimisation model was developed using Scheffe's theory, the model predicted the right mix ratio that provided the optimal concrete strength needed, and the model can also be used to make further predictions with a concrete mix containing rice husk ash.

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APPENDIX

Appendix A

Table A 1: Batch Mix for Sample Points

Sample Points	W/C Ratio S_1 ($x10^{-3}m^3$)	Cement S_2(Kg)	RHA S_3 (Kg)	F.A S_4 (Kg)	C.A S_5 (Kg)	No. of cubes
N_1	2.0787	3.9437	0.2076	7.4723	10.4198	3
N_2	2.1172	3.7362	0.4151	7.8044	10.0877	3
N_3	2.1587	3.5286	0.6227	8.1781	10.7519	3
N_4	2.0341	3.3210	0.8303	7.0987	10.7519	3
N_5	2.4493	3.1135	1.0378	8.0120	9.8386	3
N_{12}	2.0964	3.8400	0.3113	7.6384	10.2537	3
N_{13}	2.1172	3.7362	0.4151	7.8252	10.0669	3
N_{14}	2.0549	3.6324	0.5189	7.2855	10.5858	3
N_{15}	2.0964	3.5286	0.6227	7.7722	10.1292	3
N_{23}	2.1379	3.6324	0.5189	7.9913	9.7348	3
N_{24}	2.0757	3.5286	0.6227	7.4516	10.4198	3
N_{25}	2.0757	3.4248	0.7265	7.9082	9.9631	3
N_{34}	2.0964	3.4248	0.7265	7.6384	10.2330	3
N_{35}	2.1379	3.3210	0.8303	8.0950	9.7763	3
N_{45}	2.0798	3.2173	0.9340	7.5554	10.2952	3

Table A 2: Batch Mix for Sample Points

Sample Points	W/C Ratio S_1 ($x10^{-3}m^3$)	Cement S_2(Kg)	RHA S_3 (Kg)	F.A S_4 (Kg)	C.A S_5 (Kg)	No. of cubes
C_1	2.0840	3.5701	0.5812	7.5222	10.3533	3
C_2	2.0923	3.8607	0.2906	7.6135	10.2786	3
C_3	2.1172	3.6116	0.5397	7.8626	10.0212	3
C_4	2.1089	3.2795	0.8718	7.9041	9.9548	3
C_5	2.1338	3.4871	0.6642	7.96022	9.9548	3
C_{12}	2.0923	3.6116	0.5397	7.6882	10.1873	3
C_{13}	2.1006	3.2795	0.8718	7.7878	10.0711	3
C_{14}	2.1255	3.6947	0.4566	7.8584	10.0129	3
C_{15}	2.1170	3.4456	0.7057	7.8543	10.0212	3
C_{23}	2.1338	3.5286	0.6227	8.0037	9.8801	3
C_{24}	2.0840	3.4456	0.7057	7.5637	10.3035	3
C_{25}	2.0923	3.7362	0.4147	7.6467	10.2371	3
C_{34}	2.1006	3.7362	0.4147	7.7131	10.1624	3
C_{35}	2.1338	3.3626	0.7887	7.9622	9.9216	3
C_{45}	2.0840	3.7777	0.3736	7.5803	10.3035	3
Total	63.4064	106.3564	18.1818	232.2477	304.9711	90

Table A3: Sieve Analysis Results for Fine Aggregates. Weight of Sample = 500g

Sieve size	Sample retained (g)	% retained	Cumm. % retained	Cumm. % passing
10 mm	0.00	0.00	0.00	100.00
4.75 mm	7.50	1.50	1.50	98.50
2.36 mm	16.00	3.20	4.70	95.30
1.18 mm	28.50	5.70	10.40	89.60
600 µm	54.70	10.94	21.34	78.70
300 µm	195.00	39.00	60.34	39.70
150 µm	192.00	38.40	98.74	1.30
Pan	5.30	1.06	99.80	0.20
Total	499.00			

A4: Sieve Analysis Results for Coarse Aggregates. Weight of Sample = 1000g

Sieve size (mm)	Sample retained (g)	% retained	Cumm. % retained	Cumm. % passing
28.00	0.00	0.00	0.00	100.00
20.00	791.35	79.16	79.16	20.84
14.00	102.68	10.29	88.45	11.55
10.00	67.47	6.75	96.20	3.80
6.30	20.63	2.06	98.26	1.74
5.00	12.47	1.25	99.51	0.49
Pan	4.32	0.43	99.94	0.06
Total	998.92			