CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Concrete is a mixture of water, cement or binder, and aggregates. Chemical admixtures are also incorporated in most modern concrete constituents. Here, the binder phase for concrete is assumed to be based on Portland cement, the aggregates phase is the coarse and fine aggregates(Akinkurolere et al; 2007; Neville and Brook; 2008; Matthias; 2010).. This work is concerned with the effects of fine aggregates on the compressive strength and the flexural strength of concrete. It deals not primarily with fine aggregates, but with the role these fine aggregates play in the compressive and flexural strength of concrete, or how these fine aggregates affect the strengths of their resulting concretes. The investigation argues for a better understanding and appreciation of the role of fine aggregates, and illustrates how these fine aggregates crucially influence the strength of the composite material. It departs from the outdated view of natural sand seen as the only fine aggregates used in concrete production. A materials science view is taken in which each constituent of concrete with various aggregates is important in its own right, with interaction between the constituents governing the overall properties.

Currently many developing countries of the world have taken a major initiative on developing their infrastructures such as express highways, power projects and industrial structures etc. To meet the requirements of globalization, in the construction of buildings and other structures, concrete plays the rightful role and a large quantum of concrete is being utilized. River sand, which is one of the constituents used in the production of conventional concrete, has become highly expensive and also scarce. The environment is not spared as our rivers, streams and water ways have been plundered and destroyed due to the activities of people extracting these fine aggregate. In the backdrop of such a bleak atmosphere, there is large demand for alternative materials from industrial waste. The utilization of chipping dust which is also called dust of quarry rock is a waste product from quarry crushing machine, and has been accepted as a building material. As a result, a sustained research and developmental works have been under-taken with respect to increasing application of this industrial waste to be converted to wealth and employment generation. The level of utilization of quarry dust in the industrialized nations like Australia, France, Germany and UK have reached more than 60% of its total production (Vijayshree; 2012).

This work presents the feasibility of the usage of grit known as quarry dust, as a hundred percent substitute for river sand in a Conventional Concrete Mix. Tests were conducted on cubes cast to study the compressive strengths and the flexural strength of concrete made with river sand as fine aggregates and that made from quarry dust on the other hand as fine aggregates, which is a waste material. At the end of the comparison, models were developed based on Osadebe's, Ibearugbulem's regression models and regression model developed from MINITAB 17, and the results compared, computer programmes were written based on these models. The computer programs developed for each models will make it easier to determine the compressive strength and flexural strengths associated with each model or the mix that will give you a particular compressive or flexural strength.

1.2 Problem statement

The importance of concrete to the construction industries cannot be over emphasis, because large volume of concrete is been used every day during construction processes. One of the constituents in the production of concrete "river sand" has become very expensive and scarce because of the depletion of river beds. The compressive and flexural strengths of concrete depend on the properties of the materials by which it is made. Such materials are the coarse aggregates, fine aggregates, cement and quality and quantity of water used. In respect to this study which is to compare the compressive strengths of concrete made with river sand, and that made with chipping dust, are all geared towards finding an alternative replacement to river sand which is in constant use, due to the massive infrastructural development going on in Nigeria. Because of the depletion of river sand, this work is trying to find a replacement which will be cheap and affordable. Quarry dust is the material selected to be used in replacing river sand because in term of size, it has the same similarity as river sand though more finer.

Also quarry dust is a waste product produced in the course of reducing quarry lump in to various sizes in the quarry industries, and this waste is a very big problem to the society, because of its pollutant nature to the environment. This work is looking into how this waste can be put into good used and hence eliminate the problem cause by this waste to the society.

1.3 Aim and Objectives

The aim of this research is to model the strengths of concrete produced with river sand and quarry dust as fine aggregate.

The objectives of this research are to:

i) Experimentally determine the compressive and flexural strength of concrete made with river sand and quarry dust;

ii) Model the compressive and flexural strengths of concrete made with river sand and that made with quarry dust as fine aggregate; and

iii) Develop simulation software for the prediction of compressive and flexural strengths of concrete made with river sand and quarry dust as fine aggregate.

1.4 Significance of the study

This work is to compare the compressive strengths and flexural strengths of river sand and quarry dust in concrete work to generate a model based on Osadebe's and Ibearugbulem's regression models to give an optimum compressive strengths with its mix ratios. If the compressive strength and flexural strengths optimized for quarry dust is very close or higher than that optimised for river sand, recommendation will be made based on these for the replacement of river sand with quarry dust. These recommendations made will as well minimize the cost of sand used for construction. Another vital benefit of this study is to use waste material obtained from the quarry crushing industries during crushing operation in the production of concrete, thereby reduce the problem of pollution caused by this waste.

