PRODUCTION OF IMPROVED STRENGTH CONCRETE USING SUGARCANE BAGASSE ASH AND METAKAOLINE AS ADDITIVES

BY

EKE, OBINNA DARLINGTON (B.Eng.)

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CERTIFICATION

This is to certify that this work "**Production of Improved Strength Concrete using Sugarcane Bagsasse and Metakaoline** as Additive was carried out by **Eke Obinna Darlington** with Registration Number 2015-?96818 in partial fulfillment of the requirement for the award of Masters of Engineering (M.Eng) degree in civil Engineering (Structures) in the School Engineering and Engineering Technology, Federal University of Technology Owerri, Imo State, Nigeria.

………………………………	31/10/2023
Engr. Dr. Mrs. J. I. Arimanwa	**Date**
(Supervisor)	
………………………………	08/11/2023
Engr. Prof. Mrs. C. E. Okere	**Date**
(Supervisor)	
………………………………	14/11/2023
Engr. Dr. O.M. Ibearugbulem	**Date**
(Head of Department)	
………………………………	27/11/23
Engr. Prof. Remy Uche	**Date**
(Dean, SEET)	
………………………………	………………………
Prof. B. O. Esonu	Date
(Dean, PGS)	
………………………………	………………………
Engr. Prof. C. Nwoji	Date
(External Examinar)	

DEDICATION

I dedicate this piece of research to the almighty God and to my Father, mother, brothers, sisters, wife and late Barr. Sam K.

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Abstract

This research work presents Prediction of Improved Strength Concrete Using Sugarcane Bagasse Ash And Metakaolin as Additives. Mathematical model was formulated using Ibearugbulem's regression method. The materials used in this research were water, cement, metakaolin, sugarcane bagasse ash, fine aggregate, coarse aggregate and super plasticizer(CONPLAST SP 430).A total of 252 cubes of size 150 x 150 x 150mm were produced from 84 different mix ratios. The first 42 mix ratios were used for formulation of the model while the second 42 mix ratios were used to check the adequacy of the model. The concrete were cast and cured in a curing tank for 28, 60 and 90 days. The percentage replacement of cement with sugarcane bagasse ash and metakaolin adopted in this research ranges from 5% to 15% with constant water- cement ratio of 0.28. After curing, the concrete cubes were crushed in the universal testing machine. The results showed that the maximum compressive strength of the concrete cubes as 48.47MPa,which occurred at 15% replacement of cement with Sugarcane baggaseash/metakaolin and 60 days curing age , while the minimum compressive strength is 21.73 MPa at 5% replacement of cement with sugar cane baggase ash/metakaolin and28 days curing age. The percentage differences of laboratory and model predicted results were computed, and it was found that maximum percentage difference were 11.30%, 7.17%, and 13.84% respectively for 28, 60 and 90 days curing ages respectively. The minimum percentage differences were found as 0.67%, 0.68% and 0.66% for 28, 60 and 90 days curing ages respectively. The model was checked for adequacy at 95% confidence level using statistical t-test and was found adequate. From the results, the strength of concrete can be classified as improved strength concrete when compared to normal strength concrete.

Key words: Concrete, model, improved strength, sugarcane bagasse ash, metakaoline, superplaticizer.

CHAPTER ONE

INTRODUCTION

1.1 Background Information.

Concrete is a composite material made from sand, gravel, and cement. The cement is a blend of various minerals and when mixed with water a chemical reaction is created, that binds the sand and gravel, into a stiff mass. (Blanksvard; 2009).High strength concrete is defined as concrete that has compressive strength of 70MPa to 80MPa according to ACI code. It has strength but does not necessarily possess superior characteristic as high-performance concrete, durability of high strength is commonly improved by adding pozzolanic materials. It is brittle, high quality control is needed in order to maintain the special properties desired.

High performance concrete is a term used to describe concrete with special properties not attributed to normal concrete. High performance concrete means that the concrete has one or more of the following properties; low shrinkage, low permeability, a high modulus of elasticity, or high strength (Al Menhosh, 2017).

According to Henry (1997) ACI defines high performance concrete as concrete that meets special performance and uniformity requirements that cannot always be achieved routinely by using conventional materials and normal mixing, placing, and curing practices. The requirements may involve enhancement of placement and compaction without segregation, long term mechanical properties, early age strength, toughness, volume stability, or service life in severe environments (Henry, 1997). Concrete is used more than all other construction materials put together. It is used in many construction projects such as building, roads, concrete bridges, tunnels, tanks, and sewerage systems (Neville & Brooks, 1987). Due to the deterioration of concrete structures in aggressive environment high performance concrete has become imperative.

The greatest challenge before the concrete construction industry is to serve the two pressing needs of human society, namely the protection of environment and meeting the infrastructure requirements of our growing population structures which are constructed in aggressive environments are liable to be subjected to acidic attack. One of such major problems is hydrochloric acid attack against concrete structures due to which there will be loss of weight and reduction in strength of concrete ultimately affecting age of the structure. Contaminated ground water, seawater, industrial effluents are some of the sources of sulphate that attack concrete .

The use of blended cements has shown a sharp results in resisting the sulphate attack on concrete. (Balaji, 2015).

The production of high performance concrete involves appropriate selection and proportioning of the constituents to produce a composite mainly characterized by its developed strength, low porosity and fine pore structure. Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The relative quantities of cement, aggregates and water mixed together, control the properties of concrete in the wet state as well as in the hardened state (Shetty, 2005).The properties of wet concrete include workability and segregation. Workability can be best defined as the amount of useful internal work necessary to produce full compaction (Neville, 2011). Segregation can be defined as separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform. In the case of concrete, it is the difference in the size of particles and in the specific gravity of the mix constituents that are the primary causes of segregation, but its extent can be controlled by the handling. It is worth noting that a higher viscosity of the fresh cement paste component militates against the downward movement of the heavier aggregate particles; consequently, mixes with low water/cement ratios are less prone to segregation (Neville, 2011). There are two forms of segregation. In the first, the coarser particles tend to separate out because they tend to travel further along a slope or to settle more than finer particles. The second form of segregation, occurring particularly in wet mixes, is manifested by the separation of grout (cement plus water) from mix with some grading, when a lean mix is used, the first type of segregation may occur if the mix is too dry; addition of water would improve the cohesion of the mix, but when the mix becomes too wet the second types of segregation would take place. If the concrete does not have to travel and is transferred directly from skip or bucket to final position in the form, the danger of segregation is small. Segregation is difficult to measure quantitatively, but is easily detected when concrete is handled on a site (Neville, 2011)

Concrete is regarded as hardened concrete when it has developed enough strength to support its self-weight and weight of imposed load within the limit of its design strength. Concrete like every other engineering material are selected based on its ability to withstand the applied force. Traditionally, the deformation occurring as a result of applied load is expressed as strain. Kumar & Monteiro (2006).Strength and durability are two properties of hardened concrete, in which strength is considered as a short term property and durability a long term property. The strength properties of concrete include compressive strength, flexural strength, split tensile strength, static modulus of elasticity, shear strength, Poisson ratio and shear modulus.

The compressive strength is by far the most important strength property used to judge the overall quality of concrete. It may often be the only strength property of the concrete that may be determined with a few exceptions almost all the properties of concrete can be related to its compressive strength. Compressive strength is usually determined by subjecting the hardened concrete, after appropriate curing, usually 28 days, to increasing compressive load until it fails by crushing, and determining the crushing force. The flexural strength is the ability to withstand bending. Concrete is generally subjected to compressive loads. However, in some instances, such as when as pavements, they are subjected to flexure. Flexural strength is determined using laboratory test on beam specimens whose lengths are at least 3 times the width and the depth by the so called three-point load method BS12930-5 (2009). The width of the beam is made equal to the depth. Split Tensile Strength; This is another property that relates indirectly to tensile strength of the concrete. It determined by subjecting a specimen 300 by 150mm diameter to increasing load along its horizontal axis until failure occurs. The modulus of elasticity relates the relationship between the applied stresses and the strain they cause. It has a direct relationship with the compressive strength, increasing as the compressive strength increases. Shetty (2005) defined durability of cement concrete as its ability to resist weathering action, chemical attacks, abrasion or any other process of deterioration. Durable concrete will retain its original form, quality and serviceability when exposed to its environment. There are many properties used as indicator of the durability of concrete. Water absorption is one of such test. In this test dry concrete sample is completely immersed in water for 24 hours. The difference between the weight before and after immersion, expressed as a percentage of the dry weight, gives the percentage water absorption. **Aggregates;** Natural rock in the form of aggregate particles typically makes up between 70- 80 percent of the volume of a normal concrete. Natural sand, gravel and crushed rock undoubtedly form a major and fundamental part of concrete and mortars. Particles of natural rock are by far the commonest form of aggregate, but recycled crushed concrete and manufactured materials such as furnace slags and expanded clay, shale or slate pellets are also used to a more limited extent. The aggregate as a material must be strong, durable and inert to give satisfactory performance, and the sizes of the constituent particles must be appropriate for the intended application. Aggregate are described as coarse aggregate, if particles are retained on a screen with 5 mm apertures, or 4 mm apertures. (Neville, 2011).

They are described as fine aggregate or sand if they pass through them. Aggregates are normally separated into size fractions by the use of a series of different sized screens, but within any fraction there will be a grading of sizes from those particles that can just pass the larger screen to the ones that are just fractionally too large to pass the smaller screen.

Rocks may be divided into three broad groups. The first, igneous rocks, are formed when molten rock material (called magma) is generated below or within the Earth's crust and crystallizes as solid rock as it cools down, either on the surface as a lava or within the Earth's crust as an intrusion. Since igneous rocks are intruded into pre-existing rocks in various ways and are now seen at the Earth's surface. The second group is sedimentary rocks which are formed by the accumulation of fragments of pre-existing rocks resulting from processes of erosion, organic debris such as shell fragments or plant material. These are the detrital sedimentary rocks, or alternatively, they may be formed as a chemical precipitate from oversaturated sea, or ground waters, the chemical and biochemical sedimentary rocks. The third group, metamorphic rocks, are formed from pre-existing rocks of any type, sedimentary or igneous, which have then been subjected to long periods of increased temperature and /or pressure within the crust. Depending on the severity and the time rocks are subjected to these high temperatures and pressures they undergo progressive changes ('metamorphism') resulting in new minerals being formed and modifications to their original appearance (Neville, 2011)

Aggregates are classified in terms of their shape. Some are rounded aggregates. Others are angular, elongated, irregular etc. in shape. The size of aggregates makes it coarse or a fine. BS 3797, (1964) and BS 877, (1967) have it that aggregates 4mm and below are considered fine aggregates while the ones above 5mm are coarse aggregates. Some aggregates are smooth in texture while others are rough.

According to Ibearugbulem (2006), University of Massachusetts (2001) reported that aggregates are subdivided into three classes. They are lightweight aggregates, normal weight aggregates and heavyweight aggregates. Bulk density and specific gravity are normally used to classify an aggregate. The bulk density and specific gravity of normal weight aggregate should not be less than 1120km/m^3 and 2.2 respectively. The specific gravity ranged from 2.2 - 4.0. Bulk density ranges from 100kg/m^3 - 1600kg/m^3,.for lightweight aggregate, the specific gravity is less than 2.2

and the bulk density is less than 960kg/m^3. The specific gravity and bulk density of heavyweight aggregate are respectively greater than 4 and 1600kg/m^3.

Aggregates that weigh less than 1120 kg/m^3 (70 lb/ft^3) are generally considered lightweight, and find application in the production of various types of lightweight concretes. The light weight of the aggregate is due to the cellular or highly porous microstructure. Natural lightweight aggregates are made by crushing igneous volcanic rocks such as pumice, scoria, or tuff. Synthetic lightweight aggregates are manufactured by thermal treatment of a variety of materials, for instance, clays, shale, slate, diatomite, pearlite, vermiculite, and blast-furnace .The utilization of supplementary cementing materials as partial replacement of cement in concrete, such as fly ash, silica fume, ricehusk ash, metakaoline and sugarcane baggasse ash is considered effective as it allows for reduction of the cement consumption while improving the concrete (Targana et al 2002). However, incorporation of metakaolin in concrete demand more water and reduce workability . Therefore, to achieve adequate workability as well as high strength, the use of a water reducer such as superplasticizer is required to improve the flow and workability of the modified concrete mix (Neville 2011).

Sugarcane baggasse ash is an agricultural material obtained after squeezing out the sweet juice in sugarcane and incinerating the residue to ash. Bagasse is the fibrous residue obtained from sugarcane after the extraction of sugar juice at sugarcane mills or sugar producing factories.(Osinubi et al; 2005; Okoroafor, et al 2017). The climatic and soil conditions favorable for the production of sugarcane are present in the Northern part of Nigeria and consequently, there is abundant production of it in the area.

Sequel to the foregoing is massive generation of sugarcane residue waste which constitutes disposal problems and requires handling. When this waste is burned under controlled conditions, it also gives ash having amorphous silica, which has pozzolanic properties. A few studies had been carried out on the ashes obtained directly from the industries for pozzolanic activity and their suitability as binders.(partially replacing cement). Therefore, it is possible to use bagasse ash (SCBA) as cement replacement material to improve quality and reduce the cost of construction materials. (Patel & Raijiwala, 2015)

1.2 Problem Statement

The basic components of concrete are water, cement, coarse aggregate, and fine aggregate. Various chemical and mineral admixtures as well as supplementary cementitious materials (in this case sugar cane bagasse ash and metakaoline) can be added. The proportions of these components will affect properties of concrete. Such properties are shear modulus, elastic modulus, compressive strength, setting time, durability, workability, creep, shrinkage, etc. Application of optimization principles in concrete produces an optimum concrete mix. Optimum mix being a mix with the required properties (which can be with respect to any of the above mentioned properties).

However, addition of sugar cane bagasse ash (SCBA) and metakaoline as stated before increases the component of concrete from four to six . This makes the orthodox method of mix design, which is used in predicting the properties of concrete such as compressive strength more tedious. The problem of identifying optimum concrete mix becomes very complicated and extremely complex. This is in agreement with the statement credited to Ippei et al. (2000), which stated thus: “this proportion problem is classified as a multi criteria optimization problem and it is of vital importance to formulate a way to solve the multi criteria optimization problem. Using the orthodox method of developing mix designs will require carrying out several trials on various mix proportion in the laboratories making it even more difficult to identify optimum concrete mix”.

The use of a model in this case Ibearugbulam model is used.

1.3 Objectives of study

The main objective of this study is to produce high strength concrete using sugarcane baggasse ash and metakaoline as partial replacement of cement. To achieve these objectives, the following specific objectives are set aside;

- **i.** To Characterize materials use for the production of high strength concrete.
- **ii.** To determine concrete mix ratio for the high concrete strength.
- **iii.** To determine the compressive strength of the produced concrete cubes produced using metakaoline and sugarcane baggasse ash.
- **iv.** To use existing mathematical models for the prediction of compressive strength of the high strength concrete.
- **v.** To determine the adequacy of the mathematical model.

1.4 Justification of Study

The following shall be derived from this research work.

i. The models used in this research work shall be of great assistance in mix design by forming the basis of trial mix designs, thus eliminating great experimental works and the high cost often associated with such ventures.

ii. The models used shall be of great help in optimizing constituents of sugarcane bagasse ash and metakaoline cement concrete to meet a desired property. Many works have been done on partial replacement of cement with pozzolans, but none have been done with the combination of sugarcane baggasse ash and metakaoline, hence this work.

1.5 Scope of Study

The scope of this study is limited to production and optimization of compressive strength of concrete made with sugarcane bagasse ash and metakaoline using a model. The work will be limited to two phase of which the first is laboratory work to generate the compressive strength of sugarcane bagasse ash and metakaoline using the optimal mix design while the second phase involves the use of the laboratory results to develop the model that can predict the optimal mix and its mix ratio. Ibearugbulem model was adopted for prediction and optimization of compressive strength of MK-SCBA cement blended concrete. To achieve this, cubes measuring 150mm x 150mm x 150mm, were cast using a mixture of sand, coarse aggregates, cement, sugarcane bagasse ash, metakaoline and water at different proportions and the mixing were done using manual method.

CHAPTER TWO

LITERATURE REVIEW

2.1 Pozzollanic Materials

Naville (1996) defined Pozzolana as a natural or artificial material containing silica in a reactive form. Pozzollana can also be defined as a siliceous and aluminous materials which in themselves possesses little or no cementations value, but will in finely divided form and the presence of moisture, chemically react with calcium hydroxide (lime) to form compounds possessing cementations properties (Bhavikatti, 2002).

2.2 The Use of Pozzollans in Concrete

Pozzollans react (consume) the calcium hydroxide generated by hydrating cement to form cementations materials, calcium hydroxide (lime) accounts for up to 25% of the hydrated Portland cement, an a lime does not contribute to the concrete's strength or durability. Pozzollans combine with the lime to produce additional calcium silicate hydrate, the material responsible for holding concrete together, by consuming the excess lime;

1. The strength of the concrete is increase
2. Its density is increase
3. Efflorescence is decreased
4. The propensity for alkali – silica (reaction with glass) is decreased, or even virtually eliminated.

2.3 High strength concrete descriptions

High strength concrete is defined as concrete that has compressive strength of 70Mpa and above (ACI). It has strength but does not necessarily possess superior characteristics as high performance concrete. Durability of high strength is commonly improved by adding pozzolanic materials. High strength concrete comprises of cement, fine and coarse aggregate, water, and water reducing admixtures . High quality control is needed in order to maintain the properties desired. High-strength concrete is achieved at low water to cement ratio, which is obtained by adding water reducing plasticizer or high range water reducing plasticizer. It is also essential to select a high quality Portland cement, and optimize aggregate, then optimize the combination of materials by varying the proportions of cement, water, aggregates and admixtures. Placement would not be easy unless superplasticizer is used. High-strength is used for high-rise buildings, bridges with long spans, and high load carrying buildings built on weak soil.

2.4 Work done on high strength concrete.

Anil Kumar Sahet al (2014) Masters in structural Engineering of Civil Engineering Department , India Institute of Technology Guwahati, India. He researched on the effect of admixtures (fly ash and superplasticizer) on the performance of concrete . The concrete mix were proportioned to have various proportion of cement replacements by fly ash ranging from 10% to 30% by weight and superplasticizer (PC250) from 0.5% to 1.5% by weight of cement. The performance of concrete was evaluated with respect to workability and compressive strength by destructive test. At 28day concrete containing fly ash and superplasticizer shows consistently higher compressive strength compared to normal concrete without fly ash.

2.5 High performance concrete descriptions.

High performance concrete (HPC) is that concrete which meets special combination of performance and uniformity requirements which cannot always be achieved routinely using conventional constituents and normal mixing and placing and curing practices. In order to produce high performance concrete, it is generally essential to use chemical and mineral admixtures in addition to the same ingredients, which are generally used for normal concrete. In recent times, many researches are going on for improving the properties of concrete with respect to strength, durability, and performance as a structural material. There are many materials like fly ash, furnace slag, foundry sand and silica fume, metakaolin, stone dust, manufactured sand etc (Anjali et al 2017) .High performance concrete can also be described according to Rajeeve (2017) as the concrete which exceeds the normal concrete properties used in the construction works. To manufacture the high performance concrete we need special materials which are combined in proper proportions for the required performance of the structures. The high performance concrete needs special mixing, placing and curing practices to produce them. These HPC is necessary for the construction of high rise building, long span bridges. To achieve this we need: high cement content, lowest water cement ratio which affect the workability of the mix. High performance concrete is a term used to describe concrete with special properties not attributed to normal concrete. High performance concrete means that the concrete has one or more of the properties; low shrinkage, low permeability, a high modulus of elasticity, or high strength (Al menhosh, 2017).

According to Henry Russell, ACI (1997) defines high performance concrete as concrete that meets special performance and uniformity requirements that cannot always be achieved routinely by using conventional materials and normal mixing, placing, and curing practices.

The requirements may involve enhancement of placement and compaction without segregation, long term mechanical properties, early age strength, toughness, volume stability, or service life in severe environments

2.5.1 Composition and features of high performance concrete.

According to Madeh (2013) the following are the compositions of high performance concrete.

Cement: Chemical and physical properties of cement can help in selecting desired cement to produce high-performance concrete. For instance, cement with low C_3A is the most desired type of cement to produce high-performance concrete because the C_3A creates incompatibility of cement with a superplasticizer.

Water: Water is a crucial component in high-performance concrete which should be compatible with cement and mineral/chemical admixtures.

Fine Aggregate: Coarse fine aggregate is desired compared to finer sand to produce high-performance concrete since finer sand increases the water demand of concrete.

Coarse Aggregate: The selection of coarse aggregate is crucial since it may control the strength of high-performance concrete.

Super plasticizer; It is an essential component of high-performance concrete that is added into the concrete mix to reduce water to cement ratio.

Cementitious Materials; The cementitious component of high or any combination of cementitious material such as slag, fly ash, silica fume.

Silica Fume: Silica fume is a waste by-product of the production of silicon and silicon alloys. Silica fume is available in different forms, of which the most commonly used now is in a densified form. In developed countries, it is already available readily blended with cement.

Fly Ash: Fly ash has been used extensively in concrete for many years. Fly ash is, unfortunately, much more variable than silica fumes in both their physical and chemical characteristics. Most fly ashes will result in strengths of not more than 70 MPa. Therefore, for higher strengths, silica fume must be used in conjunction with fly ash. For high strength concrete, fly ash is used at dosage rates of about 15 % of cement content.

Ground Granulated Blast Furnace Slag (GGBFS)

Slags are suitable for use in high-strength concrete at dosage rates between 15-30 %. However, for very high strengths, more than 98Mpa, it is necessary to use the slag in conjunction with silica fumes

Features of High-Performance Concrete; The following are the features of high-performance concrete.

i. Compressive strength > 80 MPa ,even up to 800 MPa
ii. High-performance concrete is quite brittle.
iii. Improve ductility.
iv. High durability
v. Water binder ratio (0.25-0.35), therefore very little free water
vi. Reduced flocculation of cement grains
vii. Wide range of grain sizes
viii. Densified cement paste
ix. Low bleeding and plastic shrinkage
x. Less capillary porosity is achieved through the use of low water to cementitious materials that produce dense microstructure, hence migration of aggressive elements would be difficult. Hence, durability improved greatly.
xi. Discontinuous pores
xii. Stronger transition zone at the interface between cement paste and aggregate
xiii. Low free lime content
xiv. Endogenous shrinkage
xv. Powerful confinement of aggregates
xvi. Little micro-cracking
xvii. Smooth fracture surface
xviii. Low heat of hydration

2.6 Metakaolin in concrete:

Metakaolin (MK) has been commercially available since the mid-1990s. It has become one of the new materials, which has been used recently as a SCM in the field of civil engineering applications, that conforms to ASTM C 618, Class N Pozzolanas Specifications as shown in Table 2.1 (Siddique, 2007; Ramezanianpour, 2014). The use of metakaolin in concrete is relatively new, and it is being investigated because of its high pozzolanic properties, making it possible to modify the concrete properties to suit the desired application, as analysed by Moiseas and Joseph (2000). Nevertheless, the 'meta' prefix in the term is used to denote change. In the case of metakaolin, the change that is taking place is dehydroxylisation (Siddique, 2007; Ramezanianpour, 2014). Kaolin clay is the raw material input in the production of metakaolin (Al2Si2O7). Kaolin is a fine, white, clay mineral that has been used in the production of porcelain. Kaolinite is the mineralogical term that is applicable to kaolin clays. Kaolinite is defined as a mineral, with desilicated hydrated aluminium being its most common component. The average size of the metakaolin particles is quite small, being around three μm. Its colour is off-white. Physical properties of metakaolin are shown in Table 2.2. The main contents of metakaolin are silica oxide (SiO2) and alumina oxide (Al2O3), in addition to ferric oxide, calcium oxide, magnesium oxide, potassium oxide, etc. The chemical contents of metakaolin are shown in Table 2.3 (Siddique & Khan, 2011).

Table 2.1: Requirements of metakaolin (ASTM C 618) (Siddique, 2007)

Modified specification requirements	Limit
Item	
Silicon dioxide (SiO2) plus aluminium oxide (Al2O3) plus iron oxide	Min 85%
Available alkalis	Max 1.0%
Loss on Ignition	Max 3.0%
Fineness: amount retained when wet-sieved on 45μm sieve	Max 1.0%
Strength activity index at 7 days (% of control)	85
Increase of drying shrinkage of mortar bars at 28 days	Max 0.03%

Table 2.2: Physical properties of metakaolin (Siddique and Khan, 2011)

Property	(Poon et al., 2001)	(Al-Akhras, 2006)	(Tafraoui et al., 2009)
Specific gravity	2.62	2.5	2.5
Average particle Fineness		1	12
(m2/kg)	12680	12000	15000-30000
Colour		White	

Table 2.3: Typical chemical composition of the metakaolin (Siddique, 2011)

Chemical composition	Ambroise et al. (1994)	Wild and Khatib (1997)	Tafraoui et al. (2009)	Thomas (2013)
SiO_2	51.52	52.1	58.10	52
Al_2O_3	40.18	41.0	35.14	45
Fe_2O_3	1.23	4.32	1.21	0.6
CaO	2.00	0.07	1.15	0.05
MgO	0.12	0.19	0.20	–
K_2O	0.53	0.63	1.05	0.16
SO_3	–	–	0.03	–
Na_2O	0.08	0.26	0.07	0.21
L.O.I	2.01	0.60	1.85	0.51

In an investigation by Khatib et al. (1996), pore size distribution and porosity of modified concrete were observed with partial replacement of ordinary Portland cement by metakaolin at 0, 5, 10 and 15% and w/c ratio 0.55. The samples were under moist curing for the period up to 12 months. It was found that the rate of large pores in the concrete paste reduces with increase in metakaolin percentage and curing time. Partial replacement of cement by metakaolin up to 20% reduces the water absorption by capillary effect due to the filler effect of fine metakaolin particles. Previous studies, as reported by Bredy et al. (1989), showed that when the partial replacement with metakaolin was below 20%, the total porosity of the concrete decreased. Beyond 30%, the porosity of the modified concrete increased, which could be due to the using of metakaolin, required more water/cement ratios due to high reactivity of the pozzolanic components in metakaolin. The development of the strength quality of the hardened concrete made by partial replacement of cement by metakaolin is influenced by three elementary effects. They are the filler influence, acceleration of the hydration of cement, and the metakaolin pozzolanic effect with CH as observed by Wild et al. (1996). This is consistent with the investigation of Khatib and Wild (1998) who performed experimental investigations on the influence of metakaolin on the sulphate resistance of mortar. Cements of high C_3A and intermediate C_3A were used, with partial replacement of cement by metakaolin at 5, 10, 15, 20 and 25%. Prisms of size 25 × 25× 285 mm were moist cured in air for two weeks, and their length was measured before immersing in 5% Na2So4 solution. The result showed the expansion and deterioration decreased significantly with increase in metakaolin level for both types of cement. At least 15% metakaolin replacement with cement is the optimum replacement to provide good sulphate resistance. The agreement with similar work on metakaolin replacement by Wild and Khatib (1997). They observed that removal of (CH) by pozzolanic action reached a maximum at about 14 days. This is critical, as (CH) can be detrimental to the durability of concrete and does not significantly contribute to concrete strength; the reduction of the (CH) by the secondary reaction with the metakaolin greatly improves the concrete strength. The alkali activation of metakaolin is a way to improve strength of cementitious materials, as mentioned by Palomo et al. (1999).

Moiseas & Joseph (2000) observed the degree of hydration of partial replacement by metakaolin at 0, 10, 15, 20, and 25% of cement by weight, with W/C ratio 0.55. The degree of hydration of metakaolin pastes was specified in terms of total amount of calcium present in the hydrated process. The calcium hydroxide percentage at different times up to 360 days is shown in Figure 2.1. This shows that the calcium hydroxide amount in specimens generally decreased with the increase of metakaolin level. For the mixes of 10% and 15% metakaolin replacement, an inflexion point at 56 and 90 days, respectively, was observed. After this point, the calcium hydroxide content increased again. The variation of calcium hydroxide content was due to different hydration mechanisms: the increase in the (CH) level is due to the cement hydration, while the diminishing in the values is related to the pozzolanic effects of metakaolin. The inflexion points (for 10% and 15% metakaolin) represent the end of the pozzolanic reaction, due to the total consumption of metakaolin.

In a different study, Srinivasu et al. (2014) discussed the significant relationship between the metakaolin level and the concrete properties. It was emphasised that the inclusion of metakaolin in the concrete led to a 25% increase in strength and enhanced durability. Metakaolin increases the density of the concrete, which displays a low water permeability and sorptivity. It is also improving the acid resistance of the concrete and decreases the chloride penetration. In another study, Khatib et al. (2014) examined that the ‘the properties of the fly ash paste activated by lime and metakaolin, are affected by the metakaolin level and curing time, compared with the paste without metakaolin. Meanwhile, and with the same objective, Kannan & Ganesan (2014) showed similar results. Results of experimental research by Marinos et al. (2015) also point towards improvement in strength and durability of concrete by the partial replacement of cement by metakaolin by mass. Partial replacement of 10% of cement by metakaolin resulted in decreased chloride permeability and increased compressive strength. At a higher level of replacement, chloride penetration further decreased, at the expense of compressive strength. The higher the volume of pozzolanic materials, like metakaolin, in the binder, the higher the carbonation of the micro concrete, due to the low available amount of $Ca(OH)_2$ in the matrix.

Recently, Narmatha & Felixkala (2017), have shown an increased interest in using metakaolin in concrete structures due to its effect on improving concrete properties. The increase in metakaolin content improves the compressive strength and splitting tensile strength up to 15% cement replacement. The results encourage the use of metakaolin, as a pozzolanic material for partial replacement in producing high performance concrete.

2.6.1 Uses of metakaolin in concrete

Metakaolin is used in the following concrete applications as mentioned by (Siddique and Khan, 2011; Bapat, 2012):

i. High performance concrete, high quality concrete, and lightweight concrete
ii. Precast concrete for architectural, civil, industrial, and structural purposes
iii. Fibre cement and Ferro cement products
iv. Glass fibre reinforced concrete
v. Repair material, pool plasters
vi. Improved finish ability, colour and appearance.

2.6.2 Advantages of metakaolin in concrete

There are four major advantages to using metakaolin in concrete, they are (Siddique & Khan, 2011; Bapat, 2012):

i. Increased compressive and flexural strengths
ii. Improved the early age strength of concrete
iii. Improved durability by reducing permeability and improving the resistance to chemical attack
iv. Reduced shrinkage due to particle packing and increased concrete density
v. Reduced effects of alkali-silica reactivity

2.6.3 Disadvantages of Metakaolin in Concrete

i. Reduced workability of concrete mix with increased metakaolin level in concrete.

ii. The reaction between the metakaolin component and the by-products of the cement hydration process requires more water than the hydration cement in the conventional concrete.

2.7 Concrete Additives

Concrete admixtures (additives) enhances the properties of concrete for applications in construction with special requirements. Concrete additives are used to achieve desired workability I n case of low water cement ratio, and to enhance setting time of concrete for long distance transportation of concrete.

So, it is of much importance for a civil site engineer to know about the types of admixtures (additives) and their properties for better selection and application in concrete works.

BIS (IS – 9103: 1999) Page No.1, defined concrete admixture as a material other than water, aggregates and hydraulic cement and additives like Pozzolana or slag and fiber reinforcement, used as on ingredient of concrete or mortar and added to the batch immediately before or during its mixing to modify one or more of the properties of concrete in the plastic or hardened state.

2.7.1 Brief History of Admixtures

Historically, Admixtures are almost as old as concrete itself. It is known that the Romans used animal fat, milk and blood to improve their concrete properties. Although these were added to improve workability, blood is a very effective air-entraining agent and might well have improved the durability of Roman concrete, in more recent times; calcium chloride was often used to accelerate hydration of cement. Nowadays admixtures are important and necessary components for modern concrete technology. The concrete properties, both in fresh and hardened states, can be modified or improved by a admixture (Parker, 1995).

2.7.2 :Uses of Admixtures

i. Increase workability without increasing water content or decrease water content at the same workability.
ii. Retard or accelerate time of initial setting.
iii. Reduce or prevent settlement.
iv. Modify the rate or capacity for bleedings.
v. Reduce segregation.
vi. Improve pumpability.
vii. Reduce the rate of slump loss.

viii. Retard or reduce heat evaluation during early hardening.
ix. Accelerate the rate of strength development at early ages.
x. Increase strength (compressive, tensile or flexural).
xi. Increase durability or resistance to severe condition of exposure.
xii. Decrease permeability of concrete.
xiii. Control expansion caused by the reaction of alkalies with certain aggregate constituents.
xiv. Increase bond of concrete.
xv. Increase bond between existing and new concrete.
xvi. Improve impact resistance and abrasion resistance.
xvii. Inhibit corrosion of embedded metal.

2.7.3 Types of admixtures

The main types of admixtures in general use are: accelerators; set retarders;water-reducers/workability aids/plasticizers; superplasticizers; air-entraining admixtures; pigments. It should be noted that BS 8110—the Structural Use of Concrete, refers to pigments as an admixture.

BS 5075: Part 1, defines an accelerating admixture as: A material that increases the initial rate of reaction between cement and water & thereby accelerates the setting

Set retarders ;A retarding admixture is defined in BS 5075: Part 1 as: A material that decreases the initial rate of reaction between cement and water and thereby retards the setting of concrete.

Plasticizers; For concrete, these admixtures are covered by BS 5075: Part 1 which defines a' normal water-reducing admixture' as: A material that increases the fluidity of the cement paste without significantly affecting the air content and thereby increases the workability of the concrete at constant water/cement ratio, or permits concrete to be made with a decreased amount of water while maintaining equal workability, with a consequent increase in strength.

The Standard also covers 'accelerating water-reducing admixtures' and 'retarding water-reducing admixtures'. These admixtures combine the two described

Superplasticizing admixtures; These admixtures are covered by BS 5075: Part 3, defines such admixtures as: An admixture, that when added to a hydraulic binder concrete, imparts very high workability or allows a large decrease in water content for a given workability.

The increase in workability is dramatic, as the concrete flows, and this is measured as described in BS 1881: Part 105. This super workability only lasts for a limited period, generally about two to four hours. The very high workability obtained (150–200mm slump) ensures that the concrete is virtually self-compacting. Concrete containing superplasticizers is used for a number of purposes which include: ultra-high strength concrete; placing concrete in locations where compaction is difficult, for example, in members containing congested reinforcement; for laying large floor areas in a continuous operation with a comparatively small labor force. The basic principles underlying the improvement in workability in normalplasticizing admixtures apply to superplasticizers but on a much greater scale.

Simply expressed, the admixture particles are negatively charged and are adsorbed onto the surface of the hydrating cement particles, which also become negatively charged. As negatively charged particles repel each other, the cement particles are dispersed and workability thereby is greatly increased.

The two main basic types of superplasticizers are sulphonated naphthalene-formaldehyde condensates, and sulphonated melamine formaldehyde condensates.

Air entraining admixtures

This type of admixture is defined in BS 5075: Part 2 as: An admixture that causes a controlled and stable quantity of air to be incorporated during the mixing of concrete, without significantly effecting the setting of the concrete.

The action of the entrained air is to either reduce the water requirement of the

mix with constant workability or to increase the workability with a constant water/cement ratio. The presence of the entrained air also increases there assistance of the concrete to freezing and thawing (frost attack)

2.8 Selection of Concrete Admixtures

Concrete admixtures shall be selected carefully as per the specifications and shall be used as recommended by the manufacturer or by lab testing report. The quantity of admixtures to be used for specific application of admixtures are recommended by the manufacturers.

For use in large construction projects, the quantity of the admixture to be used shall be obtained from tests reports for concrete mixed with admixtures at various percentage admixtures use. These tests are conducted to understand the behaviour of admixtures on the desired quality and strength of concrete at different quantity of admixtures used. Thus, the optimum quantity of admixtures can be selected for specific application based on results.

The selection of specific admixtures for use in concrete to alter properties of concrete should be selected carefully as per requirement of concrete works. Concrete admixtures should be used judiciously according to specification and method of application to avoid adverse effect on concrete properties at fresh and hardened state.

After selecting the admixtures product, one should carefully choose the supplier with quality product, timely service and at competitive price. The admixture supplier should be with good history and should possess the staff with efficient and professional experience to guide on effective application/use of admixture in right way. Concrete admixtures should be accepted with test certificate, manufacturing date and its chemical composition, should comply specifications given by the authorities.

2.8.1 Review of the use of admixtures in concrete production;

Recently, Hossain et al. (2016) gave a comprehensive review on the development of sustainable binders through the use of pozzolanic materials, such as slag, fly ash, palm oil fuel ash, metakaolin, silica fume, rice husk ash etc, as partial replacement in cement. Supplementary cementing materials have an important role, when combined into cement system in a certain proportion, in the mortar and concrete properties. Based on the outcomes of the reviewed research, it is observed that the partial replacement of supplementary cementing materials improves morta and concrete properties by refinement of the pores system and the pozzolanic reactions. As consequence, concrete exhibited significant enhanced reinforcement corrosion, and chemical and sulphate resistance, and reduced chloride and carbon dioxide penetration.

A study by Palou et al. (2016) investigated the effects of four compound systems consisting of Portland cement and three supplementary cementing materials; silica fume, blast furnace slag, and metakaolin, on the hydration progress. The pozzolanic activity of the supplementary cementing increased the strength properties of blended concrete and thus overcame the dilution action especially when cured for a long time . The quadrilateral blended mixture showed formation of more thermal stable hydration products in comparison with conventional portland cement meaning the supplementary cementing materials can be considered as promising materials for the enhancement of special concrete and also for hydrothermal application.

2.8.2 Sugarcane bagasse in concrete;

Otuoze et al (2015) had investigated on "Characterization of Sugar Cane Bagasse ash and ordinary Portland Cement blends in Concrete" , The SCBA is obtained by burning Sugar cane Bagasse at between 600-700 degrees Celsius. For strength test , mix ratio of 1:2:4 was used and OPC was partially replaced with 0% ,5%, 10%, 15%, 20%, 25%, 30%, 35%, 40% by weight in concrete. Compressive strength values of hardened concrete were obtained at the ages of 7,14,21,28 days. Based on the test conducted, it can be concluded that SCBA is a good pozzolana. for concrete cementation and partial blends of it with OPC could give good strength development and other engineering properties in concrete. An optimum of 10% SCBA blends with OPC could be used for reinforced concrete with dense aggregate. Higher blends of 15% and up to 35% of SCBA with OPC are acceptable for plane or mass concrete. The value fell short of meeting requirements for reinforced concrete with dense aggregate because of excessive fines from increasing SCBA and reducing Strength of bonding.

Lavanya et al.(2012), had studied on "A Experimental Study on the Compressive Strength of Concrete by Partial replacement of Cement with Sugar cane bagasse ash". The Feasibility of using sugar cane bagasse ash, a finely grounded waste product from the sugarcane industry, as partial replacement for cement in conventional concrete is examined. The test were conducted as per Bureau of Indian Standard (BIS) codes to evaluate the stability of SCBA for partial replacement up to 30% of cement with varying water cement (W/C) ratio. They showed that addition of SCBA results in improvement of strength in all cases and according o the results obtained, it can be concluded that Bagasse ash can increase the overall strength of concrete when used up to a 15% cement replacement level with W/C ratio of 0.35, bagasse ash is a valuable pozzolanic material and it can potentially be used as a partial replacement for cement.

Srinivasan et al.(2019),has investigated on "Experimental Study on Bagasse Ash in Concrete". They had observed that Sugar Cane bagasse is fibrous waste-Product of sugar refining industry, and causing serious environmental problem which mainly contain aluminium ion and silica. Hear bagasse ash has been chemically and physically characterized, and partially replaced in the ratio of 0%, 5%, 15%, 25% by weight of cement in concrete. Fresh concrete tests like compaction factor test and slump cone test were undertaken, was well as hardened concrete test like compressive strength , split tensile strength, flexural strength and modulus of elasticity at the age of seven and 28 days was done. The results show that the SCBA in blended concrete had significantly higher compressive strength, tensile strength, and flexural strength compare to that of the concrete without SCBA. It is found that cement could be advantageously replaced with SCBA up to maximum limit of 10%. Partial replacement of cement by SCBA increases workability of fresh concrete; therefore use of superplasticizer is not substantial. The density of concrete decreases with increase in SCBA content.

Arif et al (2016). studied the effects of sugarcan bagasse ash on the flexural strength of concrete, he substituted the sand with SCBA in both stage one and stage two concrete with the water/binder (W/B) ratio of 0.45 by cement weight. There was no superplaticizer in stage one , so the specified slump varied. For stage two, a superplaticizer was added to maintain the same workability .the flexural strength of stage one increased with increasing SCBA content and age . however, the flexural strength of the stage two concrete did not greatly differ from the flexural strength of the control.

Rerkpiboon et al (2015). found that concrete with up to 50% SCBA incorporated had an elasticity modulus similar to that of the control concrete . however, Srinivasan et al (2010) . found that with increasing SCBA replacement level, the elasticity modulus decreased . The researchers thought there were two reasons for this result: i. Improper SCBA dispersion formed weaker zones, causing the elasticity modulus decreased of the concrete and ii. the amount of SCBA exceeded the amount required to react $ca(OH)_2$. The excess amount of un reacted silica caused a decreased in strength and elasticity modulus.

Some researchers found the concrete porosity was higher with different SCBA replacement levels than that of control concrete without SCBA.

(Tantawy et al , 2012., Rukzon, et al, 2012)Incorporation of a large amount of SCBA decreases the amount of OPC used and increases the mixing water amount, which leads to a high concrete total porosity (Tantawy,.2012). The fine SCBA particles segment means that the more SCBA that was used in the concrete, the greater the porosity of large pores and generate nucleation sites for hydration product precipitation (Rukzon,. 2012).The SCBA refined the pore structure and reduced Ca(OH)2 from the hydration reactivity in the paste, although the porosity increased. With a prolonged curing time, the porosities of the concretes declined because of the continuous hydration of cementitious materials (Tantawy.,2012).The narrow thickness of the interfacial transition zone (ITZ) leads to higher compression because the bond between the cement paste and aggregate becomes stronger. Due to fineness and pozzolanic reactivity, SCBA refined the pore sizes and densified the interfacial zone, and the ITZ thickness was obviously reduced at a replacement level of less than 30%. This result can clearly be confirmed by the improved compressive strength results (Hussein, et al, 2014). Incorporating SCBA into concrete narrows the ITZ thickness, and increases the elasticity modulus and hardness of the ITZ (Rossignolo, et al, 2017).

2.8.3 Effects on Concrete Durability

Many studies have found that SCBA could increase concrete durability (Joshaghani, et al., 2016, Rerkpiboon, et al., 2015, Bahurudeen et al. 2014). Bahurudeen et al. (2014). found that concrete blended with SCBA had a superior performance in oxygen and Torrentair permeability after 28 days of curing, and the permeability performance further improved during56 days of curing as a result of pozzolanic reactions .Bahurudeen et al (2014).Also found that the water penetration of the SCBA-blended concrete significantly reduced after both 28 and 56 days of curing . Ganesan et al. found that the water absorption percentage increased in the presence of SCBA during 28 days of curing, which is possibly due to the fact that SCBA is hygroscopic in nature and finer than OPC. However, the water absorption

percentage decreased obviously (50%) after 90 days of curing. This result is due to the addition ofSCBA that decreased permeable voids and the gradual closing of pores (Ganesan, et al., 2009). Evidently, the use ofSCBA significantly improves the resistance of concrete to water penetration.

2.8.4 Mechanical and Microstructural Properties

In general, SC**B**A concrete shows an excellent performance when SCBA partially replaces cement. There are two main reasons: (a) the high amorphous silica content in SCBA triggers pozzolanic reactivity and (b) the ultrafine particle sizes of the SCBA significantly improve the microstructure, leading to a high early strength (Hussein, et al., 2014, Srinivasan et al., 2010, Chusilp et al., 2009, Ganesan et al., 2007).Many researchers found that the compressive strength of concrete with SCBA increased first and then decreased when the replacement ratio was increased. The optimal replacement ratio for compressive strength was different in previous research, for example, 15% (Gar et al., 2017), 20% (Ganesan et al., 2007, Rerkpiboon et al., 2015),and 25% (Bahurudeen et al., 2015, Montarntiwong et al., 2013). It was found that concrete with 50% ground SCBA reached at least 90% of the control concretes' compressive strength at the age of 28 days

(Rerkpiboon et al., 2015).