1.5 Scope of work

This project research is limited to the study of the effects of two fine aggregates materials used in concrete production on the compressive and flexural strengths of concrete, and to develop models based on Osadebe's regression models, Ibearugbulem's regression models and regression model from MINITAB 17 in other to optimize their compressive strength, flexural strength and also to develop a computer programs to help in obtaining a given compressive strength/flexural strength when the mix ratio is known, or mix ratios when the compressive strength/flexural strength is known. These materials are river sand and quarry dust. Parameters like density, grain size distribution and slump values of the concretes were also carried out in the laboratory. The work will focus on the production of concrete cubes and beams in accordance to BS EN 12390 – 1: 2000. The cubes and the beams are based on the concrete produced with river sand as fine aggregate and that produced with quarry dust as fine aggregate.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Concrete is an assemblage of cement, aggregate and water, hence it is a composite material. The most commonly used fine aggregate is sand derived from river banks. The global consumption of natural sand is too high due to its extensive use in concrete. The demand for natural sand is quite high in developing countries owing to rapid infrastructural growth which results supply scarcity. Therefore, construction industries of developing countries are in stress to identify alternative materials to replace the demand for natural sand. On the other hand, the advantages of utilization of by-products or aggregates obtained as waste materials are pronounced in the aspects of reduction in environmental load & waste management cost, reduction of production cost as well as augmenting the quality of concrete (Lohani et al; 2012).

In this context, fine aggregate has been replaced by quarry dust, a by-product of stone crushing unit, in other to make a comparative analysis for different parameters which are tested in the laboratories in other to determine the suitability of the replacement in accordance to the British Standard of Specifications for its strength. Quarry dust has been used for different activities in the construction industry such as road construction and manufacture of building materials such as light weight aggregates, bricks, and tiles. Crushed rock aggregates are more suitable for the production of high strength concrete compared to natural gravel and sand (Lohani et al; 2012).

High percentage of dust in the aggregate increases the fineness and the total surface area of aggregate particles. The surface area is measured in terms of specific surface, i.e. the ratio of the total surface area of all the particles to their volume. The main objective is to provide more information about the effects of various proportion of dust content as partial replacement of crushed stone fine aggregate on workability, air content, compressive strength, tensile strength, absorption percentage of concrete. Attempts have been made to investigate some property of quarry dust and the suitability of those properties to enable quarry dust to be used as partial replacement material for sand in concrete (Celik et al; 1996) . The use of quarry dust in concrete is desirable because of its benefits such as useful disposal of by products, reduction of river sand consumption as well as increasing the strength parameters and increasing the workability of concrete (Jain et. Al; 1999). It is used for different activities in the construction industries such as road construction, manufacture of building materials, bricks, tiles and autoclave blocks.

Furthermore, a group of science and engineering researchers, in their work titled "STRENGTH OF CONCRETE CONTAINING DIFFERENT TYPES OF FINE AGGREGATE " determined the strength of concrete made with various fine aggregates, such as natural sand ,artificial sand, quarry dust and the combination of both natural and artificial sands. The results they obtained and concluded was that among the above four fine aggregate samples; Grit or chipping dust gives the maximum compressive strength (Sachin et al; 2012). Though grit and artificial sand gives nearly same results, grit is more preferable than artificial sand as it's more economical. Grits of various types obtained from various sources affects the strength and durability of concrete while comparatively more uniqueness is achieved in case of artificial sand. The use of manufactured sand in the construction industry helps to prevent unnecessary damages to the environment and provide optimum exploitation of the resources. Manufactured sands are made by crushing aggregate to sizes appropriate for use as a fine aggregate. During the crushing process the manufactured sand have irregular shapes and more fine particles contributing to improved compressive strength, compared to natural sand control mix. Due to the irregular particle shape of the manufactured sand, in addition to the reduced amount of water cement ratio, manufactured sand is more important for high strength concrete mixes. Manufactured sand like quarry dust offers important economic advantages in regions where the availability of natural sand is scarce or in cities where transportation cost is high. The use of manufactured sand in the construction industry helps to prevent unnecessary damages to the environment and provide optimum exploitation of the resources.