2.8.5 Some of the research works done on high performance concrete:

In 2016, Muthukumar T & Sirajudeen K investigated on high performance concrete using alternate materials". They performed the experimental investigation on high performance concrete using M_{50} grade mix proportion. High performance concrete achieved by, 100% replace the fine aggregate by crusher wash sand and partial replacement of cement by micro silica (i.e., 5%, 10%, 15%, 20% & 25%). Glenium b233 were added for workability of concrete mix. A result data obtained has been analyzed and compared with a control specimen. A relationship between Compressive strength vs. days, Tensile strength vs. days, and Flexural strength vs. days represented graphically. Result data clearly shows percentage increase in 7 and 28 days Compressive strength, Tensile strength and Flexural strength for M-50 Grade of Concrete. Combination of micro silica, crusher wash sand and super plasticizer in this experimental study show a great improvement in the compressive strength as well as tensile properties .Cement was replaced by micro silica by 20%, however strength increases by 16.5%. High Performance Concrete strength is achievable using micro silica.

Ranjitham & Vennila (2014), "Experimental Investigation on High Performance Concrete with Partial Replacement of fine aggregate by Foundry Sand with cement by Mineral Admixtures" They have prepared this paper based on the experimental investigation of high performance concrete with partial replacement of fine aggregate by foundry sand with cement by mineral admixtures. In this project, investigations were carried out on strength properties such as compressive strength, split tensile strength and flexural strength of M_{75} grade of HPC mixes with different replacement levels such as 10%, 20%, and 30% of foundry sand with fine aggregate and 10%, 20%, 30% and replacing cement by mineral admixtures such as fly ash and ground granulated blast furnace slag by adopting water-binder ratio of 0.3.

Conplast SP430 is based on Sulphonated Napthalene Polymers can be used as a super plasticizer for better workability for high performance concrete. In this study it has been found that adding optimum superplasticizers dosage the workability is reached. So that the required slump value can be obtained for HPC. The slump value for M75 grade using foundry sand and fly ash is reduced. For 30% fly ash and 30% ground granulated blast furnace slag (GGBS) replacement, the fresh properties observed were good as compared to 10%, 20%replacement.The presence of foundry sand and mineral admixtures increasing the compressive strength and also withstanding the maximum load. Compare to fly ash GGBS attains good strength as cement replacement. Dhondiram et al. (2009), "Experimental Study on High Performance Concrete"

In this paper they researched the results of study on silica fume based high performance concrete. The attempt has been made to compare, the 7 days and 28 days compressive strength, splitting tensile strength and flexural strength of concrete by using silicafume with the normal concrete of M_{60} grade with maintaining the water cement ratio 0.3. The objective of this study is to develop concrete with good strength, less porous, less capillarity, so that durability will be reached. For this purpose, the experiment has been carried out on m60 grade of concrete, using silica fume in different percentage 0%, 5%, 10%, 15% to the weight of cement. The maximum replacement level of silica fume is 10% for M60grade of concrete. Use of silica fume gives significant result on properties of concrete as compared to normal concrete.

2.8.6 Concrete mix models

The addition of sugar cane bagase ash (SCBA) and metakaolin increases the component of concrete from four to six. This makes the orthodox method of mix design, which is used in predicting the properties of concrete such as compressive strength more tedious (Okoroafor, 2017).The problem of identifying optimum concrete mix becomes very complicated and extremely complex. This is in agreement with the statement credited to Ippei et al (2000), which stated thus: "this proportion problem is classified as a multi criteria optimization problem and it is of vital importance to formulate a way to solve the multi criteria optimization problem. Using the orthodox method of developing mix designs will require carrying out several trials on various mix proportion in the laboratories making even more difficult to identify optimum concrete mix". The problem of identifying optimum concrete mix becomes very complicated and extremely complex. In order to obtain concrete of desired and suitable strength, technical personnel often try several mix proportions, which is a time consuming process, resulting in wastage of material and the cost of concrete production. Thus, for the sake of saving time and decreasing the design cost, help of fuzzy logic is taken to develop models, so that the knowledge extracted from these fuzzy logic model, can be utilized to predict the strength of concrete made with sugar cane bagasse Ash. The basic strategy for developing a fuzzy logic based model for predicting concrete compressive strength is to train a network on the results of a series of experiments, thus, minimizing the absolute difference between the target (desired) outputs and the actual outputs, thereby, resulting in approximate optimal solutions (Flood and Kartam 1994).

Several works have addressed the application of networks systems in material modeling. Snell and Roekel (1989) developed an automatic knowledge based on a multilayer feed-forward principle for mix designs. Oh, et al. (1999) used a back-propagation network for concrete mixes. Lai and Serra (1997) developed a neuro-computing model for predicting with sufficient accuracy the compressive strength of cement conglomerates. Brown et al. (1991) demonstrated the applicability of neural networks for composite material characterization**.** Ghaboussi et al. (1991) modeled the behavior of concrete under a state of plane stress using monotonic biaxial loading and compressive uniaxial loading with a back propagation neural network. Palika et al. (2015) developed artificial neural network for predicting the compressive strength of concrete. Abhijit and Sudip (1990) developed Artificial neural networks in prediction of mechanical behavior of concrete at high temperature. Several other authors have used ANNs in structural engineering. For example, Yeh (1998), Kasperkiewicz et al. (1995), Lai and Sera (1997) and Lee (2003) applied the Neural Network for predicting properties of conventional concrete and high performance concretes. Fa-Lang (1997) presented a new way of predicting cement strength by the use of fuzzy logic model. Bai et al. (2003) developed neural network models that provide effective predictive capability with respect to the workability of concrete incorporating metakaolin (MK) and fly ash (FA). Guang & Zong (2000) proposed a method to predict 28-day compressive strength of concrete by using multilayer feed forward neural networks. Dias & Pooliyadda (2001) used back propagation neural networks to predict the strength and slump of ready mixed concrete and high strength concrete, in which chemical admixtures and mineral additives were use. Demir (2005) carried out research on the prediction of elastic modulus of normal and high strength concrete using fuzzy logic model. Harun & Ahmet (2007) investigated the use of fuzzy logic model for prediction of compressive strength of lightweight concrete made with scoria aggregate and fly ash; Their result were compared with that predicted using artificial neural network, they concluded that fuzzy logic model is more user friendly and also give equivalent results like ANN model.

Other methods of optimization of concrete are discussed as follows:

2.8.7 Scheffe’s Method

Scheffe’s method has been widely been used in civil engineering materials research in recent past. It is a statistical approach of optimization name after its developer, Henry Scheff’e, an American born statistician and mathematician.

Scheffe's method is a method of adjusting significance levels in a linear regression analysis to account for multiple comparisons. It is particularly useful in analysis of variance , and in constructing simultaneous confidence bands for regressions involving basis functions (Wikipedia 2007) . It is single step multiple comparison procedure which applies to the set of estimates of all possible contrasts among the factor level.

Interestingly, this technique has been widely applied in analysis, modeling and optimization problems in civil engineering over the years.

test (RCT) less than 700 coulombs, and minimum cost. The materials (Scheffe's method was used by US development of transportation to design and optimize proportions for high performance concrete (HPC) mix that will meet the following conditions: slump of 50 to 100mm, 1-day compressive strength of 22.06mpa, 28-day compressive strength of 51.02mpa and materials (ASTM) C1202 'rapid chloride components) used included water, cement, silica fume, high-range water reducing admixture, coarse aggregate, and fine aggregate. The result proved highly dependable (Neville, 2004) Ndububa (2004) employed this method in his research titled, Mathematical Modeling and optimization of strength of fibre cement mixtures and the result was successful . Equally, Onyeyili (2008) used this method in his PhD research titled, Mathematical modeling of the flexural and crushing strength of concrete as a multivariate function of its constituent variables. Scheffe's method of optimization involves a real valued function on the simplex called 'response'. The proportions of the concrete ingredients or the target strength could be a response. Lets us take the case of ingredients of concrete with water-cement ratio, cement, sand and coarse aggregate represented by x_1, x_2, x_3 and x_4 respectivel**y.**

If we assume the mixture to be a unit quantity, then the sum of all the proportions of the components must be unity, thus:

$$x_{1+}, x_{2+}, x_3+x_4 =1 \qquad (2.1)$$

The total mass or volume of the concrete mixture is fixed with the factors or components comprising the whole and the sum of the volume fractions is restricted to sum to unity and the component variables i.e. ingredients are dependent.

Scheffe's simplex lattice can be stated as follows, for the properties a q-component mixture which depend only on component ratio, the space is a regular (q – 1) simplex and for the mixture the relationship holds.

$$\sum_{i=1}^{q} \text{xi} = 1 \qquad (2.2)$$

Where xi≥0 is the component fraction and q is the number of components.

A simplex is a graphical representation of the lines or planes joining the assumed positions (points) of the constituent materials of a mixture (Ramachandran, 2006)

2.8.8 Osadebe's Regression model;

Osadebe's regression model is a modified regression theory and a form of mixture experiment which is a general technique for modeling relationships between responses and components of a mixture. Mixture experiment techniques are mainly for case where responses depend on the mass or volume proportions of individual components and not on their total mass or volume . This is typical concrete properties.

Let us consider an arbitrary amount, S of a given mixture with q components. Let the proportion of the component of the mixture be Si. Then from the principle of absolute volume (or mass).

S1+S2+……….+Sq =S or

$$\frac{s1}{s}+\frac{s2}{s}+\ldots\ldots+\frac{sq}{s}=1 \qquad (2.3)$$

Where $\frac{si}{s}$ is the proportion of the ith constituent of the mixture

Let $\frac{si}{s}$ =zi (2.4)

Therefore, substituting Equation (2.3) into Equation (2.4) yields;

$$Z1 + Z2 + \ldots Zq = \sum_{i=1}^{q} Z = 1 \qquad (2.5)$$

2.8.9 Ibearugbulem Method

Ibearugbulem method has been widely been used in civil engineering materials research in recent past. Interestingly, this technique has been widely applied in analysis, modeling and optimization problems in civil engineering over the years. This method was used to design and optimize proportions for high performance concrete (HPC) mix that will meet the following conditions : slump of 50 to 100mm, 28-day compressive strength of 22.06mpa, 60-day compressive strength of 47.02mpa and materials used included water, cement, sugarcane bagasse ash, calcine clay, high-range water reducing admixture, coarse aggregate, and fine aggregate. The result proved highly dependable.

The response function adopted in this method is a quadratic function of the component proportions given as:

$$y = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5{x_1}^2 + a_6{x_2}^2 + a_7{x_3}^2 + a_8{x_4}^2 + a_9x_1x_2 + a_{10}x_1x_3 + a_{11}x_1x_4 + a_{12}x_2x_3 + a_{13}x_2x_4 + a_{14}x_3x_4 \qquad (2.6)$$

That is:

$$y = [x_i][a_i] \quad (2.7)$$

Equation was used to obtain the array response equation for the set of mix ratios used in the formulation as:

$$[y^k] = [x_i{}^k][a_i] \quad (2.8)$$

Where k denotes the mix number (or observation point number); [a_i] is the coefficient vector, and [x_i] is the shape function vector. They are:

$$[a_i] =, [a_1 a_2 a_3 a_4 a_5 a_6 a_7 a_8 a_9 a_{10} a_{11} a_{12} a_{13} a_{14}]^T \quad (2.9)$$

$$[x_i] = [x_1 x_2 x_3 x_4 x_1{}^2 x_2{}^2 x_3{}^2 x_4{}^2 x_1 x_2 x_1 x_3 x_1 x_4 x_2 x_3 x_2 x_4 x_3 x_4] \quad (2.10)$$

Pre-multiplying both sides of Equation with a weighting function (transpose of the shape function) for the set of mixes for the formulation gives the weighted response equation (WRE) as:

$$[x_i{}^k]^T[y^k] = [x_i{}^k]^T.[x_i{}^k][a_i] \quad (2.11)$$

This multiplication did not change the generality of the regression function as the weighting function can easily cancel out from both the left and right hand sides of equation. It is clear from here that the approach used in the original work of Ibearugbulem model (Ibearugbulem et al., 2013) is weighted response approach (WRA).

The weighted response equation can be rewritten as:

$$[F] = [CC][a_i] \quad (2.12)$$

Where the weighted response vector, F and CC matrix are defined as:

$$F = [x_i{}^k]^T[y\ ^k] \quad (2.13)$$

$$[CC] = [x_i{}^k]^T.[x_i{}^k] \quad (2.14)$$

In simpler words, [CC] is the matrix whose arbitrary element CC_{ij} is obtained by array multiplication of transpose of Column "i" with Column "j" of the shape function vector.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Material

The materials used in this work includes; water, super plasticizer, cement, sand, metakolin, sugarcane bagasse ash and granite gravel.

3.1.1 Water

Water used for this research work was obtained from a borehole within the premises of Federal University of Technology, Owerri, Imo State. The water is potable and conforming to the standard of BS EN 1008: (2002). Since it meets the standard for drinking, it is also good for making concrete and curing concrete.

3.1.2 Super plasticizer (conplast SP430)

Super plasticizer is a chemical admixture for improved workability and it was secured from Lagos state. This admixtures was covered by BS 5075: Part 3.

3.1.3 Cement

Dangote brand of ordinary Portland cement which conforms to the requirements of BS EN197-1:2000 was obtained from dealer in Owerri.

(a) Cement used : OPC 42.5 grade

(b) Specific gravity of cement : 3.15

3.1.4 Sand

Granular river sand obtained from Otammiri River in Owerri was used. It was relatively clean devoid of deleterious materials and therefore did not require further washing. The grain sizes were graded and recorded, also the specific gravity of the sand was determined. The maximum size of fine aggregate used is 5mm.The specific gravity

3.1.5 Metakolin

Clay was obtained from Mbaise, in Imo state. The sample was just clay, it was kept in isolated cool room to avoid contamination with chemicals or anything that may affect its properties. The specific gravity of metakaolin was determined and recorded.

(c) Calcined clay used : (Calcined clay conforming to EN 197)

(d) Specific gravity of clay : 2.07

3.1.6 Sugarcane bagasse ash

Sugarcane waste was brought from sugarcane deport at Avu junction Port Harcourt Road, The chaff was burntin anopen drum to a red hot state. The ash was sieved. The specific gravity of the ash was determined as 1.62.

3.1.7 Granite gravel;

The coarse aggregates used for this work was purchased from tipper stand at Owerri, Imo State Nigeria, It was washed and sun-dried for seven days inside the laboratory before usage. The gravel used was free from deleterious matters. The maximum size of gravel used was 19mm.The packing density of gravel was determined and recorded. The specific gravity is 2.54.

3.2. Methods

Mix ratio for concrete production were obtained through concrete mix design based on British standard, BS 5328: Part 1, 1997. These mix ratios were used in concrete cube productions. During the production of the concrete cubes the following were done ; Material batching, mixing of materials , measuring slump value, casting concrete into moulds, removing concrete cubes from the moulds and putting them inside water in curing tank. After curing the cubes, they were crushed to determine their compressive strengths. The obtained values were used to fit into a model to predict the compressive cube strength when the mix ratio is known and vise versa.

3.2.1 Laboratory investigations on materials;

The properties of materials investigated include the physical properties of fine aggregate and coarse aggregate, sieve analysis of the aggregates and packing densities.

3.2.2 Physical property test:

The fine and coarse aggregates were tested to determine their specific gravities, packing densities and gradation (sieve analysis). . Collection of samples were in accordance to BS EN 932-1(1997) while the sieve analysis was in accordance to BS 812-103.1(1995).

3.2.3 Sieve analysis of the aggregates:

The Sieve Analysis of the fine aggregate and coarse aggregate were performed to determine the Particle size Distribution, the method adopted in this experiment was the dry sieving method, The sieving was done with series of test sieves made of different nominal aperture sizes mounted one over the other in order of size, with largest sieve at the top and smallest sieve at the bottom. The total mass sieved was 1000g, the percentage passing by mass was calculated using equation 3.1

$$\text{Percentage Passing} = \frac{\text{Mass of Sand Passing}}{\text{Total Mass Sieved}} * 100\% \qquad (3.1)$$

Grain *Size* Distribution Analysis of Aggregate (fine and coarse***):*** The Grain size distribution of the two sets of aggregate was carried out to obtain the various proportions by mass of the different sizes of sand particles present. The results obtained From the analysis are presented on table 4.4 and 4.5

3.2.4 Workability test;

Slump test was performed on the mixes used to produce the concrete. Slump test gives total collapse for a plastic mix due to the presence of superplasticizer. The test was conducted in accordance with the specification of BS EN 12350-2 :2000. The procedures for the slump test are as described below:

A slump cone of 300mm height was placed on a tray, with the cone pressed upon the tray the concrete mix was loaded into it, using the scoop. The mix was placed in three layers, with each layer compacted (with tamping rod of 16mm diameter and 350 mm height) 25 times. After compaction, it was allowed to overfull the slump cone and then the tamping rod was used to level it. Immediately the cone was removed from the concrete by raising it slowly and carefully in a vertical direction. This allowed the concrete to subside thus showing no difference in altitude between the height of the mould and that of the highest point on the subsided concrete.

The type of slump was taken into account.

3.3 Determination of mix ratios

3.3.1 Parameters for mix proportioning:

- **a.** (a) Grade designation : 50Mpa
- **b.** (b) Type of cement : Dangote Portland limestone cement (42.5 grade)
- **c.** (c) Types of mineral admixture : Calcined clay and Sugarcane bagasse ash
- **d.** (d) Maximum nominal size of aggregate : 12.5mm
- **e.** (e) Minimum cement content : 400kg/m^3
- **f.** (f) Maximum water cement ratio : 0.35
- **g.** (g) Workability :100mm (slump)
- **h.** (h) Exposure condition : Most severe (for reinforcement concrete)
- **i.** (i) Method of concrete placing : Pumping
- **j.** (j) Degree of supervision : Good
- **k.** (k) Type of aggregate : (Crushed angular aggregate)

l. (l) Maximum cement content : $550kg/m^3$

m. (m) Chemical admixture type : Superplasticizer

n. (n) Risk factor in % : 5

o. (o) Water cement ratio : 0.314

Target Strength for Mix Proportioning

$F'_{ck} = F_{ck} + 1.64\ S$ (3.2)

Where F'_{ck} = target average compressive strength at 28days.

F_{ck} = characteristic compressive strength at 28days and

S = Standard Deviation

Standard Deviation S = $5N/mm^2$

Therefore, target strength = 50 + 1.64 x 5= $58.2N/mm_2$

From Table 6 of BS 5328 : Part 1, 1997

Maximum water cement ratio = 0.45

Based on literature reviewed, adopt water – cement ratio as 0.35

0.35 < 0.45, hence it is okay.

3.3.2 Determination of cement content and corresponding water content

From Table 6 of BS 5328: Part 1, 1997: corresponding minimum cement content = $400kg/m^3$

Based on literature reviewed, adopt minimum cement content = $550kg/m^3$

$550kg/m^3 > 400kg/m^3$, hence it is okay.

Clean water content

$W = C \times \frac{W}{C}$ (3.3)

Where: C = Cement content, W= Water content, Therefore, water content is

W = 550 x 0.35 = $193kg/m^3$

As superplasticizer is used, the water content can be reduced up to 20 percent and above. Based on trials with superplasticizer, water content reduction of 19% has been achieved.

Hence, the achieved water content is 193 x 0.81 = 156 kg/m^3

So, water cement ratio = $\frac{156}{550} = 0.28364$

Superplasticizer content

Volume of chemical admixture (superplasticizer), whose mass corresponds to 3% by mass cementitious material is recommended by the manufacturer.

That is, the mass of super plasticizer is:

$$\text{SP} = \frac{3}{100} \times C = \frac{3}{100} \times 550\ kg = 16.5\ kg$$

The total quantity of water used is obtained by adding the mass of clean water and the mass of super plasticizer. That is:

$$W_t = W + SP = 156kg + 16.5kg = 172.5\ kg \qquad (3.4)$$

The total quantity of cementitious materials (that is cement plus sugarcane bagger ash plus calcined clay) is 550 kg. For the purpose of this work, let blend of the cementitious materials (that is cement plus sugarcane bagger ash plus calcined clay) be called binder and designated as B. The quantity of binder is 550 kg.

Hence, the total water-binder ratio (instead of water-cement ratio) is given as:

$$\frac{W_t}{B} = \frac{172.5\ kg}{550\ kg} = 0.314$$

3.3.3 Determination of cementitious materials contents at various replacement levels

The cement is replaced by sugarcane bagasse ash and calcined clay. The replacement is such that 5%, 10% and 15% of cement are being replaced by the mixture of sugarcane bagasse ash and calcined clay. For each replacement level, a total of nine observation points are used. These observation points are the points of blending of the sugarcane bagger ash and the calcined clay. Each blend sum up to 100% of the total replacement. The mixture of the sugarcane bagasse ash and calcined clay are as shown on Table 3.2. The first five blend (observation points are used in formulating the models and the last four are used in running adequacy tests for the models. Thus, for 5% replacement of cement, the nine observation points shall apply. The same thing goes for 10% replacement of cement where the nine observation points on Table 3.2 are used. For 15% cement replacement, the nine observation points on Table 3.2 are also used.

These gives three sets of mixes. The mixes from 5% replacement, the ones from 10% replacement and the ones from 15% replacement. This means three sets of models shall be formulated. One set of models for 5% cement replacement, another sets of models shall be for 10% cement replacements and yet another sets of models are for 15% cement replacement.

Table 3.1: Properties of liquid conplast SP 430 super plasticizer

Observation points	sugarcane bagasse ash (%)	calcined clay (%)
1	40	60
2	45	55
3	50	50
4	55	45
5	60	40
6	42	58
7	48	52
8	52	48
9	58	42

For 5% replacement of cement, the sugarcane bagasse ash and calcined clay blend content is calculated:

550 x 5% = 27.5kg/m^3

Cement content at 5% replacement = 550 – 27.5 = 522.5kg/m^3

For 10% replacement of cement, the sugarcane bagasse ash and calcined clay blend content is calculated:

550 x 10% = 55kg/m^3

Cement content at 10% replacement = 550 – 55 = 495kg/m^3

For 15% replacement of cement, the sugarcane bagasse ash and calcined clay blend content is calculated:

550 x 15% = 82.5kg/m^3

Cement content at 15% replacement = 550 – 82.5 = 467.5kg/m^3

The cement content (C), the water content (W), the super plasticizer content and the corresponding sugarcane bagasse ash content (SBA) and calcined clay content (CC) at various observation points and various replacement levels are presented on Table 3.2

Table 3.2: Proportions of sugarcane bagasse ash and calcined clay

Observation points	SBA (%)	CC (%)	C (kg)	W (kg)	SP (kg)	SBA (kg)	CC (kg)
A1	40	60	522.5	156.00	16.5	11.06	16.44
A2	45	55	522.5	156.00	16.5	12.26	15.24
A3	50	50	522.5	156.00	16.5	13.75	13.75
A4	55	45	522.5	156.00	16.5	15.24	12.26
A5	60	40	522.5	156.00	16.5	16.44	11.06
A6	42	58	522.5	156.00	16.5	11.66	15.84
A7	48	52	522.5	156.00	16.5	13.15	14.35
A8	52	48	522.5	156.00	16.5	14.35	13.15
A9	58	42	522.5	156.00	16.5	15.84	11.66
B1	40	60	495	156.00	16.5	22.12	32.88
B2	45	55	495	156.00	16.5	24.51	30.49
B3	50	50	495	156.00	16.5	27.50	27.50
B4	55	45	495	156.00	16.5	30.49	24.51
B5	60	40	495	156.00	16.5	32.88	22.12
B6	42	58	495	156.00	16.5	23.32	31.68
B7	48	52	495	156.00	16.5	26.30	28.70
B8	52	48	495	156.00	16.5	28.70	26.30
B9	58	42	495	156.00	16.5	31.68	23.32
C1	40	60	467.5	156.00	16.5	33.18	49.32
C2	45	55	467.5	156.00	16.5	36.77	45.73
C3	50	50	467.5	156.00	16.5	41.25	41.25
C4	55	45	467.5	156.00	16.5	45.73	36.77
C5	60	40	467.5	156.00	16.5	49.32	33.18
C6	42	58	467.5	156.00	16.5	34.97	47.53
C7	48	52	467.5	156.00	16.5	39.46	43.04
C8	52	48	467.5	156.00	16.5	43.04	39.46
C9	58	42	467.5	156.00	16.5	47.53	34.97

3.3.4 Determination of volumes material in one cubic meter volume of concrete

Volume of a material is obtained by dividing the mass of the material by its density. On the other hand, the density of a material is the product of the materials specific gravity and density of water. Thus:

$$V_m = \frac{M}{G_m X P_W} \tag{3.5}$$

The volume of cement is defined as:

$$V_C = \frac{C}{G_C X P_W} = \frac{C}{3.15 X 1000 \ kg/m^3}$$

That is:

$$V_C = \frac{C}{3150\ kg/m^3} \tag{3.6}$$

Where:

V_C, C, G_C and P_W are the volume of cement, mass of cement (cement content), the Specific gravity of cement and the density of water respectively.

The volume of sugarcane bagasseis defined as:

$$V_{SBA} = \frac{SCA}{G_{SBA} X P_W} = \frac{SCA}{1.62X1000\ kg/m^3}$$

That is:

$$V_{SBA} = \frac{SCA}{1620\ kg/m^3} \tag{3.7}$$

Where:

V_{SBA} , SBA, G_{SBA} and P_W are the volume of sugarcane bagger ash, mass of sugarcane bagger ash (sugarcane bagasse ash content), the Specific gravity of sugarcane bagger as hand the density of water respectively.

The volume of calcined clay is defined as:

$$V_{CC} = \frac{CC}{G_{CC} X P_W} = \frac{CC}{2.07X1000\ kg/m^3}$$

That is:

$$V_{CC} = \frac{CC}{2070\ kg/m^3} \tag{3.8}$$

Where:

V_{CC}, CC, G_{CC} and P_W are the volume of calcined clay, mass of calcined clay (calcined clay content), the Specific gravity of calcined clay and the density of water respectively.

The volume of water is defined as:

$$V_w = \frac{W}{G_W X P_W} = \frac{W}{1.00X1000\ kg/m^3}$$

That is:

$$V_w = \frac{W}{1000\ kg/m^3} \tag{3.9}$$

Where:

V_W, W, G_W and P_W are the volume of water, water (water content), the Specific gravity of water and the density of water respectively.

The volume of super plasticizer is defined as:

$$V_{SP} = \frac{SP}{G_{SP} X P_W} = \frac{SP}{1.20X1000\ kg/m^3}$$

That is:

$$V_{SP} = \frac{SP}{1200\ kg/m^3} \quad (3.10)$$

Where:

V_{SP}, SP, G_{SP} and P_W are the volume of water, water (water content), the Specific gravity of water and the density of water respectively.

Total volume of cement paste (V_P) in one cubic meter volume of concrete is obtained by adding the volumes of cement, water, super plasticizer, sugarcane bagger ash and calcined clay. That is:

$$V_P = V_C + V_W + V_{SP} + V_{SBA} + V_{CC} \quad (3.11)$$

The volume of aggregates, V_A (fine aggregate plus coarse aggregate) is obtained by subtracting the volume of paste from one (that is: 1). This is given as:

$$V_a = 1 - V_P \quad (3.12)$$

Using Equations 3.5 to 3.12 and Table 3.3 the volumes of cement, water, super plasticizer, sugarcane bagasse ash and calcined clay for various observation points and cement replacement levels are calculated as presented on Table 3.3

Table 3.3: Volumes of cement, sugarcane bagasse ash, calcined clay, water, super plasticizer, cement paste and aggregate

Observation Points	V_C (m^3)	V_{SBA} (m^3)	V_{CC} (m^3)	V_W (m^3)	V_{SP} (m^3)	V_P (m^3)	V_A (m^3)
A1	0.16587	0.00683	0.00794	0.156002	0.01375	0.35039	0.64961
A2	0.16587	0.00757	0.00736	0.156002	0.01375	0.35055	0.64945
A3	0.16587	0.00849	0.00664	0.156002	0.01375	0.35076	0.64924
A4	0.16587	0.00941	0.00592	0.156002	0.01375	0.35096	0.64904
A5	0.16587	0.01015	0.00534	0.156002	0.01375	0.35112	0.64888
A6	0.16587	0.00720	0.00765	0.156002	0.01375	0.35047	0.64953
A7	0.16587	0.00812	0.00693	0.156002	0.01375	0.35067	0.64933
A8	0.16587	0.00886	0.00635	0.156002	0.01375	0.35084	0.64916
A9	0.16587	0.00978	0.00563	0.156002	0.01375	0.35104	0.64896
B1	0.15714	0.01365	0.01588	0.156002	0.01375	0.35643	0.64357
B2	0.15714	0.01513	0.01473	0.156002	0.01375	0.35675	0.64325
B3	0.15714	0.01698	0.01329	0.156002	0.01375	0.35716	0.64284
B4	0.15714	0.01882	0.01184	0.156002	0.01375	0.35756	0.64244
B5	0.15714	0.02030	0.01069	0.156002	0.01375	0.35788	0.64212

B6	0.15714	0.01439	0.01531	0.156002	0.01375	0.35659	0.64341
B7	0.15714	0.01624	0.01386	0.156002	0.01375	0.35699	0.64301
B8	0.15714	0.01771	0.01271	0.156002	0.01375	0.35732	0.64268
C1	0.14841	0.02048	0.02383	0.156002	0.01375	0.36247	0.63753
C2	0.14841	0.02270	0.02209	0.156002	0.01375	0.36295	0.63705
C3	0.14841	0.02546	0.01993	0.156002	0.01375	0.36356	0.63644
C4	0.14841	0.02823	0.01776	0.156002	0.01375	0.36416	0.63584
C5	0.14841	0.03044	0.01603	0.156002	0.01375	0.36464	0.63536
C6	0.14841	0.02159	0.02296	0.156002	0.01375	0.36271	0.63729
C7	0.14841	0.02436	0.02079	0.156002	0.01375	0.36331	0.63669
C8	0.14841	0.02657	0.01906	0.156002	0.01375	0.36380	0.63620
C9	0.14841	0.02934	0.01690	0.156002	0.01375	0.36440	0.63560

3.3.5 Determination of coarse aggregate and fine aggregate contents in one cubic meter volume of concrete

From trial packing density test, the combination of coarse aggregate and fine aggregate that gives the highest packing density of the blend of coarse aggregate and fine aggregate is 0.51 is to 0.49. That is: the ratio of coarse aggregate and fine aggregate in the blend are 0.51 and 0.49 respectively.

The mass of coarse aggregate is defined as:

$$CA = 0.51\, V_A . G_{CA} . P_W = 0.51\, V_A \times 2.54 \times 1000\ kg/m^3$$

That is:

$$CA = 1295.4\, kg/m^3 \times V_A \tag{3.13}$$

Where:

CA, V_A, G_{CA} and P_W are coarse aggregate content, volume of Aggregate blend, specific gravity of coarse aggregate and density of water respectively.

The mass of fine aggregate is defined as:

$$FA = 0.49\, V_A . G_{FA} . P_W = 0.49\, V_A \times 2.59 \times 1000\ kg/m^3$$

That is:

$$FA = 1269.1\, kg/m^3 \times V_A \tag{3.14}$$

Using Equations 3.13 and 3.14 the volumes of aggregate blend on Table 3.3, the masses of coarse aggregate and fine aggregate for various cement replacement and various observation points are determined as presented on Table 3.4.

It should be observed from Table 3.4 that the cement content, water content and super plasticizer content are all constants. They do not vary as the observation points vary. Hence, during the model formulations, they shall not be included as one of the variable quantities. The quantities to be included in the model are the sugarcane bagasse ash, calcined clay, coarse aggregate and fine aggregate.

It was said earlier that the mass of the binder (that is cement plus sugarcane bagasse ash plus calcined clay) at all the observation points and all the levels of cement replacement is 550 kg. Dividing the masses on Table 3.4 by 550 kg give the mix ratios of all the materials as presented on Table 3.5

Table 3.4: Mass of the concrete materials in one cubic meter volume of the concrete

Observation points	C (kg)	W (kg)	SP (kg)	SBA (kg)	CC (kg)	CA (kg)	FA (kg)
A1	522.5	156.00	16.5	11.06	16.44	841.50	824.41
A2	522.5	156.00	16.5	12.26	15.24	841.29	824.21
A3	522.5	156.00	16.5	13.75	13.75	841.03	823.96
A4	522.5	156.00	16.5	15.24	12.26	840.77	823.70
A5	522.5	156.00	16.5	16.44	11.06	840.56	823.50
A6	522.5	156.00	16.5	11.66	15.84	841.40	824.31
A7	522.5	156.00	16.5	13.15	14.35	841.14	824.06
A8	522.5	156.00	16.5	14.35	13.15	840.93	823.85
A9	522.5	156.00	16.5	15.84	11.66	840.67	823.60
B1	495	156.00	16.5	22.12	32.88	833.68	816.75
B2	495	156.00	16.5	24.51	30.49	833.26	816.34
B3	495	156.00	16.5	27.50	27.50	832.74	815.83
B4	495	156.00	16.5	30.49	24.51	832.22	815.33
B5	495	156.00	16.5	32.88	22.12	831.81	814.92
B6	495	156.00	16.5	23.32	31.68	833.47	816.55
B7	495	156.00	16.5	26.30	28.70	832.95	816.04
B8	495	156.00	16.5	28.70	26.30	832.53	815.63
B9	495	156.00	16.5	31.68	23.32	832.01	815.12
C1	467.5	156.00	16.5	33.18	49.32	825.85	809.09
C2	467.5	156.00	16.5	36.77	45.73	825.23	808.48
C3	467.5	156.00	16.5	41.25	41.25	824.45	807.71
C4	467.5	156.00	16.5	45.73	36.77	823.67	806.95
C5	467.5	156.00	16.5	49.32	33.18	823.05	806.34
C6	467.5	156.00	16.5	34.97	47.53	825.54	808.78
C7	467.5	156.00	16.5	39.46	43.04	824.76	808.02
C8	467.5	156.00	16.5	43.04	39.46	824.14	807.41
C9	467.5	156.00	16.5	47.53	34.97	823.36	806.64

Table 3.5: Mix ratios of the components of the concrete

Observation points	C/B	W/B	SP/B	SBA /B	CC /B	CA/B	FA / B
				S_1	S_2	S_3	S4
A1	0.95	0.28364	0.03	0.02011	0.02989	1.53000	1.49893
A2	0.95	0.28364	0.03	0.02229	0.02771	1.52962	1.49856
A3	0.95	0.28364	0.03	0.02500	0.02500	1.52915	1.49811
A4	0.95	0.28364	0.03	0.02771	0.02229	1.52867	1.49764
A5	0.95	0.28364	0.03	0.02989	0.02011	1.52829	1.49727
A6	0.95	0.28364	0.03	0.02120	0.02880	1.52982	1.49875
A7	0.95	0.28364	0.03	0.02391	0.02609	1.52935	1.49829
A8	0.95	0.28364	0.03	0.02609	0.02391	1.52896	1.49791
A9	0.95	0.28364	0.03	0.02880	0.02120	1.52849	1.49745
B1	0.9	0.28364	0.03	0.04022	0.05978	1.51578	1.48500
B2	0.9	0.28364	0.03	0.04456	0.05544	1.51502	1.48425
B3	0.9	0.28364	0.03	0.05000	0.05000	1.51407	1.48333
B4	0.9	0.28364	0.03	0.05544	0.04456	1.51313	1.48242
B5	0.9	0.28364	0.03	0.05978	0.04022	1.51238	1.48 167
B6	0.9	0.28364	0.03	0.04240	0.05760	1.51540	1.48464
B7	0.9	0.28364	0.03	0.04782	0.05218	1.51445	1.48371
B8	0.9	0.28364	0.03	0.05218	0.04782	1.51369	1.48296
B9	0.9	0.28364	0.03	0.05760	0.04240	1.51275	1.48204
C1	0.85	0.28364	0.03	0.06033	0.08967	1.50155	1.47107
C2	0.85	0.28364	0.03	0.06685	0.08315	1.50042	1.46996
C3	0.85	0.28364	0.03	0.07500	0.07500	1.49900	1.46856
C4	0.85	0.28364	0.03	0.08315	0.06685	1.49758	1.46718
C5	0.85	0.28364	0.03	0.08967	0.06033	1.49645	1.46607
C6	0.85	0.28364	0.03	0.06358	0.08642	1.50098	1.47051
C7	0.85	0.28364	0.03	0.07175	0.07825	1.49956	1.46913
C8	0.85	0.28364	0.03	0.07825	0.07175	1.49844	1.46802
C9	0.85	0.28364	0.03	0.08642	0.06358	1.49702	1.46662

3.3.6 Compressive Strength Test for concrete produced with metakaolin and sugarcane baggasse ash;

Compressive strength test was carried out in order to determine the compressive strength of the concrete produced with metakaolin and sugarcane baggasse ash. The concrete cubes were produced using manual mixing method in a mould measuring 150mm x 150mm x 150 mm in size.

The moulds were first oiled for easy removal of the samples after setting. The fresh concrete sample was introduced into the mould in three layers with proper vibration. A total of 252 cubes were produced according to mix ratios, determined from the mix design used. The first set of 81 cubes made from the mix ratios, were used to obtain the twenty eight (28th) day compressive strength, while the second set of 81 cubes, were used to obtain the 60-day compressive strength. The last set of 81 cubes were used to obtain the 90-day compressive strength. However, 9 cubes were cast as control (with no sugarcane bagger ash and no calcined clay). The concrete cubes were cured by immersing the concrete cubes in a curing tank full of good water. The compression testing machine used for testing the cube specimens is of standard make. The capacity of the testing machine is 2000 KN.

After the required period of curing, the cube specimens are removed from the curing tubs and cleaned to wipe of the surface water. It is placed on the machine such that the load is applied centrally. The smooth surfaces of the specimen are placed on the bearing surfaces. The top plate is bought in contact with the specimen by rotating the handle. The oil pressure valve is closed and the machine was switched on.

The compression load at failure was recorded and used in Equation (3.15) to determine the compressive strength of the concrete produced with sugarcane bagasse ash a nd metakaolin.

$$\text{Compressive strength} = \frac{\text{compressive load of cube at failure (N)}}{\text{cross sectional area of mould (mm}^2\text{)}} \qquad (3.15)$$

The densities of the 28-day, 60-day and 90-day compressive strength were obtained since some structural characteristic depends on it. The cubes for the compressive Strength test were weighed in a digital weighing balance that has accuracy of 0.01g and recorded and the density of the samples were computed using Equation 3.2

$$\text{Density} = \frac{\text{mass of sample}}{\text{volume of sample}} \qquad (3.16)$$

3.3.7 Fitting the concrete produced into a model for predicting of compressive strength when mix ratio is known and vise versa

The mix component is six. It comprises of Aqueous liquid (water plus superplasticizer, which is denoted as W), cement (denoted as C), Fine aggregate (in this case sand, which is denoted as FA), Coarse aggregate (in this case crushed granitic stone, which is denoted as CA), Sugarcane Bagger Ash (which is denoted as SBA) and Calcined clay (which is denoted CC). Ratios of these components against the binder are used in the mathematical model. The binder is obtained by adding cement, sugarcane bagasse ash and calcined clay. These ratios are designated as W/B, C/B, SBA/B, CC/B, FA/B and CA/B. Out of these six ratios, two (W/B and C/B) are constants. Thus, only four of the ratios vary at various points of observation. Hence, the four varying ratios are used in formulating the model. For the purpose of the model, these four variable ratios (SBA/B, CC/B, FA/B and CA/B) are designated as S_1, S_2, S_3 and S_4 respectively. Summing up the four variable ratios at each observation point gives sum of ratios designated as S. The model mix quantity (x_i) of each of the four variable ratios is determined by dividing the individual ratio (s_i) by the sum of the ratios (S). That is:

$$x_i = \frac{s_i}{S} \quad (3.17)$$

$$S = s_1 + s_2 + s_3 + s_4 \quad (3.18)$$

In this work, the spatial domain in which the model is restricted to are mix ratio domains given as:

$$s_{1min} \le s_1 \le s_{1max} \quad (3.19)$$

$$s_2 = 1 \quad (3.20)$$

$$s_{3min} \le s_3 \le s_{3max} \quad (3.21)$$

$$s_{4min} \le s_4 \le s_{4max} \quad (3.22)$$

From Equation (3.17)

$$s_i = x_i \, . \, S[where\ 1 \le i \le 4\,] \quad (3.23)$$

Substituting Equation (3.23) into Equation (3.18) gives the sum of all the mix quantities to be unity as:

$$x_1 + x_2 + x_3 + x_4 = 1 \quad (3.24)$$

The response function to be adopted herein is a quadratic function of the component proportions given as:

$$y = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5{x_1}^2 + a_6{x_2}^2 + a_7{x_3}^2 + a_8{x_4}^2 + a_9x_1x_2 + a_{10}x_1x_3 + a_{11}x_1x_4 + a_{12}x_2x_3 + a_{13}x_2x_4 + a_{14}x_3x_4 \quad (3.25)$$

That is:

$$y = [x_i][a_i] \quad (3.26)$$

Equation (3.26)was used to obtain the array response equation for the set of mix ratios used in the formulation as:

$$[y^k] = [{x_i}^k][a_i] \quad (3.27)$$

Where k denotes the mix number (or observation point number); $[a_i]$ is the coefficient vector, and $[x_i]$ is the shape function vector. They are:

$$[a_i] =, [a_1 a_2 a_3 a_4 a_5 a_6 a_7 a_8 a_9 a_{10} a_{11} a_{12} a_{13} a_{14}]^T \qquad (3.28)$$

$$[x_i] = [x_1 x_2 x_3 x_4 {x_1}^2 {x_2}^2 {x_3}^2 {x_4}^2 x_1 x_2 x_1 x_3 x_1 x_4 x_2 x_3 x_2 x_4 x_3 x_4] \qquad (3.29)$$

Pre-multiplying both sides of Equation 3.23 with a weighting function (transpose of the shape function) for the set of mixes for the formulation gives the weighted response equation (WRE) as:

$$[{x_i}^k]^T [y^k] = [{x_i}^k]^T . [{x_i}^k][a_i] \qquad (3.30)$$

This multiplication did not change the generality of the regression function as the weighting function can easily cancel out from both the left and right hand sides of equation (3.30). It is clear from here that the approach used in the original work of Ibearugbulem model (Ibearugbulem et al., 2013) is weighted response approach (WRA).

The weighted response equation (Equation 3.30) can be rewritten as:

$$[F] = [CC][a_i] \qquad (3.31)$$

Where the weighted response vector, F and CC matrix are defined as:

$$F = [{x_i}^k]^T [y^{\ k}] \qquad (3.32)$$

$$[CC] = [{x_i}^k]^T . [{x_i}^k] \qquad (3.33)$$

In simpler words, [CC] is the matrix whose arbitrary element CC_{ij} is obtained by array multiplication of transpose of Column "i" with Column "j" of the shape function vector.

3.3.8 Fitting the model with the mixes used herein

Table 3.7 contains the values of quantities of mix components, x_i. Dividing the components designated as S_1, S_2, S_3 and S_4 by their sum ($S_1 + S_2 + S_3 + S_4$) gives the values of $x_i$as presented on Table 3.6.

The summation of x_i in each mix ratio on Table 3.6, was ensured to be equal to unity (in accordance with Equation 3.20). The values of x_i on Table 3.7were used to determine the shape function and weighted response.