Moreover, some alternatives materials have already been used as a part of natural sand e.g. fly ash, slag limestone and siliceous stone powder were used in concrete mixtures as a partial replacement of natural sand (Priyanka et al; 2012). However, scarcity in required quality is the major limitation in some of the above materials. Nowadays sustainable infrastructural growth demands the alternative material that should satisfy technical requisites of fine aggregate as well as it should be available abundantly. Amnon et al;(2006) studied the effect of high levels of fines content on concrete properties. Hudson; (1997) has taken a review of various tests in his article manufactured sand for concrete. Ilangovan et al; (2006) studies the strength and behaviour of concrete by using crushed rock dust as fine aggregate, they investigated the possibility of using crushed rock as 100 % replacement for sand, with varying compacting factors. Nagraj; (2000) studied the proportioning concrete mixes with rock dust as fine aggregate. Safiuddin et al; (2007) carried out an investigation on utilization of quarry waste fine aggregate in concrete mixtures.

2.2 Historical Development of Concrete

Concrete is a manmade building material that looks like stone. It is used in building construction, it consisting of a hard, chemically inert particulate substance, known as an aggregate (usually made from different types of sand and gravel), that is bonded together by cement and water (Bellis; 2013). The word “concrete” is derived from the Latin *concretus*, meaning “to grow together.” Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together. Alternatively, we can say that concrete is a composite material that consists essentially of a binding medium in which are embedded particles or fragments of aggregates. Depending on what kind of binder is used, concrete can be named in different ways. For instance, if a concrete in made with non hydraulic cement, it is called non hydraulic cement concrete; if a concrete made of hydraulic cement, it is called hydraulic cement concrete; if a concrete is made of asphalt, it is called asphalt concrete; if a concrete is made of polymer, it is called polymer concrete. Both non hydraulic and hydraulic cement need water to mix in and react. They differ here in the ability to gain strength in water. Non hydraulic cement cannot gain strength in water, while hydraulic cement does.

Non hydraulic cement concretes are the oldest used in human history. As early as around 6500 BC, non hydraulic cement concretes were used by the Syrians and spread through Egypt, the Middle East, Crete, Cyprus, and ancient Greece (Zongji Li; 2011). However, it was the Romans who refined the mixture’s use. The non hydraulic cements used at that time were gypsum and lime. The Romans used a primal mix for their concrete. It consisted of small pieces of gravel and coarse sand mixed with hot lime and water, and sometimes even animal blood. The Romans were known to have made wide usage of concrete for building roads. It is interesting to learn that they built some 5300 miles of roads using concrete. Concrete is a very strong building material. Historical evidence also points out that the Romans used pozzalana, animal fat, milk, and blood as admixtures for building concrete. To trim down shrinkage, they were known to have used horse hair.The Egyptians used gypsum instead of lime because it could be calcined at a much lower temperatures. As early as about

3000 BC, the Egyptians used gypsum mortar in the construction of the Pyramid of Cheops in Gaza. However, this pyramid was looted long before archaeologists knew about the building materials used. The Chinese also used lime mortar to build the Great Wall in the Qin dynasty (220 BC)

Historical evidence shows that the Assyrians and Babylonians used clay as the bonding material. A hydraulic lime was developed by the Greeks and Romans using limestone containing argillaceous (clayey) impurities. The Greeks even used volcanic ash from the island of Santorin, while the Romans utilized volcanic ash from the Bay of Naples to mix with lime to produce hydraulic lime. It was found that mortar made of such hydraulic lime could resist water. Thus, hydraulic lime mortars were used extensively for hydraulic structures from second half of the first century BC to the second century AD. However, the quality of cementing materials declined throughout the Middle Ages. The art of burning lime was almost lost and siliceous impurities were not added. High-quality mortars disappeared for a long period.

In 1756, John Smeaton was commissioned to rebuild the Eddystone Light house off the coast of Cornwall, England. Realizing the function of siliceous impurities in resisting water, Smeaton conducted extensive experiments with different limes and pozzolans, and found that limestone with a high proportion of clayey materials produced the best hydraulic lime for mortar to be used in water (Zongji Li, 2011). Eventually, Smeaton used a mortar prepared from a hydraulic lime mixed with pozzolan imported from Italy. He made concrete by mixing coarse aggregate (pebbles) and powdered brick and mixed it with cement, very close to the proportions of modern concrete. The rebuilt Eddystone Lighthouse lasted for 126 years until it was replaced with a modern structure. After Smeaton's work, development of hydraulic cement proceeded quickly James Parker of England filed a patent in 1796 for a natural hydraulic cement made by calcining nodules of impure limestone containing clay. Vicat of France produced artificial hydraulic lime by calcining synthetic mixtures of limestone and clay. Portland cement was invented by Joseph Aspdin of England. The name Portland was coined by Aspdin because the colour of the cement after hydration was similar to that of limestone quarried in Portland, a town in southern England. Portland cement was prepared by calcining finely ground limestone, mixing it with finely divided clay, and calcining the mixture again in a kiln until the CO_2 was driven off. This mixture was then finely ground and used as cement. However, the temperature claimed in Aspdin's invention was not high enough to produce true Portland cement. It was Isaac Johnson who first burned the raw materials to the clinkering temperature in 1845 to produce modern Portland cement. After that, the application of Portland cement spread quickly throughout Europe and North America. The main application of Portland cement is to make concrete. It was in Germany that the first systematic testing of concrete took place in 1836. The test measured the tensile and compressive strength of concrete. Aggregates are another main ingredient of concrete, and which include sand, crushed stone, clay, gravel, slag, and shale. Plain concrete made of Portland cement and aggregate is usually called the first generation of concrete. The second generation of concrete refers to steel bar-reinforced concrete. Francois Coignet was a pioneer in the development of reinforced concrete. (Day et al; 1996). Coignet started experimenting with iron-reinforced concrete in 1852 and was the first builder ever to use this technique as a building material (Britannica; 1991). He decided, as a publicity stunt and to promote his cement business, to build a house made of *b´eton arm´e*, a type of reinforced concrete. In 1853, he built the first iron-reinforced concrete structure anywhere; a four-story house at 72 Rue Charles Michels (Sutherland et al; 2001). This location was near his family cement plant in St. Denis, a commune in the northern suburbs of Paris. The house was designed by local architect Theodore Lachez (Collins; 2004).

Coignet had an exhibit at the 1855 Paris Exposition to show his technique of reinforced concrete. At the exhibit, he forecast that the technique would replace stone as a means of construction. In 1856 he patented a technique of reinforced concrete using iron tyrants. In 1861 he put out a publication on his techniques. Reinforced concrete was further developed by Hennebique at the end of the 19th century, and it was realized that performance could be improved if the bars could be placed in tension, thus keeping the concrete in compression. Early attempts worked, with the beams showing a reduced tendency to crack in tension, but after a few months the cracks reopened. A good description of this early work is given in Leonhard; (1964). The first reinforced concrete bridge was built in 1889 in the Golden Gate Park in San Francisco, California. To overcome the cracking problem in reinforced concrete, prestressed concrete was developed and was first patented by a San Francisco engineer as early as 1886. Prestressed means that the stress is generated in a structural member before it carries the service load. Prestressed concrete was referred to as the third generation of concrete. Prestressing is usually generated by the stretched reinforcing steel in a structural member. Prestressed concrete became an accepted building material in Europe after World War II, partly due to the shortage of steel. North America's first prestressed concrete structure, the Walnut Anch O Lane Memorial Bridge in Philadelphia, Pennsylvania, was completed in 1951. Nowadays, with the development of prestressed concrete, long-span bridges, tall buildings, and ocean structures have been constructed. The Barrios de Lura Bridge in Spain is currently the longest-span prestressed concrete, cable-stayed bridge in the world, with a main span of 440 m. In Canada, the prestressed Toronto CN tower reaches a height of 553 m.