Table 3.6: The model mix quantity (x_i)

Observation points	S	x1	x2	x3	x4
A1	3.07893	0.006531	0.009708	0.496926	0.486834
A2	3.07818	0.007242	0.009002	0.496923	0.486834
A3	3.07725	0.008124	0.008124	0.496919	0.486833
A4	3.07631	0.009007	0.007246	0.496918	0.486829
A5	3.07556	0.009719	0.006538	0.496914	0.486829
A6	3.07856	0.006886	0.009355	0.496926	0.486833
A7	3.07764	0.007769	0.008478	0.496922	0.486832
A8	3.07687	0.00848	0.007771	0.496921	0.486828
A9	3.07595	0.009363	0.006892	0.496917	0.486827
B1	3.10078	0.01297	0.01928	0.488839	0.478911
B2	3.09927	0.014379	0.017887	0.48883	0.478904
B3	3.09740	0.016143	0.016143	0.488821	0.478894
B4	3.09555	0.017908	0.014396	0.488808	0.478888
B5	3.09405	0.019322	0.012999	0.488803	0.478877
B6	3.10004	0.013677	0.01858	0.488833	0.478909
B7	3.09816	0.015434	0.016843	0.488823	0.4789
B8	3.09665	0.016851	0.015442	0.488815	0.478892
B9	3.09478	0.018612	0.0137	0.488805	0.478882
C1	3.12262	0.019319	0.028717	0.480861	0.471102
C2	3.12038	0.021425	0.026646	0.480844	0.471085
C3	3.11756	0.024057	0.024057	0.480824	0.471061
C4	3.11476	0.026694	0.021464	0.480801	0.471041
C5	3.11253	0.02881	0.019382	0.480784	0.471023
C6	3.12149	0.020369	0.027685	0.480854	0.471092
C7	3.11869	0.023005	0.025092	0.480831	0.471072
C8	3.11645	0.02511	0.023021	0.480814	0.471054
C9	3.11364	0.027755	0.02042	0.480794	0.471031

Table 3.7 The transpose of the response of the mix ratios for 5% replacements for the first five points of observation

x_1	0.00661	0.00733	0.00822	0.00911	0.00982
x_2	0.00982	0.00911	0.00822	0.00733	0.00661
x_3	0.50607	0.50607	0.50607	0.50607	0.50607
x_4	0.47749	0.47749	0.47749	0.47749	0.47749
x_1^2	0.00004	0.00005	0.00007	0.00008	0.00010

x_2^2	0.00010	0.00008	0.00007	0.00005	0.00004
x_3^2	0.25611	0.25611	0.25611	0.25611	0.25611
x_4^2	0.22800	0.22800	0.22800	0.22800	0.22800
x_1x_2	0.00006	0.00007	0.00007	0.00007	0.00006
x_1x_3	0.00334	0.00371	0.00416	0.00461	0.00497
x_1x_4	0.00316	0.00350	0.00392	0.00435	0.00469
x_2x_3	0.00497	0.00461	0.00416	0.00371	0.00334
x_2x_4	0.00469	0.00435	0.00392	0.00350	0.00316
x_3x_4	0.24165	0.24165	0.24165	0.24165	0.24165

Table 3.8 Substituting this matrix into Equation (3.33) gives the CC matrix for 5% cement replacement.

	x_1	x_2	x_3	x_4	x_1^2	x_2^2	x_3^2	x_4^2	x_1x_2	x_1x_3	x_1x_4	x_2x_3	x_2x_4	x_3x_4
x_1	0.000344	0.000331	0.020793	0.019619	0.000003	0.000003	0.010523	0.009368	0.000003	0.000174	0.000164	0.000167	0.000158	0.009929
x_2	0.000331	0.000344	0.020793	0.019619	0.000003	0.000003	0.010523	0.009368	0.000003	0.000167	0.000158	0.000174	0.000164	0.009929
x_3	0.020793	0.020793	1.280550	1.208229	0.000174	0.000174	0.648052	0.576920	0.000167	0.010523	0.009929	0.010523	0.009929	0.611452
x_4	0.019619	0.019619	1.208229	1.139993	0.000164	0.000164	0.611452	0.544337	0.000158	0.009929	0.009368	0.009929	0.009368	0.576920
x_1^2	0.000003	0.000003	0.000174	0.000164	0.000000	0.000000	0.000088	0.000079	0.000000	0.000001	0.000001	0.000001	0.000001	0.000083
x_2^2	0.000003	0.000003	0.000174	0.000164	0.000000	0.000000	0.000088	0.000079	0.000000	0.000001	0.000001	0.000001	0.000001	0.000083
x_3^2	0.010523	0.010523	0.648052	0.611452	0.000088	0.000088	0.327962	0.291964	0.000085	0.005325	0.005025	0.005325	0.005025	0.309440
x_4^2	0.009368	0.009368	0.576920	0.544337	0.000079	0.000079	0.291964	0.259917	0.000075	0.004741	0.004473	0.004741	0.004473	0.275474
x_1x_2	0.000003	0.000003	0.000167	0.000158	0.000000	0.000000	0.000085	0.000075	0.000000	0.000001	0.000001	0.000001	0.000001	0.000080
x_1x_3	0.000174	0.000167	0.010523	0.009929	0.000001	0.000001	0.005325	0.004741	0.000001	0.000088	0.000083	0.000085	0.000080	0.005025
x_1x_4	0.000164	0.000158	0.009929	0.009368	0.000001	0.000001	0.005025	0.004473	0.000001	0.000083	0.000079	0.000080	0.000075	0.004741
x_2x_3	0.000167	0.000174	0.010523	0.009929	0.000001	0.000001	0.005325	0.004741	0.000001	0.000085	0.000080	0.000088	0.000083	0.005025
x_2x_4	0.000158	0.000164	0.009929	0.009368	0.000001	0.000001	0.005025	0.004473	0.000001	0.000080	0.000075	0.000083	0.000079	0.004741
x_3x_4	0.009929	0.009929	0.611452	0.576920	0.000083	0.000083	0.309440	0.275474	0.000080	0.005025	0.004741	0.005025	0.004741	0.291964

$$[CC] = [x_i{}^k]^T . [x_i{}^k]$$

Where CC = set of matrix for 5% cement replacement.

$[x_i{}^k]^T . [x_i{}^k]$= multiplication of the transpose of the mix ratios of 5% cement replacement,

By the matrix ratio of 5%

Table 3.9 The transpose of the response of the mix ratios for 10% replacements for the first five points of observation is:

x_1	0.01300	0.01459	0.01617	0.01775	0.01968
x_2	0.01933	0.01775	0.01617	0.01459	0.01283
x_3	0.49789	0.49789	0.49789	0.49789	0.49780
x_4	0.46977	0.46977	0.46977	0.46977	0.46969
x_1^2	0.00017	0.00021	0.00026	0.00032	0.00039
x_2^2	0.00037	0.00032	0.00026	0.00021	0.00016
x_3^2	0.24790	0.24790	0.24790	0.24790	0.24781
x_4^2	0.22069	0.22069	0.22069	0.22069	0.22061
x_1x_2	0.00025	0.00026	0.00026	0.00026	0.00025
x_1x_3	0.00648	0.00726	0.00805	0.00884	0.00980
x_1x_4	0.00611	0.00685	0.00759	0.00834	0.00924
x_2x_3	0.00963	0.00884	0.00805	0.00726	0.00639
x_2x_4	0.00908	0.00834	0.00759	0.00685	0.00603
x_3x_4	0.23389	0.23389	0.23390	0.23389	0.23381

Table 3.10: Substituting this matrix into Equation (3.33) gives the CC matrix for 10% level of cement replacement as:

	x_1	x_2	x_3	x_4	x_1^2	x_2^2	x_3^2	x_4^2	x_1x_2	x_1x_3	x_1x_4	x_2x_3	x_2x_4	x_3x_4
x_1	0.001346	0.001283	0.040422	0.038139	0.000023	0.000021	0.020125	0.017916	0.000021	0.000670	0.000632	0.000639	0.000603	0.018988
x_2	0.001283	0.001328	0.040162	0.037894	0.000021	0.000022	0.019996	0.017801	0.000021	0.000639	0.000603	0.000661	0.000624	0.018866
x_3	0.040422	0.040162	1.239390	1.169394	0.000670	0.000661	0.617059	0.549329	0.000639	0.020125	0.018988	0.019996	0.018866	0.582210
x_4	0.038139	0.037894	1.169394	1.103351	0.000632	0.000624	0.582210	0.518305	0.000603	0.018988	0.017916	0.018866	0.017801	0.549329
x_1^2	0.000023	0.000021	0.000670	0.000632	0.000000	0.000000	0.000334	0.000297	0.000000	0.000011	0.000011	0.000010	0.000010	0.000315
x_2^2	0.000021	0.000022	0.000661	0.000624	0.000000	0.000000	0.000329	0.000293	0.000000	0.000010	0.000010	0.000011	0.000010	0.000311
x_3^2	0.020125	0.019996	0.617059	0.582210	0.000334	0.000329	0.307217	0.273496	0.000318	0.010019	0.009454	0.009955	0.009393	0.289867
x_4^2	0.017916	0.017801	0.549329	0.518305	0.000297	0.000293	0.273496	0.243477	0.000283	0.008920	0.008416	0.008863	0.008362	0.258050
x_1x_2	0.000021	0.000021	0.000639	0.000603	0.000000	0.000000	0.000318	0.000283	0.000000	0.000010	0.000010	0.000010	0.000010	0.000300
x_1x_3	0.000670	0.000639	0.020125	0.018988	0.000011	0.000010	0.010019	0.008920	0.000010	0.000334	0.000315	0.000318	0.000300	0.009454
x_1x_4	0.000632	0.000603	0.018988	0.017916	0.000011	0.000010	0.009454	0.008416	0.000010	0.000315	0.000297	0.000300	0.000283	0.008920
x_2x_3	0.000639	0.000661	0.019996	0.018866	0.000010	0.000011	0.009955	0.008863	0.000010	0.000318	0.000300	0.000329	0.000311	0.009393
x_2x_4	0.000603	0.000624	0.018866	0.017801	0.000010	0.000010	0.009393	0.008362	0.000010	0.000300	0.000283	0.000311	0.000293	0.008863
x_3x_4	0.018988	0.018866	0.582210	0.549329	0.000315	0.000311	0.289867	0.258050	0.000300	0.009454	0.008920	0.009393	0.008863	0.273496

CC matrix for 10 % cement replacement =

$$[CC] = [x_i{}^k]^T . [x_i{}^k]$$

Where CC = set of matrix for 10% ,

$[x_i{}^k]^T . [x_i{}^k]$= multiplication of the transpose of the mix ratios for 10%,cement replacement by the mix ratios of 10%.

Table 3.11 The transpose of the response of the mix ratios for 15% replacements for the first five points of observation is:

x_1	0.01937	0.02144	0.02387	0.02629	0.02854
x_2	0.02853	0.02629	0.02387	0.02144	0.01903
x_3	0.48988	0.48997	0.48997	0.48997	0.49005
x_4	0.46222	0.46230	0.46230	0.46230	0.46238
x_1^2	0.00038	0.00046	0.00057	0.00069	0.00081
x_2^2	0.00081	0.00069	0.00057	0.00046	0.00036
x_3^2	0.23999	0.24007	0.24007	0.24007	0.24015
x_4^2	0.21365	0.21372	0.21372	0.21372	0.21379
x_1x_2	0.00055	0.00056	0.00057	0.00056	0.00054
x_1x_3	0.00949	0.01051	0.01169	0.01288	0.01399
x_1x_4	0.00895	0.00991	0.01103	0.01215	0.01320
x_2x_3	0.01398	0.01288	0.01169	0.01051	0.00932
x_2x_4	0.01319	0.01215	0.01103	0.00991	0.00880
x_3x_4	0.22643	0.22651	0.22651	0.22651	0.22659

Substituting this matrix into Equation (3.33) gives the CC matrix for 15% level of cement replacement as:

Table 3.12: CC matrix for 15 % cement replacement =

	x_1	x_2	x_3	x_4	x_1^2	x_2^2	x_3^2	x_4^2	x_1x_2	x_1x_3	x_1x_4	x_2x_3	x_2x_4	x_3x_4
x_1	0.002	0.002	0.058	0.055	0.000	0.000	0.028	0.025	0.000	0.001	0.001	0.001	0.001	0.027
x_2	0.002	0.002	0.058	0.055	0.000	0.000	0.028	0.025	0.000	0.001	0.001	0.001	0.001	0.026
x_3	0.058	0.058	1.200	1.132	0.001	0.001	0.588	0.523	0.001	0.028	0.027	0.028	0.026	0.554
x_4	0.055	0.055	1.132	1.068	0.001	0.001	0.554	0.494	0.001	0.027	0.025	0.026	0.025	0.523
x_1	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
x_2	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
x_3	0.028	0.028	0.588	0.554	0.000	0.000	0.288	0.256	0.000	0.014	0.013	0.014	0.013	0.271
x_4	0.025	0.025	0.523	0.494	0.000	0.000	0.256	0.228	0.000	0.012	0.011	0.012	0.011	0.242
x_1	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
x_1	0.001	0.001	0.028	0.027	0.000	0.000	0.014	0.012	0.000	0.000	0.000	0.000	0.000	0.013
x_1	0.001	0.001	0.027	0.025	0.000	0.000	0.013	0.011	0.000	0.000	0.000	0.000	0.000	0.012
x_2	0.001	0.001	0.028	0.026	0.000	0.000	0.014	0.012	0.000	0.000	0.000	0.000	0.000	0.013
x_2	0.001	0.001	0.026	0.025	0.000	0.000	0.013	0.011	0.000	0.000	0.000	0.000	0.000	0.012
x_3	0.027	0.026	0.554	0.523	0.000	0.000	0.271	0.242	0.000	0.013	0.012	0.013	0.012	0.256

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Result presentations

4.1.1 Laboratory results on materials

The following results presented on Table 4.2 to 4.4 are for Packing density, specific gravity of fine and coarse aggregates respectively.

4.1.2.1 Results of the physical property test;

Table 4.1 Packing density

PACKING DENSITY						
FINE AGGREGATE	COASE AGGREGATE	WEIGHT	DIAMETER	HIGHT	VOLUME	DENSITY
(%)	(%)	(kg)	(m)	(m)	(m^3)	(kg/m^3)
65	35	6.57	0.1512	0.1815	3.260	2.015
60	40	6.74	0.1512	0.1815	3.260	2.067
55	45	6.83	0.1512	0.1815	3.260	2.095
50	50	6.95	0.1512	0.1815	3.260	2.132
45	55	6.93	0.1512	0.1815	3.260	2.126

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Table 4.2 specific gravity of Coarse aggregates

	SPECIFIC GRAVITY OF COASE AGGREGATE						
	Weight Of Bottle +Water	Weight Of Bottle + Ca +Water	Volume Of Water	Volume Of Water +Ca	Weight Of Ca	Weight Of Water Displaced	Specific Gravity
	(g)	(g)	(ml)	(ml)	(g)	(g)	
1	1078.35	1579.09	500	695	500.74	195	2.57
2	1082.69	1581.01	500	695	498.32	195	2.56
3	1082.45	1582.57	500	700	500.12	200	2.50
				O		AVE	2.54

Table 4.3 Specific gravity of fine aggregates

	SPECIFIC GRAVITY OF FINE AGGREGATE				
	Weight Of Empty Bottle	Weight Of Bottle + Sand	Weight Of Bottle + Sand +Water	Weight Of Bottle +Water	Specific Gravity
	M1	M2	M3	M4	
1	113.49	313.37	496.12	372.77	2.61
2	113.7	313.4	494.42	372.51	2.57
				AVE	2.59

4.1.2.2 Sieve analysis of the aggregates:

The sieve analysis result of the fine aggregates is as presented in Table 4.5

Table 4.4 fine Aggregate for Concrete Test

Soil Description; fine Aggregate for Concrete Test									
Mass of Pan; Mp (g) =			295.31						
Mass of Pan + Dry Sample; Mp + Mds (g) =			795.31						
Mass of Dry Sample; Mds (g) =			500	DATA SHEET					
Sieve Number	Sieve Size / Sieve opening	Mass of Weighting Sieve; (M1)	Mass of Sieve + Soil Retained (M2)		Mass of Sample Retained on each Sieve; (M2av-M1)	Percentage Retained on each Sieve; ((M2av-M1)/Mds)x100	Cumulative percentage Retained; Zr	percentage passing; 100-Zr	
#	(mm)	(g)	(g)		(g)	(%)	(%)	(%)	
3/8"	9.5	450.74	453.08		2.34	0.47	0.00	100	
4	4.75	373.53	378.12		4.59	0.92	0.92	99.082	
8	2.36	358.22	364.57		6.35	1.27	2.19	97.812	
16	1.18	363.70	384.38		20.68	4.14	6.32	93.676	
20	0.85	378.01	436.87		58.86	11.77	18.10	81.904	
40	0.425	327.37	570.60		243.23	48.65	66.74	33.258	
50	0.3	318.36	412.82		94.46	18.89	85.63	14.366	
100	0.15	298.25	330.65		32.40	6.48	92.11	7.886	
200	0.075	313.92	337.72		23.80	4.76	96.87	3.126	
Pan		298.28	304.25		5.97	1.19	98.07	1.932	
TOTAL		3480.38			492.68	98.54			
Outcome									
Outcome									
% Loss During Analysis=			1.932	Weight Check (Materials Accounted For)	Weight	Percentage			

D10 =	0.20	Cc =	1.311	Av. Weight of Coarse Fraction (+4.75mm Fraction) (g) =	6.93	1.39	Maximum Aggregate Size (Identified) (mm)		9.5
D30 =	0.40	Cu =	3.050	Av. Weight of Sand Fraction (-4.75mm to +0.075mm Fraction) (g) =	479.78	95.96	Av. Percentage Passing 4.75mm Sieve(%)		97.15
D40 =	0.46	FM =	5.330	Av. Weight of Fine collected (-0.075mm Fraction) (g) =	5.97	1.19	Av. Percentage Passing 75µm Sieve(%)		1.19
D60 =	0.61	GM =		Av. Weight of Materials Accounted for (g)	492.68	98.54			
Mds --> Mass of Specimen			M1, M2 --> Mass of Sample Retained						
M1 --> Mass of each Sieve			Zr --> Cumulative % Retained						
M2 --> Mass of each + Retained Sample			100 - Zr --> Percentage Finer / Percentage cumulative Passing Through						
D10 --> Grain Diameter (Ø) at 10% finer			Cc -->Coefficient of Curveture						
D30 --> Grain Diameter (Ø) at 30% finer			Cu --> Uniformity Coefficient						
D40 --> Grain Diameter (Ø) at 40% finer			FM --> Fineness Modulus						
D60 --> Grain Diameter (Ø) at 60% finer			GM --> Grading Modulus						

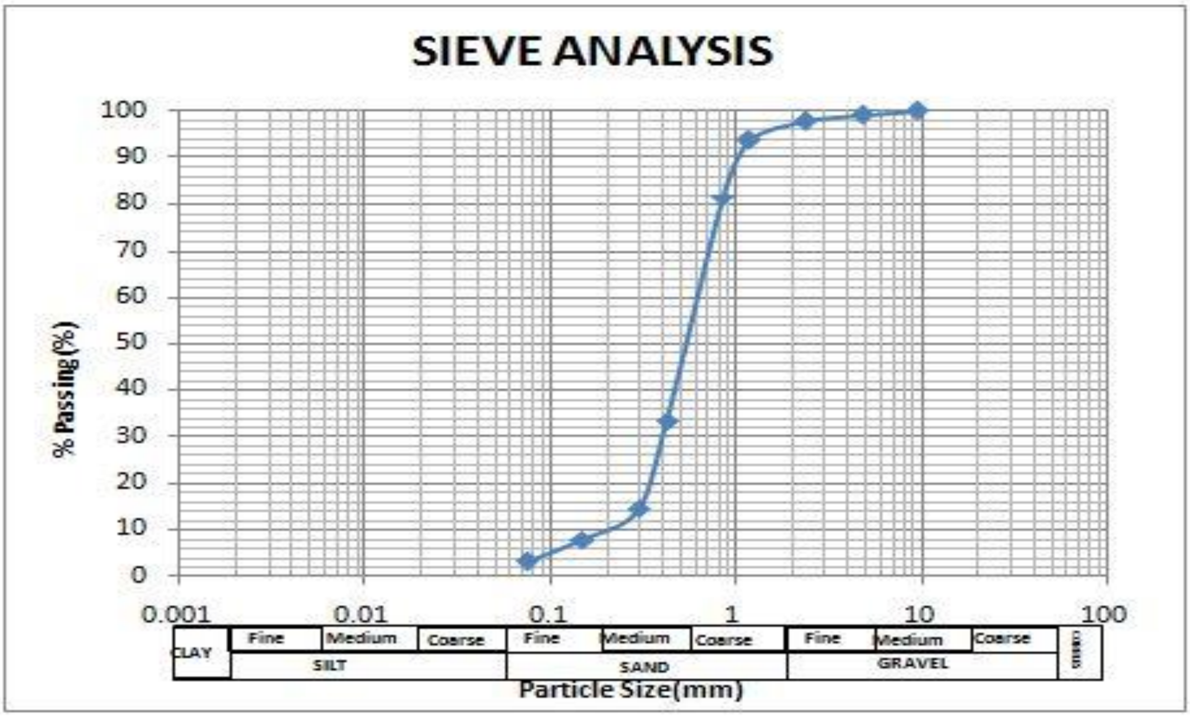

Figure 4.1 Graph of sieve analysis of the fine aggregates

Table 4.5 Coarse Aggregate for Concrete Test

Sieve Analysis	
Soil Description; Coarse Aggregate for Concrete Test	
Mass of Pan; Mp (g) =	273.20
Mass of Pan + Dry Sample; Mp + Mds (g) =	1273.20
Mass of Dry Sample; Mds (g) =	1000.00

DATA SHEET

Sieve Number	Sieve Size / Sieve opening	Mass of Weighting Sieve; (M1)	Mass of Sieve + Soil Retained (M2)	Mass of Sample Retained on each Sieve; (M2av-M1)	Percentage Retained on each Sieve; ((M2av-M1)/Mds)x 100	Cumulative percentage Retained; Zr	percentage passing; 100-Zr
#	(mm)	(g)	(g)	(g)	(%)	(%)	(%)
	26.5	637.34	637.34	0.00	0.00	0.00	100
7/8"	22.4	722.57	796.66	74.09	7.41	7.41	92.591
3/4"	19	775.95	1056.27	280.32	28.03	35.44	64.559
5/8"	16	745.76	966.35	220.59	22.06	57.50	42.5
0.53"	13.2	753.38	926.62	173.24	17.32	74.82	25.176
7/16"	11.2	812.25	928.04	115.79	11.58	86.40	13.597
3/8"	9.5	676.10	734.96	58.86	5.89	92.29	7.711
4	4.75	687.17	754.65	67.48	6.75	99.04	0.963
Pan		719.21	726.20	6.99	0.70	99.74	0.264
TOTAL		6529.73	7527.09	997.36	99.74		
Outcome							
Outcome							

% Loss During Analysis=			0.264	Weight Check (Materials Accounted For)	Weight	Percentage		
D10 =	10.0	Cc =	1.032	Av. Weight of Coarse Fraction (+4.75mm Fraction) (g) =	990.37	99.04	Maximum Aggregate Size (Identified) (mm)	22.4
D30 =	14.0	Cu =	1.900	Av. Weight of Sand Fraction (-4.75mm to +0.075mm Fraction) (g) =	6.99	0.70	Av. Percentage Passing 4.75mm Sieve(%)	0.96
D40 =	16.0	FM =	3.474	Av. Weight of Fine collected (-0.075mm Fraction) (g) =	-	-	Av. Percentage Passing 75µm Sieve(%)	-
D60 =	19	GM =		Av. Weight of Materials Accounted for (g)	997.36	99.74		