As a structural material, the compressive strength at an age of 28 days is the main design index for concrete. There are several reasons for choosing compressive strength as the representative index. First, concrete is used in a structure mainly to resist the compression force. Second, the measurement of compressive strength is relatively easier. Finally, it is thought that other properties of concrete can be related to its compressive strength through the microstructure. Pursuing high compressive strength has been an important direction of concrete development. As early as 1918, Duff Adams found that the compressive strength of a concrete was inversely proportional to the water-to-cement ratio. Hence, a high compressive strength could be achieved by reducing the *w*/*c* ratio. However, to keep a concrete workable, there is a minimum requirement on the amount of water; hence, the *w*/*c* ratio reduction is limited, unless other measures are provided to improve concrete's workability. For this reason, progress in achieving high compressive strength was very slow before the 1960s. At that time, concrete with a compressive strength of 30 MPa was regarded as high-strength concrete. Since the 1960s, the development of high-strength concrete has made significant progress due to two main factors: the invention of water-reducing admixtures and the incorporation of mineral admixtures, such as silica fume, fly ash, and slag. Water-reducing admixture is a chemical admixture that can help concrete keep good workability under a very low *w*/*c* ratio; the latter are finer mineral particles that can react with a hydration product in concrete, calcium hydroxide, to make concrete microstructure denser. Silica fume also has a packing effect to further improve the matrix density. In 1972, the first 52-MPa concrete was produced in Chicago for the 52-story Mid-Continental Plaza. In 1972, a 62-MPa concrete was produced, also in Chicago, for Water Tower Place, a 74-story concrete building, the tallest in the world at that time. In the 1980s, the industry was able to produce a 95-MPa concrete to supply to the 225 West Whacker Drive building project in Chicago. The highest compressive strength of 130 MPa was realized in a 220-m-high, 58-story building, the Union Plaza constructed in Seattle, Washington (Caldarone; 2009). Concrete produced after the 1980s usually contains a sufficient amount of fly ash, slag, or silica fume as well as many different chemical admixtures, so its hydration mechanism, hydration products, and other microstructure characteristics are very different from the concrete produced without these admixtures. Moreover, the mechanical properties are also different from the conventional concrete; hence, such concretes are referred to as contemporary concretes. There have been two innovative developments in contemporary concrete: self-compacting concrete (SCC) and ultra-high-performance concrete (UHPC). SCC is a type of high-performance concrete. High-performance concrete is a concept developed in the 1980s. It is defined as a concrete that can meet special performance and uniformity requirements, which cannot always be achieved routinely by using only conventional materials and normal mixing, placing, and curing practices. The requirements may involve enhancement of the characteristics of concrete, such as placement and compaction without segregation, long-term mechanical properties, higher early-age strength, better toughness, higher volume stability, or longer service life in severe environments. Self-compacting concrete is a typical example of high-performance concrete that can fill in formwork in a compacted manner without the need of mechanical vibration. SCC was initially developed by Professor Okamura and his students in Japan in the late 1980s (Ozama et al; 1989). At that time, concrete construction was blooming everywhere in Japan. Since Japan is in an earthquake zone, concrete structures are usually heavily reinforced, especially at beam–column joints. Hence, due to low flowability, conventional concrete could hardly flow past the heavy reinforced iron bars, leaving poor-quality cast concrete and leading to poor durability. Sometimes, the reinforcing steel was exposed to air immediately after demolding. To solve the problem, Professor Okamura and his students conducted research to develop a concrete with high flowability. With the help of the invention of the high-range water reducer or plasticizer, such a concrete was finally developed. They were so excited that they called this concrete “high-performance concrete” at the beginning. It was corrected later on to SCC, as HPC covers broader meanings.

Durability is a main requirement of HPC. It has been found that many concrete structures could not fulfil the service requirement, due not to lack of strength, but to lack of durability. For this reason, concrete with high performance to meet the requirement of prolonging concrete service life was greatly needed.

In the 1990s, a new “concrete” with a compressive concrete strength higher than 200 MPa was developed in France. Due to the large amount of silica fume incorporated in such a material, it was initially called reactive powder concrete and later on changed to ultra-high-strength (performance) concrete (UHSC), due to its extremely high compressive strength (Richard et al;1995). The ultra-high-strength concrete has reached a compressive strength of 800 MPa with heating treatment.

2.3 Concrete as a structural material

The term concrete usually refers to Portland cement concrete, if not otherwise specified. For this kind of concrete, the compositions can be listed as follows:

Portland cement + water (& admixtures) → cement **paste**
+ fine aggregate → **mortar**
+ coarse aggregate →**concrete**

Here we should indicate that admixtures are almost always used in modern practice and thus have become an essential component of contemporary concrete. Admixtures are materials other than aggregate (fine and coarse), water, and cement that are added into a concrete batch immediately before or during mixing. The use of admixtures is widespread mainly because many benefits can be achieved by their application. For instance, chemical admixtures can modify the setting and hardening characteristics of cement paste by influencing the rate of cement hydration. Water-reducing admixtures can plasticize fresh concrete mixtures by reducing surface tension of the water.

Air-entraining admixtures can improve the durability of concrete, and mineral admixtures such as pozzolans (materials containing reactive silica) can reduce thermal cracking (Zongji; 2011). Concrete is the most widely used construction material in the world, and its popularity can be attributed to two aspects. First, concrete is used for many different structures, such as dams, pavements, building frames, or bridges, much more than any other construction material. Second, the amount of concrete used is much more than any other material. Its worldwide production exceeds that of steel by a factor of 10 in tonnage and by more than a factor of 30 in volume.