Mds --> Mass of Specimen	M1, M2 --> Mass of Sample Retained
M1 --> Mass of each Sieve	Zr --> Cumulative % Retained
M2 --> Mass of each + Retained Sample	100 - Zr --> Percentage Finer / Percentage cumulative Passing Through

D10 --> Grain Diameter (Ø) at 10% finer	Cc -->Coefficient of Curveture					
D30 --> Grain Diameter (Ø) at 30% finer	Cu --> Uniformity Coefficient					
D40 --> Grain Diameter (Ø) at 40% finer	FM --> Fineness Modulus					
D60 --> Grain Diameter (Ø) at 60% finer	GM --> Grading Modulus					

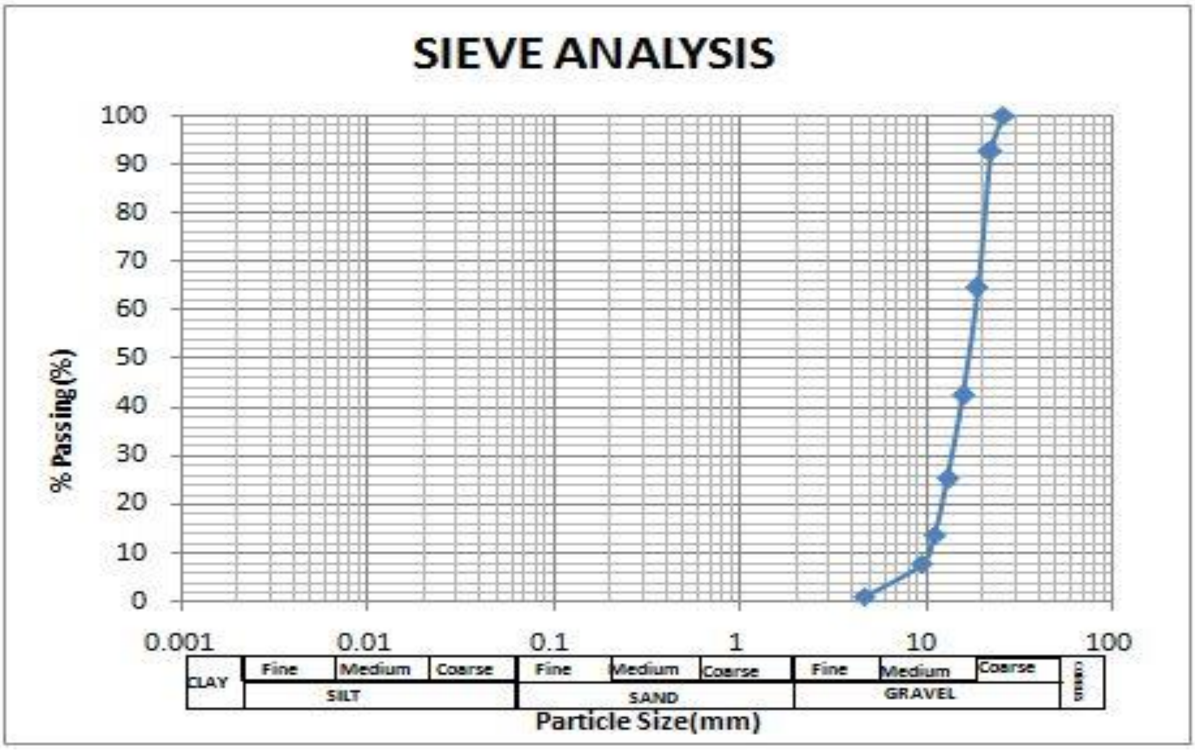

Figure 4.2 Graph of coarse aggregates

4.1.2 Mix ratios

The mix ratios presented on Table 4.1 are for Grade 50 concrete using 5%, 10% and 15% cement replacement by sugarcane bagger Sash and calcined clay

Table 4.7: Mix ratios of the components of the concrete

Observation points	C/B	W/B	SP/B	SBA /B	CC /B	CA/B	FA / B
A1	0.95	0.28364	0.03	0.02011	0.02989	1.53000	1.49893
A2	0.95	0.28364	0.03	0.02229	0.02771	1.52962	1.49856
A3	0.95	0.28364	0.03	0.02500	0.02500	1.52915	1.49811
A4	0.95	0.28364	0.03	0.02771	0.02229	1.52867	1.49764
A5	0.95	0.28364	0.03	0.02989	0.02011	1.52829	1.49727
A6	0.95	0.28364	0.03	0.02120	0.02880	1.52982	1.49875
A7	0.95	0.28364	0.03	0.02391	0.02609	1.52935	1.49829
A8	0.95	0.28364	0.03	0.02609	0.02391	1.52896	1.49791
A9	0.95	0.28364	0.03	0.02880	0.02120	1.52849	1.49745
B1	0.9	0.28364	0.03	0.04022	0.05978	1.51578	1.48500
B2	0.9	0.28364	0.03	0.04456	0.05544	1.51502	1.48425
B3	0.9	0.28364	0.03	0.05000	0.05000	1.51407	1.48333
B4	0.9	0.28364	0.03	0.05544	0.04456	1.51313	1.48242
B5	0.9	0.28364	0.03	0.05978	0.04022	1.51238	1.48167
B6	0.9	0.28364	0.03	0.04240	0.05760	1.51540	1.48464
B7	0.9	0.28364	0.03	0.04782	0.05218	1.51445	1.48371
B8	0.9	0.28364	0.03	0.05218	0.04782	1.51369	1.48296
B9	0.9	0.28364	0.03	0.05760	0.04240	1.51275	1.48204
C1	0.85	0.28364	0.03	0.06033	0.08967	1.50155	1.47107
C2	0.85	0.28364	0.03	0.06685	0.08315	1.50042	1.46996
C3	0.85	0.28364	0.03	0.07500	0.07500	1.49900	1.46856
C4	0.85	0.28364	0.03	0.08315	0.06685	1.49758	1.46718
C5	0.85	0.28364	0.03	0.08967	0.06033	1.49645	1.46607
C6	0.85	0.28364	0.03	0.06358	0.08642	1.50098	1.47051
C7	0.85	0.28364	0.03	0.07175	0.07825	1.49956	1.46913
C8	0.85	0.28364	0.03	0.07825	0.07175	1.49844	1.46802
C9	0.85	0.28364	0.03	0.08642	0.06358	1.49702	1.46662
Control	1.00	0.28364	0.03	0.00	0.00	1.54422	1.51287

4.1.3 Workability Test;

Due to the presence of superplaticizer, the result obtained was total collapse. This implies that the workability of the concrete is high.

4.1.4 Compressive Strength of the concrete produced with metakaolin and sugarcane bagasse ash;

The compressive strength of the concrete measured at the different levels of cement replacements, observation points and ages of curing are presented on Table 4.8.

Table 4.8: The compressive strengths of the concrete measured in the laboratory

Observation points	28 days in Mpa	60 days in Mpa	90 days in Mpa
A1	21.73	33.73	27.73
A2	27.87	36.87	29.87
A3	25.93	37.93	30.93
A4	29.87	39.87	32.87
A5	32.93	42.93	32.93
A6	26.31	37.25	28.99
A7	28.28	38.98	31.23
A8	27.14	41.19	29.82
A9	30.12	37.9	31.91
B1	29.4	35.23	30.37
B2	31.13	33.47	36.6
B3	31.2	35.18	30.73
B4	37.97	37.63	32.00
B5	33.88	35.69	36.8
B6	33.18	33.56	33.15
B7	35.13	34.39	32.79
B8	33.32	35.3	30.95
B9	33.96	35.13	33.28
C1	38.8	37.17	36.13
C2	44.53	45.03	47.33
C3	46.33	46.90	47.13
C4	36.01	37.83	39.67
C5	33.53	34.57	34.93
C6	44.79	44.25	44.07
C7	42.44	46.73	44.56
C8	45.47	46.86	48.47
C9	38.13	39.97	40.71
Control	34.47	33.8	35.87

4.1.5 Models for predicting of compressive strength when mix ratio is known and vise versa

Using the compressive strengths for the first five points of observation for each cement replacement level and curing ages and Equation 3.28 the response vectors are obtained for the three cement replacement levels and for the three curing ages. For cement replacement of 5%, the three response vectors corresponding to curing ages of 28 days, 60 days and 90 days are presented as contained in Table 4.3. columns1, 2 and 3.

Table 4.9: Response vectors for 5% cement replacement

	F1	F2	F3
x_1	1.143492454	1.414680896	1.174029353
x_2	1.10424301	1.411879123	1.17044623
x_3	68.73886091	86.44418408	71.70057099
x_4	67.34340362	84.6892559	70.24495342
x_1^2	0.009633663	0.01173	0.009745507
x_2^2	0.00899388	0.011681967	0.009685141
x_3^2	34.15767368	42.95583446	35.62943988
x_4^2	32.78489128	41.22942093	34.19747371
x_1x_2	0.00894805	0.011257465	0.009331619
x_1x_3	0.568222947	0.702982271	0.583397848
x_1x_4	0.556687795	0.688711161	0.57155438
x_2x_3	0.548720413	0.701591619	0.581618698
x_2x_4	0.537580667	0.687348073	0.569810773
x_3x_4	33.46424387	42.08377574	34.90611456

$$F = [x_i{}^k]^T[y^k]$$

Where F1, F2, and F3 = response vectors of 28days ,60days and 90days of ages for 5% replacement

$[x_i{}^k]^T$= transpose of the mix quantities (mix ratios) for 5% replacement in table 3.7 from A1 to A9

$[y^k]$= Compressive strength for the first five observation points of 28days, 60days and 90days of ages for 5% replacement.

For cement replacement of 10%, the three response vectors corresponding to curing ages of 28 days, 60 days and 90 days are presented as contained in Table 4.4. columns 1, 2 and 3 of the Table 4.4 represent the response vectors for curing ages of 28 days, 60 days and 90 days respectively for 10% cement replacement.

Table 4.10: Response vectors for 10% cement replacement

	F1	F2	F3
x_1	2.667182307	2.869576123	2.700333716
x_2	2.614295896	2.851431396	2.675262698
x_3	79.96100973	86.61884513	81.3884588
x_4	78.33751207	84.86014736	79.73594479
x_1^2	0.044337742	0.047406099	0.04468481
x_2^2	0.042611577	0.046799742	0.04385584
x_3^2	39.08645973	42.34099513	39.78427166
x_4^2	37.51537963	40.63907796	38.18511048
x_1x_2	0.041786463	0.045250204	0.042507617
x_1x_3	1.303764398	1.402699792	1.319970808
x_1x_4	1.277293703	1.374220029	1.293170481
x_2x_3	1.277922367	1.393841143	1.307725876
x_2x_4	1.251975489	1.365540307	1.281173365
x_3x_4	38.29286324	41.48130906	38.97649046

$$F = [x_i{}^k]^T[y^k]$$

Where F1, F2, and F3 = response vectors of 28days ,60days and 90days of ages for 10% replacement

$[x_i{}^k]^T$= transpose of the mix quantities (mix ratios) for 10% replacement in table 3.7 from A1 to A9

$[y^k]$= Compressive strength for the first five observation points of 28days, 60days and 90days of ages for 10% replacement.

For cement replacement of 15%, the three response vectors corresponding to curing ages of 28 days, 60 days and 90 days are presented as contained in Table 4.5. Columns 1, 2 and 3 of the Table 4.5 represent the response vectors for curing ages of 28 days, 60 days and 90 days respectively for 15% cement replacement.

Table 4.11: Response vectors for 15% cement replacement

	F1	F2	F3
x_1	4.745485986	4.816966195	4.911173528
x_2	4.838132495	4.877580533	4.96100435
x_3	95.78034407	96.88610635	98.66029901
x_4	93.83603745	94.91934692	96.65752311
x_1^2	0.115226709	0.117337839	0.119748501
x_2^2	0.11961309	0.120182913	0.122074291
x_3^2	46.05358604	46.58519917	47.43825055
x_4^2	44.20282106	44.71306427	45.53183296
x_1x_2	0.113116898	0.114451423	0.116575854
x_1x_3	2.281730755	2.316096911	2.361392785
x_1x_4	2.235411624	2.269080022	2.313456387
x_2x_3	2.326312507	2.345276918	2.385388057
x_2x_4	2.27909	2.297669278	2.336966147
x_3x_4	45.11871477	45.63953335	46.47526762

$$F = [x_i{}^k]^T [y^k]$$

Where F1, F2, and F3 = response vectors of 28days ,60days and 90days of ages for 15% replacement

$[x_i{}^k]^T$= transpose of the mix quantities (mix ratios) for 15% replacement in table 3.7 from A1 to A9

$[y^k]$= Compressive strength for the first five observation points of 28days, 60days and 90days of ages for 15% replacement.

4.1.5.1 The coefficients of the Models

Substituting the CC matrices and the response vectors into Equation 3.27 and solving the equation gives the coefficient vectors for the three curing ages for each level cement replacement.

For cement replacement of 5%, the three model coefficient vectors corresponding to curing ages of 28 days, 60 days and 90 days are presented as contained in Table 4.12 Columns 1, 2 and 3 .

Table 4.12: The model coefficient vectors for 5% cement replacement

	A1	A2	A3
x_1	6078.190186	-97499.41492	2982.58783
x_2	-1886.524002	-18484.47821	8634.641876
x_3	3973.96936	-24561.29187	-16220.91965
x_4	-12548.43754	-101318.3055	99920.00082
x_1^2	5561.536987	170931.0811	-83025.61981
x_2^2	9241.530701	183983.2328	-107267.73
x_3^2	18302.91167	155850.5979	-150354.5316
x_4^2	10128.91974	75764.6189	-70710.52368

x_1x_2	2182.088745	-55794.53632	11694.09686
x_1x_3	4640.282471	61371.87781	-45343.42102
x_1x_4	-9713.313873	7775.960785	52653.73743
x_2x_3	-666.3139648	-85933.16858	29122.49976
x_2x_4	5793.508423	-6707.187988	-33853.63855
x_3x_4	-11549.30504	25384.67657	54728.16431

$$[F] = [CC][a_i]$$

Where;

$F = [x_i{}^k]^T[y^k]$isvector responses of 28days, 60days and 90days of ages for 5%

$[a_i]$= coefficients vectors of 28days, 60days and 90days of

CC= $[x_i{}^k]^T.[x_i{}^k]$ ages for 5% replacement

$[a_i]$ = vector responses of 28days,60days and 90days of ages for 5% replacement, multiplied by the inverse matrix of CC.

For cement replacement of 10%, the three model coefficient vectors corresponding to curing ages of 28 days, 60 days and 90 days are presented as contained in Table 4.7. Columns 1, 2 and 3 of the Table 4.7 represent the model coefficient vectors for curing ages of 28 days, 60 days and 90 days respectively for 10% cement replacement.

Table 4.13: The model coefficient vectors for 10% cement replacement

	A1	A2	A3
x_1	105690.2786	37332.71067	-55808.95945
x_2	24218.04073	23604.48105	9126.154625
x_3	-159606.5724	-42134.52462	103819.7862
x_4	393695.9498	147360.8624	-197808.2784
x_1^2	152991.8249	79991.65443	-46823.16685
x_2^2	-12004.43826	-6506.052734	4859.330536
x_3^2	-223677.8881	-85956.19141	109456.674
x_4^2	-194942.1704	-114293.4251	42385.01053
x_1x_2	350828.7342	119162.0621	-192761.9634
x_1x_3	5043.016639	-5544.743553	-10176.55346
x_1x_4	-235353.3592	-119606.2437	77127.09851
x_2x_3	-346425.893	-171816.6875	116673.2613
x_2x_4	305707.9983	84780.05017	-194370.799
x_3x_4	-52999.43002	-10904.7887	38526.35297

$$[F] = [CC][a_i]$$

Where;

$F = [x_i{}^k]^T[y^k]$ is vector responses of 28days, 60days and 90days of ages for 10%

$[a_i]$= coefficients vectors of 28days, 60days and 90days of

CC= $[x_i{}^k]^T.[x_i{}^k]$ ages for 10% replacement

$[a_i]$ = vector responses of 28days ,60days and 90days of ages for 10% replacement, multiplied by the inverse matrix of CC.

For cement replacement of 15%, the three model coefficient vectors corresponding to curing ages of 28 days, 60 days and 90 days are presented as contained in Table 4.8. Columns 1, 2 and 3 of the Table 4.8 represent the model coefficient vectors for curing ages of 28 days, 60 days and 90 days respectively for 15% cement replacement.

Table 4.14: The model coefficient vectors for 15% cement replacement

	A1	A2	A3
x_1	-656019.3892	-727924.9095	-808407.5773
x_2	-512414.1774	-564809.3522	-622344.8576
x_3	177703.175	201859.7834	230694.3137
x_4	-296957.4733	-350702.3584	-424773.1397
x_1^2	-270451.8422	-318179.9557	-384612.0397
x_2^2	-1412837.779	-1521594.082	-1611726.077
x_3^2	839065.3658	925673.3815	1018196.896
x_4^2	375877.5576	417818.4036	467030.1849
x_1x_2	-1214023.535	-1307493.327	-1389672.175
x_1x_3	-559615.5249	-595436.6717	-621546.8668
x_1x_4	136536.6684	146991.0033	155314.7338
x_2x_3	-777894.9337	-852569.2548	-928503.5122
x_2x_4	136+-536.5901	146990.9342	155314.6866
x_3x_4	-797984.9512	-848537.9961	-878698.0972

$$[F] = [CC][a_i]$$

Where;

$F = [x_i{}^k]^T[y^k]$ is vector responses of 28days, 60days and 90days of ages for 15%

$[a_i]$= coefficients vectors of 28days, 60days and 90days of

CC= $[x_i{}^k]^T.[x_i{}^k]$ ages for 15% replacement

$[a_i]$ = vector responses of 28days,60days and 90days of ages for 15% replacement, multiplied by the inverse matrix of CC.

4.1.5.2 The compressive strengths predicted by the models

Using Equation 3.25 and the model coefficients contained on Tables 4.12, 4.13 and 4.14 the compressive strength predicted by the models are obtained and are presented on Table 4.9 for the three curing ages and the three levels of cement replacements.

Table 4.15: The compressive strengths of the concrete predicted by the models

Observation points	28 days	60 days	90 days
A1	22.99	34.14	28.48
A2	25.04	35.94	29.30
A3	27.62	38.21	30.58
A4	30.29	40.61	32.30
A5	32.39	42.42	33.67
A6	24.05	35.10	28.97
A7	26.62	37.37	30.15
A8	28.77	39.30	31.44
A9	31.38	41.57	33.07
B1	28.51	34.15	32.57
B2	31.41	34.95	32.15
B3	33.45	35.58	32.73
B4	35.95	36.41	33.15
B5	34.26	36.11	35.89
B6	30.93	34.82	31.75
B7	33.48	35.55	31.96
B8	34.95	36.04	32.58
B9	35.22	36.29	34.44
C1	38.47	36.92	36.37
C2	44.19	44.23	45.08
C3	46.02	47.33	49.09
C4	39.34	40.75	42.00
C5	31.18	32.27	32.65
C6	42.93	42.40	42.82
C7	45.00	45.77	47.12
C8	43.71	45.11	46.72
C9	36.97	38.46	39.55

Compressive strengths equations predicted by the model, for 5%, 10% and 15% replacement are given below.

For 5% cement replacement, the equations are below:

$Y_{28} = 6078.190186x_1 - 1886.524002x_2 + 3973.96936x_3 - 12548.43754x_4 + 5561.536987{x_1}^2 + 9241.530701{x_2}^2 + 18302.91167{x_3}^2 + 10128.91974{x_4}^2 + 2182.088745x_1x_2 + 4640.282471x_1x_3 - 9713.313873x_1x_4 - 666.3139648x_2x_3 + 5793.508423x_2x_4 - 11549.30504x_3x_4$

$Y_{60} = -97499.41492x_1 - 18484.47821x_2 - 24561.29187x_3 - 101318.3055x_4 + 170931.0811{x_1}^2 + 183983.2328{x_2}^2 + 155850.5979{x_3}^2 + 75764.6189{x_4}^2 - 55794.53632x_1x_2 + 61371.87781x_1x_3\ s + 7775.960785x_1x_4 - 85933.16858x_2x_3 - 6707.187988x_2x_4 + 25384.67657x_3x_4$

$Y_{90} = 2982.58783x_1 + 8634.641876x_2 - 16220.91965x_3 + 99920.00082x_4 - 83025.61981{x_1}^2 - 107267.73{x_2}^2 - 150354.5316{x_3}^2 - 70710.52368{x_4}^2 + 11694.09686x_1x_2 - 45343.42102x_1x_3 + 52653.73743x_1x_4 + 29122.49976x_2x_3 - 33853.63855x_2x_4 + 54728.16431x_3x_4$

Where Y_{28}, Y_{60} and Y_{90} are the curing ages, the x-values are the mix ratios for 5% cement replacement.

For 10% cement replacement, the equations are below:

$Y_{28} = 105690.2786x_1 + 24218.04073x_2 - 159606.5724x_3 + 393695.9498x_4 + 152991.8249{x_1}^2 - 12004.43826{x_2}^2 - 223677.8881{x_3}^2 - 194942.1704{x_4}^2 + 350828.7342x_1x_2 + 5043.016639x_1x_3 - 235353.3592x_1x_4 - 346425.893x_2x_3 + 305707.9983x_2x_4 - 52999.43002x_3x_4$

$Y_{60} = 37332.71067x_1 + 23604.48105x_2 - 42134.52462x_3 + 147360.8624x_4 + 79991.65443{x_1}^2 - 6506.052734{x_2}^2 - 85956.19141{x_3}^2 - 114293.4251{x_4}^2 +$

$119162.0621x_1x_2 - 5544.743553x_1x_3 - 119606.2437x_1x_4 - 171816.6875x_2x_3 + 84780.05017x_2x_4 - 10904.7887x_3x_4$

$Y_{90} = -55808.95945x_1 + 9126.154625x_2 + 103819.7862x_3 - 197808.2784x_4 - 46823.16685{x_1}^2 + 4859.330536{x_2}^2 + 109456.674{x_3}^2 + 42385.01053{x_4}^2 - 192761.9634x_1x_2 - 621546.8668x_1x_3 + 77127.09851x_1x_4 + 116673.2613x_2x_3 - 194370.799x_2x_4 + 38526.35297x_3x_4$

Where Y_{28}, Y_{60} and Y_{90} are the curing ages, the x-values are the mix ratios for 10% cement replacement.

For 15% cement replacement, the equations are below:

$Y_{28} = -656019.3892x_1 - 512414.1774x_2 + 177703.175x_3 - 296957.4733x_4 - 270451.8422{x_1}^2 - 1412837.779{x_2}^2 + 839065.3658{x_3}^2 + 375877.5576{x_4}^2 - 1214023.535x_1x_2 - 559615.5249x_1x_3 + 136536.6684x_1x_4 + -777894.9337x_2x_3 + 136536.5901x_2x_4 - 797984.9512x_3x_4$

$Y_{60} = -727924.9095x_1 - 564809.3522a_2x_2 + 201859.7834x_3 - 350702.3584x_4 - 318179.9557{x_1}^2 - 1412837.779{x_2}^2 + 839065.3658{x_3}^2 + 417818.4036{x_4}^2 - 1307493.327x_1x_2 - 595436.6717x_1x_3 + 146991.0033x_1x_4 - 852569.2548x_2x_3 + 146990.9342x_2x_4 + -848537.9961x_3x_4$

$Y_{90} = -808407.5773x_1 - 622344.8576x_2 + 230694.3137x_3 + -424773.1397x_4 - 384612.0397{x_1}^2 - 1611726.077{x_2}^2 + 1018196.896{x_3}^2 + 467030.1849{x_4}^2 - 1389672.175x_1x_2 - 621546.8668x_1x_3 + 155314.7338x_1x_4 - 928503.5122x_2x_3 + 155314.6866x_2x_4 - 878698.0972x_3x_4$

Where Y_{28}, Y_{60} and Y_{90} are the curing ages, the x-values are the mix ratios for 15% cement replacement.

4.1.5.3 The adequacy (goodness of fit) for using the models

The predicted compressive strengths were subjected to F –distribution test at 95% confidence level as presented on Table 4.16 to Table 4.23.

For 28 days curing age and 5% cement replacement, the model adequacy test is presented on

Table 4.16: The model adequacy test for 28 days curing age and 5% cement replacement

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $ÿ_P$	Y_M - $ÿ_M$	$(Y_P - \ddot{Y}_p)^2$	$(Y_M - ÿ_M)^2$
C1	21.73	22.99	-6.06778	-4.69145	36.81793	22.00972
C2	27.87	25.04	0.072222	-2.64381	0.005216	6.989729
C3	25.93	27.62	-1.86778	-0.06443	3.488594	0.004151
C4	29.87	30.29	2.072222	2.610645	4.294105	6.815469
C5	32.93	32.39	5.132222	4.705942	26.3397	22.14589
C6	26.31	24.05	-1.48778	-3.63269	2.213483	13.19642
C7	28.28	26.62	0.482222	-1.06175	0.232538	1.127317
C8	27.14	28.77	-0.65778	1.084234	0.432672	1.175564
C9	30.12	31.38	2.322222	3.693312	5.392716	13.64055
TOTAL	250.18	249.1435			79.21696	87.10481
MEAN	27.79778	27.68261				

LEGEND $ÿ_P = \Sigma Y_P / N$, $ÿ_M = \Sigma Y_M / N$, N = 9

$S_p^2 = \Sigma(Y_p ÿ_p) / (N – 1)$ =9.90

$S_M^2 = \Sigma(Y_M ÿ_M) / (N – 1)$ =10.89

Therefore, $S_1^2 = 10.89$ and S_2^2 =9.90

$F_{calculated} = S_1^2 / S_2^2$ =1.10

From Statistic tables, F.0.05 (8,8) = 3.39

Thus, the condition $S_1^2 / S_2^2 < F$ has been satisfied

The difference between lab result and model result is not significant

For 60 days curing age and 5% cement replacement, the model adequacy test is presented on Table 4.11.

Table 4.17: The model adequacy test for 60 days curing age and 5% cement replacement

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $ÿ_P$	Y_M - $ÿ_M$	$(Y_P - Ÿ_p)^2$	$(Y_M - ÿ_M)^2$
C1	33.73	34.14	-4.78667	-4.15556	22.91218	17.26864
C2	36.87	35.94	-1.64667	-2.35556	2.711511	5.548642
C3	37.93	38.21	-0.58667	-0.08556	0.344178	0.00732
C4	39.87	40.61	1.353333	2.314444	1.831511	5.356653
C5	42.93	42.42	4.413333	4.124444	19.47751	17.01104
C6	37.25	35.1	-1.26667	-3.19556	1.604444	10.21158
C7	38.98	37.37	0.463333	-0.92556	0.214678	0.856653
C8	41.19	39.3	2.673333	1.004444	7.146711	1.008909
C9	37.9	41.57	-0.61667	3.274444	0.380278	10.72199
TOTAL	346.65	344.66			56.623	67.99142
MEAN	38.51667	38.29556				

LEGEND $ÿ_P = \Sigma Y_P / N$, $ÿ_M = \Sigma Y_M / N$, N = 9

$S_p^2 = \Sigma(Y_p ÿ_p) / (N - 1)$ =7.08

$S_M^2 = \Sigma(Y_M ÿ_M) / (N - 1)$ =8.50

Therefore, S_1^2 = 8.50and S_2^2 =7.08

$F_{calculated} = S_1^2 / S_2^2$ =1.20

From Statistic tables, F.0.05 (8,8) =3.39

Thus, the condition $S_1^2 / S_2^2 < F$ has been satisfied

For 90 days curing age and 5% cement replacement, the model adequacy test is presented on Table 4.12.

Table 4.18: The model adequacy test for 90 days curing age and 5% cement replacement

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $ÿ_P$	Y_M - $ÿ_M$	$(Y_P - Ÿ_p)^2$	$(Y_M - ÿ_M)^2$
C1	27.73	28.48	-2.96778	-2.40444	8.807705	5.781353
C2	29.87	29.3	-0.82778	-1.58444	0.685216	2.510464
C3	30.93	30.58	0.232222	-0.30444	0.053927	0.092686
C4	32.87	32.3	2.172222	1.415556	4.718549	2.003798
C5	32.93	33.67	2.232222	2.785556	4.982816	7.75932
C6	28.99	28.97	-1.70778	-1.91444	2.916505	3.665098
C7	31.23	30.15	0.532222	-0.73444	0.28326	0.539409
C8	29.82	31.44	-0.87778	0.555556	0.770494	0.308642
C9	31.91	33.07	1.212222	2.185556	1.469483	4.776653
TOTAL	276.28	277.96			24.68796	27.43742
MEAN	30.69778	30.88444				

LEGEND $ÿ_P = \Sigma Y_P / N$, $ÿ_M = \Sigma Y_M / N$, N = 9

$S_p^2 = \Sigma(Y_p ÿ_p) / (N – 1) = 3.09$

$S_M^2 = \Sigma(Y_M ÿ_M) / (N – 1) = 3.43$

Therefore, $S_1^2 = 3.43$ and $S_2^2 = 3.09$

$F_{calculated} = S_1^2 / S_2^2 = 1.11$

From Statistic tables, F.0.05 (8,8) = 3.39

Thus, the condition $S_1^2 / S_2^2 < F$ has been satisfied

The difference between lab result and model result is not significant

For 28 days curing age and 10% cement replacement, the model adequacy test is presented on Table 4.13.

Table 4.19: The model adequacy test for 28 days curing age and 10% cement replacement

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $ÿ_P$	Y_M - $ÿ_M$	$(Y_P - \ddot{Y}_p)^2$	$(Y_M - ÿ_M)^2$
C1	29.4	28.51	-3.84111	-4.61889	14.75413	21.33413
C2	31.13	31.41	-2.11111	-171889	4.45679	2.954579
C3	31.2	33.45	-2.04111	0.321111	4.166135	0.103112
C4	37.97	35.95	4.728889	2.821111	22.36239	7.958668
C5	33.88	34.26	0.638889	1.131111	0.408179	1.279412
C6	33.18	30.93	-0.06111	-2.19889	0.003735	4.835112
C7	35.13	33.48	1.888889	0.351111	3.567901	0.123279
C8	33.32	34.95	0.078889	1.821111	0.006223	3.316446
C9	33.96	35.22	0.718889	2.091111	0.516801	4.372746
TOTAL	299.17	298.16			50.24229	46.27749
MEAN	33.24111	33.1288 9				

LEGEND $ÿ_P = \Sigma Y_P / N$, $ÿ_M = \Sigma Y_M / N$, N = 9

$S_p^2 = \Sigma(Y_p\ ÿ_p) / (N – 1) = 6.28$

$S_M^2 = \Sigma(Y_M\ ÿ_M) / (N – 1) = 5.78$

Therefore, $S_1^2 = 6.28$ and $S_2^2 = 5.78$

$F_{calculated} = S_1^2 / S_2^2 = 1.09$

From Statistic tables, F.0.05 (8,8) = 3.39

Thus, the condition $S_1^2 / S_2^2 < F$ has been satisfied

The difference between lab result and model result is not significant

For 60 days curing age and 10% cement replacement, the model adequacy test is presented on Table 4.14.

Table 4.20: The model adequacy test for 60 days curing age and 10% cement replacement

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $\ddot{y}_P$	Y_M - $\ddot{y}_M$	$(Y_P - \ddot{Y}_p)^2$	$(Y_M - \ddot{y}_M)^2$
C1	35.23	34.15	0.165556	-1.39444	0.027409	1.944475
C2	33.47	34.95	-1.59444	-0.59444	2.542253	0.353364
C3	35.18	35.58	0.115556	0.035556	0.013353	0.001264
C4	37.63	36.41	2.565556	0.865556	6.582075	0.749186
C5	35.69	36.11	0.625556	0.565556	0.39132	0.319853
C6	33.56	34.82	-1.50444	-0.72444	2.263353	0.52482
C7	34.39	35.55	-0.67444	0.005556	0.454875	3.09E-05
C8	35.3	36.04	0.235556	0.495556	0.055486	0.245575
C9	35.13	36.29	0.065556	0.745556	0.004298	0.555853
TOTAL	315.58	319.9			12.33442	4.694422
MEAN	35.06444	35.54444				

LEGEND $\ddot{y}_P = \Sigma Y_P / N$, $\ddot{y}_M = \Sigma Y_M / N$, N = 9

$S_p^2 = \Sigma(Y_p\ \ddot{y}_p) / (N - 1) = 1.54$

$S_M^2 = \Sigma(Y_M\ \ddot{y}_M) / (N - 1) = 0.59$

Therefore, $S_1^2 = 1.54$and $S_2^2 = 0.59$

$F_{calculated} = S_1^2 / S_2^2 = 2.63$

From Statistic tables, F.0.05 (8,8) = 3.39

Thus, the condition $S_1^2 / S_2^2 < F$ has been satisfied

The difference between lab result and model result is not significant

For 90 days curing age and 10% cement replacement, the model adequacy test is presented on Table 4.15.

Table 4.21: The model adequacy test for 90 days curing age and 10% cement replacement

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $ÿ_P$	Y_M - $ÿ_M$	$(Y_P - Ÿ_p)^2$	$(Y_M - ÿ_M)^2$
C1	30.37	32.57	-2.59333	-0.45444	6.725378	0.20652
C2	36.6	32.15	3.636667	-0.87444	13.22534	0.764653
C3	30.73	32.73	-2.23333	-0.29444	4.987778	0.086698
C4	32	33.15	-0.96333	0.125556	0.928011	0.015764
C5	36.8	35.89	3.836667	2.865556	14.72001	8.211409
C6	33.15	31.75	0.186667	-1.27444	0.034844	1.624209
C7	32.79	31.96	-0.17333	-1.06444	0.030044	1.133042
C8	30.95	32.58	-2.01333	-0.44444	4.053511	0.197531
C9	33.28	34.44	0.316667	1.415556	0.100278	2.003798
TOTAL	296.67	297.22			44.8052	14.24362
MEAN	32.96333	33.02444				

LEGEND $ÿ_P = ΣY_P / N$, $ÿ_M = ΣY_M / N$, N = 9

$S_p^2 = Σ(Y_p\ ÿ_p) / (N – 1)\ ) = 5.60$

$S_M^2 = Σ(Y_M\ ÿ_M) / (N – 1) = 1.78$

Therefore, $S_1^2 = 5.60$and $S_2^2 = 1.78$

$F_{calculated} = S_1^2 / S_2^2 = 3.15$

From Statistic tables, F.0.05 (8,8) = 3.39

Thus, the condition $S_1^2 / S_2^2 < F$ has been satisfied

The difference between lab result and model result is not significant

For 28 days curing age and 15% cement replacement, the model adequacy test is presented on Table 4.16.

Table 4.22: The model adequacy test for 28 days curing age and 15% cement replacement

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $ÿ_P$	Y_M - $ÿ_M$	$(Y_P - Ÿ_p)^2$	$(Y_M - ÿ_M)^2$
C1	38.8	38.47	-2.31444	-2.39778	5.356653	5.749338
C2	44.53	44.19	3.415556	3.322222	11.66602	11.03716
C3	46.33	46.02	5.215556	5.152222	27.20202	26.54539
C4	36.01	39.34	-5.10444	-1.52778	26.05535	2.334105
C5	33.53	31.18	-7.58444	-9.68778	57.5238	93.85304
C6	44.79	42.93	3.675556	2.062222	13.50971	4.25276
C7	42.44	45	1.325556	4.132222	1.757098	17.07526
C8	45.47	43.71	4.355556	2.842222	18.97086	8.078227
C9	38.13	36.97	-2.98444	-3.89778	8.906909	15.19267
TOTAL	370.03	367.81			170.9484	184.118
MEAN	41.11444	40.86778				

LEGEND $ÿ_P = \Sigma Y_P / N$, $ÿ_M = \Sigma Y_M / N$, $N = 9$

$S_p^2 = \Sigma(Y_p\ ÿ_p) / (N – 1)$ =21.37

$S_M^2 = \Sigma(Y_M\ ÿ_M) / (N – 1)$ =23.01

Therefore, S_1^2 = 23.01and S_2^2 =21.37

$F_{calculated} = S_1^2 / S_2^2$ =1.08

From Statistic tables, F.0.05 (8,8) =3.39

Thus, the condition $S_1^2 / S_2^2 < F$ has been satisfied

The difference between lab result and model result is not significant

For 60 days curing age and 15% cement replacement, the model adequacy test is presented on Table 4.17

Table 4.23: The model adequacy test for 60 days curing age and 15% cement replacement

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $ÿ_P$	Y_M - $ÿ_M$	$(Y_P - Ÿ_p)^2$	$(Y_M - ÿ_M)^2$
C1	37.17	36.92	-4.97556	-4.55111	24.75615	20.71261
C2	45.03	44.23	2.884444	2.758889	8.32002	7.611468
C3	46.9	47.33	4.754444	5.858889	22.60474	34.32658
C4	37.83	40.75	-4.31556	-0.72111	18.62402	0.520001
C5	34.57	32.27	-7.57556	-9.20111	57.38904	84.66045
C6	44.25	42.4	2.104444	0.928889	4.428686	0.862835
C7	46.73	45.77	4.584444	4.298889	21.01713	18.48045
C8	46.86	45.11	4.714444	3.638889	22.22599	13.24151
C9	39.97	38.46	-2.17556	-3.01111	4.733042	9.06679
TOTAL	379.31	373.24			184.0988	189.4827
MEAN	42.14556	41.47111				

LEGEND $ÿ_P = \Sigma Y_P / N$, $ÿ_M = \Sigma Y_M / N$, $N = 9$

$S_p^2 = \Sigma(Y_p\ ÿ_p) / (N – 1) = 23.01$

$S_M^2 = \Sigma(Y_M\ ÿ_M) / (N – 1) = 23.69$

Therefore, $S_1^2 =$ 23.69 and $S_2^2 = 23.01$

$F_{calculated} = S_1^2 / S_2^2 = 1.03$

From Statistic tables, F.0.05 (8,8) = 3.39

Thus, the condition $S_1^2 / S_2^2 < F$ has been satisfied

The difference between lab result and model result is not significant

For 90 days curing age and 15% cement replacement, the model adequacy test is presented on Table 4.18.

Table 4.24: The model adequacy test for 90 days curing age and 15% cement replacement

RESPONSE SYMBOL	Y_P	Y_M	Y_P - $ÿ_P$	Y_M - $ÿ_M$	$(Y_P - Ÿ_p)^2$	$(Y_M - ÿ_M)^2$
C1	36.13	36.37	-6.42556	-6.00778	41.28776	36.09339
C2	47.33	45.08	4.774444	2.702222	22.79532	7.302005
C3	47.13	49.09	4.574444	6.712222	20.92554	45.05393
C4	39.67	42.00	-2.88556	-0.37778	8.326431	0.142716
C5	34.93	32.65	-7.62556	-9.72778	58.1491	94.62966
C6	44.07	42.82	1.514444	0.442222	2.293542	0.19556
C7	44.56	47.12	2.004444	4.742222	4.017798	22.48867
C8	48.47	46.72	5.914444	4.342222	34.98065	18.85489
C9	40.71	39.55	-1.84556	-2.82778	3.406075	7.996327
TOTAL	383	381.4			196.1822	232.7572
MEAN	42.55556	42.37778				

LEGEND $ÿ_P = \Sigma Y_P / N$, $ÿ_M = \Sigma Y_M / N$, $N = 9$

$S_p^2 = \Sigma(Y_p\ ÿ_p) / (N – 1)) = 24.52$

$S_M^2 = \Sigma(Y_M\ ÿ_M) / (N – 1) = 29.09$

Therefore, $S_1^2 = 29.09$and $S_2^2 = 24.52$

$F_{calculated} = S_1^2 / S_2^2 = 1.19$

From Statistic tables, F.0.05 (8,8) =3.39

Thus, the condition $S_1^2 / S_2^2 < F$ has been satisfied

The difference between lab result and model result is not significant.

4.2 Discussion of Results;

The following results are discussed in this work; Mix ratios used, laboratory results on materials, physical property test results, sieve analysis of fine and coarse aggregate, workability test, compressive strength of concrete produced with the addition of sugarcane bagasse ash and calcined clay, the adequacy result from the model used.

4.2.1 Discussion of Material properties;

Packing density of the coarse aggregates for this work ranges from 2.015Kg/m^3 to 2.136Kg/m^3. The value obtained here is within the allowable range for reinforced concrete member.

According to BS EN 932-1(1997), the allowable specific gravity of coarse aggregates ranges from 2.5-2.9. The results obtained here ranges from 2.50 to 2.56. it is within allowable range.

The specific gravity for fine aggregates used for the work ranges from 2.57 to 2.61, it is within the range recommended for reinforced aggregates according to BS EN 932-1(1997).

4.2.1.2 Sieve analysis of the aggregates Result

From Table 4.5, for fine aggregate the value for Cc is 1.311 and Cu is 3.050.

Since C_c is greater than 1.0 but less than 3.0 the aggregate is well graded, Also C_u is less than 2.0 making the aggregate uniformly graded.

This means that in terms of symmetry and shape of gradation curve, Fine aggregate used is well graded and also contains uniform range of particle size.

The same is applicable to coarse aggregate test on Table 4.6, the value for Cc is 1.032 and that of Cu is 1.9, also since Cc is greater than 1.0 but less than 3.0 the aggregate is well graded , furthermore Cu is less than 2.0 making the aggregate uniformly graded.

4.2.3 Workability test;

For the production of high performance concrete, super-plasticizeris needed to reduce the water cement ratio and improves the flow of fresh concrete. Due the presence of this chemical addictive, the workability test result shows total collapse.

4.2.4 Compressive Strength of the concrete produced with metakaolin and sugarcane baggasse ash

The compressive strength (i.e. the responses) developed at the 28th day (concrete age of 28 days) at each observation point is affected by mix proportion at that point. These responses obtained from the experimental investigation were used to formulate Ibearugbulem Model. This Model was used to predict the compressive strength of sugarcane baggasse ash and metakaoline Concrete. The results obtained from the model are presented in Table 4.9. From the F-Test carried on the model, the results indicated that the differences obtained are very insignificance, which makes the model adequate to predict the strength of concrete.

4.2.5 Determination of Compressive Strength from Ibearugbulem Model

The Model obtained from this work is as shown in Equation (3.21)

$$y = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5{x_1}^2 + a_6{x_2}^2 + a_7{x_3}^2 + a_8{x_4}^2 + a_9x_1x_2 + a_{10}x_1x_3 + a_{11}x_1x_4 + a_{12}x_2x_3 + a_{13}x_2x_4 + a_{14}x_3x_4$$

The predicted compressive strength obtained from this model were subjected to F-distribution test for 95% confidence level.

Visual check for the adequacy of the model by taking a glance at the tables from Table 4.10 – Table 4.18. The condition that must be satisfied in other to prove the model satisfactory that $S^21/S^22<F$

Where F is calculated from the statistics table and S^21/S^22 is F calculated. It is observed from Tables 4.16 – 4.23 that F-calculated is always less than the F-from the statics table. It shows that the difference between the laboratory results and model results is not significant.

Therefore, the model can comfortably predict the compressive strength of high-grade concrete made with sugar cane baggasse cement concrete and Calcined-clay.

Table 4.25: Percentage difference between model results and laboratory results for 5%

Percentage difference for 5% cement replacement												
	Curing method											
	Total Immersion into a curing Tank											
	28 days curing				60 days curing				90 days curing			
	Model result	Exp. result	Diff.	(m-p) x100	Model result	Exp. result	Diff.	(m-p) x100	Model result	Exp. result	Diff.	(m-p) x 100
Mix ratio	M	P	m-p	M	M	P	m-p	M	M	P	m-p	M
x1	22.99	21.73	1.26	5.48	34.14	33.73	0.41	1.20	28.48	27.73	0.75	2.63
x2	25.04	27.87	-2.83	11.30	35.94	36.87	-0.93	2.59	29.30	29.87	-0.57	1.95
x3	27.62	25.93	1.69	6.11	38.21	37.93	0.28	0.73	30.58	30.93	-0.35	1.14
x4	30.29	29.87	0.42	1.39	40.61	39.87	0.74	1.82	32.30	32.87	-0.57	1.76
x5	32.39	32.93	-0.54	1.67	42.42	42.93	-0.51	1.20	33.67	32.93	0.74	2.19
x6	24.05	26.31	-2.26	9.39	35.10	37.25	-2.15	6.13	28.97	28.99	-0.02	0.07
x7	26.62	28.28	-1.66	6.23	37.37	38.98	-1.61	4.31	30.15	31.23	1.08	3.38
x8	28.77	27.14	1.63	5.67	39.30	41.19	-1.89	4.8	31.44	29.82	1.62	5.15
x9	31.38	30.12	1.26	4.02	41.57	37.9	3.67	8.83	33.07	31.91	1.16	3.50

Table 4.26: Percentage difference between model results and laboratory results for 10%

Percentage difference for 10% cement replacement												
Mix ratio	Curing method											
	Total Immersion into a curing Tank											
	28 days curing				60 days curing				90 days curing			
	Model result M	Exp. result P	Diff. m-p	(m-p) x100 M	Model result M	Exp. result P	Diff. m-p	(m-p) x100 M	Model result M	Exp. result P	Diff. m-p	(m-p) x 100 M
x1	28.51	29.4	-0.89	3.12	34.15	35.23	-1.08	3.16	32.57	30.37	2.20	6.75
x2	31.41	31.13	0.27	0.86	34.95	33.47	1.48	4.23	32.15	36.60	-4.45	13.84
x3	33.45	31.20	2.25	6.73	35.58	35.18	0.4	1.12	32.73	30.73	2.00	6.11
x4	35.95	37.97	-2.02	5.62	36.41	37.63	-1.28	3.51	33.15	32.00	1.15	3.47
x5	34.26	33.88	0.38	1.11	36.11	35.69	0.42	1.16	35.89	36.80	-0.91	2.54
x6	30.93	33.18	-2.25	7.27	34.84	33.56	1.28	3.67	31.75	33.15	-1.40	4.41
x7	33.48	35.13	-1.65	4.93	35.55	34.39	1.16	3.26	31.96	32.79	-0.83	2.59
x8	34.95	33.32	1.63	4.66	36.06	35.30	0.76	2.11	32.58	30.95	1.63	5.00
x9	35.22	33.96	1.26	3.58	36.29	35.13	1.16	3.19	34.44	33.28	1.16	3.37

Table 4.27: Percentage difference between model results and laboratory results for 15%

Percentage difference for 15% cement replacement												
Mix ratio	Curing method											
	Total Immersion into a curing Tank											
	28 days curing				60 days curing				90 days curing			
	Model result	Exp. result	Diff.	(m-p) x100	Model result	Exp. result	Diff.	(m-p) x100	Model result	Exp. result	Diff.	(m-p) x 100
	M	P	m-p	M	M	P	m-p	M	M	P	m-p	M
X1	38.47	38.80	-0.33	0.86	36.92	37.17	-0.25	0.68	36.37	36.13	0.24	0.66
x2	44.19	44.53	-0.34	0.77	44.23	45.03	-0.80	1.81	45.08	47.33	-2.25	4.99
x3	46.02	46.33	-0.31	0.67	47.33	46.90	0.43	0.91	49.09	47.13	1.96	3.99
x4	39.34	36.01	3.33	8.46	40.75	37.83	2.92	7.17	42.00	39.67	2.33	5.55
x5	31.18	33.53	-2.35	7.54	32.27	34.57	-2.3	7.13	32.65	34.93	-2.28	6.98
x6	42.93	44.79	-1.87	4.36	42.40	44.25	-1.85	4.36	42.82	44.07	-1.25	2.92
x7	45.00	42.44	2.56	5.68	45.77	46.73	-0.96	2.10	47.12	44.56	2.56	5.43
x8	43.71	45.47	-1.76	4.07	45.11	46.86	-1.75	3.88	46.72	48.47	-1.75	3.75
x9	36.97	38.47	-1.5	4.06	38.46	39.97	-1.51	3.93	39.55	40.71	-1.16	2.93

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the results of this work the following conclusions were made:

i. Since the experiment values were found to be very close the results predicted using Ibearugbulem model ,then the model can be used for prediction
ii. The model formulated could be used to predict the compressive strength of sugarcane bargasse ash and calcined clay within the range of experimental data collected
iii. The speed in arriving at Ibearugbulem model predicted results is very high and impressive as compared to the time used in generating the data in the laboratory.
iv. The accuracy of the model results depends on the input data. Therefore inaccuracy of data leads to inaccuracy of predicted results.
v. Strenuous and time consuming calculations do not hold when using the model.
vi. The maximum percentage difference between the results of the model and experimental results is insignificant
vii. Partial replacement of cement by 15% metakaolin and sugarcane bagasse ash into concrete mixtures has gained significant compressive strength

5.2 Recommendations

At the end this work and after meeting the specific objectives the following recommendations are made:

i. Since the model equations are adequate enough to optimize the concrete made with sugarcane bagasse ash and calcined clay, the model developed should be used to determine the compressive strength of concrete made with these addictives.

ii. students should improve in the knowledge of mathematical matrix as to handle the model

iii. More research work should be done on this work as to ascertain if the model will handle more variables than the ones used in this work.

5.3 Contributions to knowledge

The contribution to knowledge is fitting of a model for predicting of compressive strength when mix ratio is known and vise versa:

$$y = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5{x_1}^2 + a_6{x_2}^2 + a_7{x_3}^2 + a_8{x_4}^2 + a_9x_1x_2 + a_{10}x_1x_3 + a_{11}x_1x_4 + a_{12}x_2x_3 + a_{13}x_2x_4 + a_{14}x_3x_4$$

Compressive strengths equations predicted by the model, for 5%, 10% and 15% replacement are given below.

For 5% cement replacement, the equations are below:

$$Y_{28} = 6078.190186x_1 - 1886.524002x_2 + 3973.96936x_3 - 12548.43754x_4 + 5561.536987{x_1}^2 + 9241.530701{x_2}^2 + 18302.91167{x_3}^2 + 10128.91974{x_4}^2 + 2182.088745x_1x_2 + 4640.282471x_1x_3 - 9713.313873x_1x_4 - 666.3139648x_2x_3 + 5793.508423x_2x_4 - 11549.30504x_3x_4$$

$$Y_{60} = -97499.41492x_1 - 18484.47821x_2 - 24561.29187x_3 - 101318.3055x_4 + 170931.0811{x_1}^2 + 183983.2328{x_2}^2 + 155850.5979{x_3}^2 + 75764.6189{x_4}^2 - 55794.53632x_1x_2 + 61371.87781x_1x_3\ s + 7775.960785x_1x_4 - 85933.16858x_2x_3 - 6707.187988x_2x_4 + 25384.67657x_3x_4$$

$$Y_{90} = 2982.58783x_1 + 8634.641876x_2 - 16220.91965x_3 + 99920.00082x_4 - 83025.61981{x_1}^2 - 107267.73{x_2}^2 - 150354.5316{x_3}^2 - 70710.52368{x_4}^2 + 11694.09686x_1x_2 - 45343.42102x_1x_3 + 52653.73743x_1x_4 + 29122.49976x_2x_3 - 33853.63855x_2x_4 + 54728.16431x_3x_4$$

For 10% cement replacement, the equations are below:

Y_{28}= $105690.2786x_1 + 24218.04073x_2 - 159606.5724x_3 + 393695.9498x_4 + 152991.8249{x_1}^2 - 12004.43826{x_2}^2 - 223677.8881{x_3}^2 - 194942.1704{x_4}^2 + 350828.7342x_1x_2 + 5043.016639x_1x_3 - 235353.3592x_1x_4 - 346425.893x_2x_3 + 305707.9983x_2x_4 - 52999.43002x_3x_4$

Y_{60}= $37332.71067x_1 + 23604.48105x_2 - 42134.52462x_3 + 147360.8624x_4 + 79991.65443{x_1}^2 - 6506.052734{x_2}^2 - 85956.19141{x_3}^2 - 114293.4251{x_4}^2 + 119162.0621x_1x_2 - 5544.743553x_1x_3 - 119606.2437x_1x_4 - 171816.6875x_2x_3 + 84780.05017x_2x_4 - 10904.7887x_3x_4$

Y_{90}= $-55808.95945x_1 + 9126.154625x_2 + 103819.7862x_3 - 197808.2784x_4 - 46823.16685{x_1}^2 + 4859.330536{x_2}^2 + 109456.674{x_3}^2 + 42385.01053{x_4}^2 - 192761.9634x_1x_2 - 621546.8668x_1x_3 + 77127.09851x_1x_4 + 116673.2613x_2x_3 - 194370.799x_2x_4 + 38526.35297x_3x_4$

Where Y_{28}, Y_{60} and Y_{90} are the curing ages, the x-values are the mix ratios for 10% cement replacement.

For 15% cement replacement, the equations are below:

Y_{28}= $-656019.3892x_1 - 512414.1774x_2 + 177703.175x_3 - 296957.4733x_4 - 270451.8422{x_1}^2 - 1412837.779{x_2}^2 + 839065.3658{x_3}^2 + 375877.5576{x_4}^2 - 1214023.535x_1x_2 - 559615.5249x_1x_3 + 136536.6684x_1x_4 + -777894.9337x_2x_3 + 136536.5901x_2x_4 - 797984.9512x_3x_4$

Y_{60}= $-727924.9095x_1 - 564809.3522a_2x_2 + 201859.7834x_3 - 350702.3584x_4 - 318179.9557{x_1}^2 - 1412837.779{x_2}^2 + 839065.3658{x_3}^2 + 41718.4036{x_4}^2 - 1307493.327x_1x_2 - 595436.6717x_1x_3 + 146991.0033x_1x_4 - 852569.2548x_2x_3 + 146990.9342x_2x_4 + -848537.9961x_3x_4$

$Y_{90} = -808407.5773x_1 - 622344.8576x_2 + 230694.3137x_3 + -424773.1397x_4 - 384612.0397{x_1}^2 - 1611726.077{x_2}^2 + 1018196.896{x_3}^2 + 467030.1849{x_4}^2 - 1389672.175x_1x_2 - 621546.8668x_1x_3 + 155314.7338x_1x_4 - 928503.5122x_2x_3 + 155314.6866x_2x_4 - 878698.0972x_3x_4$

Where Y_{28}, Y_{60} and Y_{90} are the curing ages, the x-values are the mix ratios for 15% cement replacement.

REFERENCES

Al menhosh, A.A(2017), An experimental study of higher performance concrete using metakaolin additive and polymer admixture. University of Salford Manchester.

Ambroise, J., maximilien ,S., & pera, J .(1994). Properties of metakaolin blended cements. Advanced cement Based Materials, 1(4),161-168.

American Concrete Institute (2010). ***Concrete terminology***

American Concrete Institute Committee Report and IS 9103 and 1999.

Anjali Prajapati, Piyush Prajapati, Mohammed Qureshi. (2017). An experimental study on high performance concrete using mineral admixtures.

Arif, E.; Clark, M.W. Lake, N. Sugar cane bagasse ash from a high-efficiency co-generation boiler as filler inconcrete. Constr. Build. Mater. **2017**, 151, 692–703.

ASTM C 330 (2009). Standard Testing method for determining Density of Structural Lightweight Concrete. ASTM International West Conshohocken, PA, 20180, 157–167.

Bahurudeen, A.; Kanraj, D.; Dev, V.G.; Santhanam, M. Performance evaluation of sugarcane bagasse ashblended cement in concrete. Cem. Concr. Compos. **2015**, 59, 77–88.

Bahurudeen, A.; Santhanam, M. Performance evaluation of sugarcane bagasse ash-based cement for durable concrete. Emerg. Binder Mater. 2014, 275–281.

Balaji Kvgd (2015),Partial replacement of cement in concrete with sugarcane Bagasse Ash. GITAM University.

Bapat, J. D. (2012). Mineral admixtures in cement and concrete. CRC press.

Bhavikatti, S.S. (2000). Elements of civil engineering. New Delhi:Vikas publishing house

Bredy, P., Chabannet, M., & Pera, J. (1989). Microstructural and porosity of metakaolin blended cements. Paper presented at the In MRS proceedings Cambridge University Press England

Brown, A. (1991), Nerve Cells and Nervous Systems, Springer-Verlag, Berlin.

BS 812. (1995). Aggregate test: - Method for determination of particle size distribution. Part 103British Standard Institute. London

BS EN 197 (2000). Cement. Composition, specifications and conformity criteria for common cements. Part 1. British Standard Institute London.

BS EN 932. (1997). Test for general properties of aggregate. Method of sampling. Part 1. British Standard Institute. London

BS EN 12390-3:2009 - Testing hardened concrete.

BS 3797. (1964). Lightweight aggregate for concrete. Part 1: British Standard Institute

Chusilp, N.; Chai, J.; Kiattikomol, K. Effects of LOI of ground bagasse ash on the compressive strength and sulfate resistance of mortars. Constr. Build. Mater. 2009, 23, 3523–3531.

Concrete Sustainability, Madrid, Spain, 13–15 June 2016; pp. 576–596.,containing ground bagasse ash. Constr. Build. Mater. **2015**, 101, 983–989., containing ground bagasse ash. Constr. Build. Mater. **2015**, 101, 983–989. Department of civil engineering, Faculty of engineering of technology and research, Bardoli, India.

F.Demir, A new way of prediction elastic modulus of normal and high strength concrete-fuzzy logic, Cement Concr Res, 2005, 35(8), pp.1531–1538.

Ganesan, K.; Rajagopal, K.; Thangavel, K. Evaluation of bagasse ash as supplementary cementitious material. Cem. Concr. Compos. 2007, 29, 515–524.

Ganesan, K.; Rajagopal, K.; Thangavel, K. Evaluation of bagasse ash as corrosion resisting admixture for carbon steel in concrete. Anti-Corros. Methods Mater. 2007, 54, 230–236.

Gar, P.S.; Suresh, N.; Bindiganavile, V. Sugar cane bagasse ash as a pozzolanic admixture in concrete for resistance to sustained elevated temperatures. Constr. Build. Mater. 2017, 153, 929–936

Guang, N.H. and Zong, W.J. Prediction of compressive strength of concrete by neural Networks", Cement and Concrete Research, 30(8), 2000, pp. 1245-1250.

Henry G, Russell (1997), high performance concrete-from building to bridges, concrete international volume 19.1

Hussein, A.A.E.; Shafiq, N.; Nuruddin, M.F.; Memon, F.A. Compressive strength and microstructure of sugar cane bagasse ash concrete. Res. J. Appl. Sci. Eng. Technol. 2014, 7, 2569–2577.

I. Flood & N.kastam, 1994,Neural Network in civil engineering 1; Principles and understanding ASCE.

Ippei, M, Takafumi N and Manbu Kanematsu. (2006). *Optimization of the concrete mix proportions centered on Fresh properties through the genetics algorithm.* University of Tokyo, Japan.

Ippei, M., Manabu Kanemastu, Takafumu Noguchi and FuminoriTomosawa.(2000).Optimization of mix proportion of concrete under various severe conditions by applying genetic algorithm. University of Tokyo, Japan.

Jayminkumar A. Patel & Dr.D.B. Raijiwale (2015). Global journal of Research in Engineering, Volume 15, issue 5, Version 1.0

Joshaghani, A.; Ramezanianpour, A.A.; Rostami, H. Effect of incorporating Sugarcane Bagasse Ash (SCBA) in mortar to examine durability of sulfate attack. In Proceedings of the Second International Conference.

Kannan, V., and Ganesan, K. (2014) .Chloride and chemical resistance of self compacting concrete containing rice husk ask and metakaolin . Construction and Building materials , 51,225-234.doi;10.1016/j. conbuildmat.2013.10.050.

Kasperkiewicz, J., Racz, J., and Dubrawski, A. (1995). “HPC strength prediction using artificial neural network”.*Journal of Computing in Civil Engineering*, ASCE, Vol. 9, No. 4, pp. 279–284.

Khatib, J.M., & Wild, S, (1996) . pore size distribution of metakaolin paste. Cement and concrete Research, 26(10), 1545-1553.

Khatib, J.M., & Wild, S, (1998) . Sulphate resistance of metakaolin motar. Cement and concrete research, 28(1), 83-92.

Lai, S. and Serra, M. Concrete strength prediction by means of neural networks", Construction and Building Materials, 11(2), 1997, pp. 93-98.

Lee, K.M. and Buyukozturk, O. (1995), ―Fracture toughness of mortar-aggregate interface in high-strengthconcrete‖, ACI Materials Journal, v 92, n 6

M. Ranjitham, B. Piranesh, A. Vennila (2014), “Experimental Investigation on High Performance Concrete with Partial Replacement of fine aggregate by Foundry Sand with cement by Mineral Admixtures “.

Madeh Izat Hamakareem.(2013). High-Performance Concrete: Composition, and Features. Concrete technology.

Marinos, A. S.,Katsiotis, M.S.,Gallias, J.L.,and Beazi-Katsioti, M. (2015). An investigation of the durability of air cured concretes containing metakaolin . International journal of Engineering and Technical Research (IJETR).3(8).

Microstructure, Properties and Materials. University of California Berkeley

Mehta & Monteiro. (1993). Properties of cement mortar produced from mixed waste. Journal Environmental Engineering Science.

Moiseas, F., and Joseph, C. (2000).pore size distribution and degree of hydration of metakaolin-cement pastes. Cement and concrete Research , 30,561-569.

Montakarntiwong, K.; Chusilp, N.; Tangchirapat, W.; Jaturapitakkul, C. Strength and heat evolution ofconcretes containing bagasse ash from thermal power plants in sugar industry. Mater. Des. 2013, 49, 414–420

Mr. Lavanya M.R,Sugumaran .B, Pradeep. T (2012). “*An Experimental study on the compressive strength of concrete by partial replacement of cement with SCBA*”.International journal of Engineering Inventions, Volume 1.

Mr. Sabale Vishal Dhondiram , Miss. Borgave Manali Deepak ,Mr. Shinde Suraj Dadasaheb ,Miss. Bhagwat MayuriDattatray "Experimental Study On High Performance Concrete"

Muthu Kumar. T, Sirajudeen. K (2016), “Experimental Investigation on High Performance Concrete Using AlternateMaterials.

Narmatha, M., and Felixkala, T.(2017). Analysis and mechanical properties of metakaolin using As a partial Replacement of concrete in cement. International journal of Advanced Research, Ideas and Innovations in Technology.

Neville, A.M. (2011). Properties of Concrete, 5th ed. Pearson Education Ltd.,

Neville, M.A and Brooks J (1987). Concrete technology 2nd ed. England: person education ltd.

Neville, M.A.(2011). Properties of concrete (5th ed.) .90 Tottenham Court Road. London WIT 4LP . Licensing Agency Ltd.

Oh, J.W., Lee, I.W., Kim, J.T., and Lee, G.W. (1999). "Application of neural networks for proportioning of concrete mixes."*ACI Material Journal*, Vol. 96, No. 1, pp. 61–67.

Okoroafor, S.U; Anyanwu S.C and Lewechi Anyaogu (2017). Mathematical model to to predict the compressive strength of sugarcane Baggase concrete. International journal of scientific and engineering research. Vol.9 iss 1.

Otoze , H.S. Amartey, Y.D Sada, B.H Ahmed, H.A.Sanni, M.I & Suleiman M.A. (2012). Characterization of sugarcane baggase ash and ordinary Portland cement blends in concrete. Proceedings 4th African Built Environment Research Conference Abuja, Nigeria.

Palomo, A., Blanco-Varela, M. T., Granizo, M. L., Puertas, F., Vazquez, T., and Grutzeck, M. W. (1999). Chemical stability of cementitious materials based on metakaolin. *cement and concrete research, 29*(7), 997-1004 4

P. Kumar Mehta & Paulo J. M Monteiro. (2001). concrete

Rajeev Mishra.(2017**).** High performance concrete using admixture. International conference on advance studies in engineering and sciences.

Ramezanianpour, A.A. (2014). Metakaolin. Springer Berlin Heidelberg.

Rerkpiboon, A.; Tangchirapat,W.; Jaturapitakkul, C. Strength, chloride resistance, and expansion of concretes

Rerkpiboon, A.; Tangchirapat,W.; Jaturapitakkul, C. Strength, chloride resistance, and expansion of concretes

Rossignolo, J.A.; Rodrigues, M.S.; Frias, M.; Santos, S.F.; Savastano, H. Improved interfacial transition zonebetween aggregate-cementitious matrix by addition sugarcane industrial ash. Cem. Concr. Compos. **2017**,

Rukzon, S.; Chindaprasirt, P. Utilization of bagasse ash in high-strength concrete. Mater. Des. **2012**, 34, 45–50.

Shetty M. S. (2005). ***Concrete Technology, Theory and Practice.*** revised ed, pp. 124-217,New Delhi: S. Chand and Company Ltd,

Shetty, M.S. (2005). Concrete Technology. New Delhi: Rejendra ravindra printers

Siddique, R. (2007) . Waste materials and by-products in concrete. Springer science and business media.

Siddique, R., & Khan, M.I (2011). Supplementary Cementing Materials. Engineering materials. Springer.

Singh, P. (2008). Civil Engineering Materials. New Delhi: S.K Kataria.

Srinivasan, R.; Sathiya, K. Experimental study on bagasse ash in concrete. Int. J. Serv. Learn. Eng. **2010**, 5, 60.

Srinivasan, R.; Sathiya, K. Experimental study on bagasse ash in concrete. Int. J. Serv. Learn. Eng. 2010, 5, 60.

Srinivasan, R.; Sathiya, K. Experimental study on bagasse ash in concrete. Int. J. Serv. Learn. Eng. 2010

Srinivasu, K., Krishna sai, M.L.N.,& Venkata Sairam Kumar, N. (2014) . A review on use of metakaolin in cement morta and concrete. Paper presented at the international journal of innovative Research in Science, Engineering and Technology.

Tafraoui, A., Escadeillas, G., Lebaili, S., &Vidal , T. (2009) . Metakaolin in the formulation of UHPC. Construction and Building Materials, 23(2), 669-674.

Tantawy, M.A. El-Roudi, A.M.; Salem, A.A. Immobilization of Cr(VI) in bagasse ash blended cement pastes.Constr. Build. Mater. **2012**, 30, 218–223.

Targana, S,, Olgun, A., Erdoganb, Y., and Sevinc, V. (2002) . Effects of supplementary cementing materials on the properties of cement and concrete. Cement and concrete research , 32, 1551-1558.

Thomas, Blanksvard, (2009) . Strengthening of concrete structures by the use of mineral based composites. Lulea University of technology.

Thomas, M. (2013). Supplementary Cementing Materials in concrete. Tylor & Francis Group.

Wild, S.,& Khatib, J. M.(1997). Portlandite consumption in metakaolin cement pastes and mortars. Cement and concrete research.

Yeh, I.C. Modeling of strength of high performance concrete using artificial neural networks", cement and Concrete Research, 28(12), 1998, pp. 1797-1808

Zhang,M.H., and Malhotra, V.M. (1995). Characteristics of a thermally activated aluminosilicate pozzolanic material and its use in concrete. Cement and Concrete Research, 25(8), 1713-1725