In a concrete structure, there are two commonly used structural materials: concrete and steel. A structural material is a material that carries not only its self-weight, but also the load passing from other members.
Steel is manufactured under carefully controlled conditions, always in a highly sophisticated plant; the properties of every type of steel are determined in a laboratory and described in a manufacturer’s certificate. Thus, the designer of a steel structure need only specify the steel

complying with a relevant standard, and the constructor needs only to ensure that the correct steel is used and that connections between the individual steel members are properly executed (Neville and Brooks; 1993). On the other hand, concrete is produced in a cruder way and its quality varies considerably. Even the quality of cement, the binder of concrete, is guaranteed by the manufacturer in a manner similar to that of steel; however, the quality of concrete is hardly guaranteed because of many other factors, such as aggregates, mixing procedures, and skills of the operators of concrete production, placement, and consolidation. It is possible to obtain concrete of specified quality from a ready-mix supplier, but, even in this case, it is only the raw materials that are bought for a construction job. Transporting, placing, and, above all, compacting greatly influence the quality of cast concrete structure. Moreover, unlike the case of steel, the choice of concrete mixes is virtually infinite and therefore the selection has to be made with a sound knowledge of the properties and behaviour of concrete. It is thus the competence of the designer and specifier that determines the potential qualities of concrete, and the competence of the supplier and the contractor that controls the actual quality of concrete in the finished structure. It follows that they must be thoroughly conversant with the properties of concrete and with concrete and with concrete making and placing. In a concrete structure, concretes mainly carry the compressive force and shear force, while the steel carries the tension force. Moreover, concrete usually provides stiffness for structures to keep them stable. Concretes have been widely used to build various structures. High-strength concrete has been used in many tall building constructions. In Hong Kong, grade 80 concrete (80 MPa) was utilized in the columns of the tallest building in the region. Concrete has also been used in bridge construction.

The economy, efficiency, durability, mouldability and rigidity of concrete make it an attractive material for a wide range of structural applications (Ferguson et al; 1988).One of the biggest problems that cause concrete deterioration is when cement based materials, such as concrete, mortars and buildings are exposed to this environment. This is caused by the presence of sulphate ions in soil, ground water and sea water which causes deterioration of reinforced concrete structures by provoking expansion and cracking due to factors such as type of cement, sulphate cation type, sulphate concentration and the period of exposure (Amin et al; 2008, Marchand et al; 2002,Hekal et al; 2004,Bolanle et al; 2014).A lot of research work has been carried out on the production of concrete that can resist sulphate attack (Nabil; 2006, Torri et al; 1995, Sideris 2006;Salah; 2007;Hanifi; 2006; and

Hooton;2013). To stop the negative effects of sulphates on concrete, mineral admixture have to be introduce by partially replacing it with cement (Sai-Prasad and Jha; 2006, Dahunsi and Bamisaye; 2002, Koffi; 2008, Job et al; 2009).

2.3.1 In summary the characteristics of concrete is listed out below

Strength and Durability

- Used in the majority of buildings, bridges, tunnels and dams for its strength
- Gains strength over time
- Not weakened by moisture, mould or pests

Concrete structures can withstand natural disasters such as earthquakes and hurricanes. Roman buildings over 1,500 years old such as the Coliseum are living examples of the strength and durability of concrete.

Versatility

- Concrete is used in buildings, bridges, dams, tunnels, sewerage systems pavements, runways and even roads

Low maintenance

- Concrete, being inert, compact and non-porous, does not attract mould or lose its key properties over time

Affordability

- Compared to other comparable building materials, concrete is less costly to produce and remains extremely affordable.

Fire-resistance

- Being naturally fire-resistant concrete forms a highly effective barrier to fire spread.

Thermal mass

- Concrete walls and floors slow the passage of heat moving through, reducing temperature swings.
- This reduces energy needs from heating or air-conditioning, offering year-round energy savings over the life-time of the building

Locally produced and used

- The weight of the material limits concrete sales to within 300km of a plant site
- Very little cement and concrete is traded and transported internationally
- This saves significantly on transport emissions of CO_2 that would otherwise occur.

Albedo effect

- The high "albedo" (reflective qualities) of concrete used in pavements and building walls means more light is reflected and less heat is absorbed, resulting in cooler temperatures
- This reduces the "urban heat island" effect prevalent in cities today, and hence reduces energy use for e.g. air-conditioning

Low life-cycle CO_2 emission

- 80% of a building CO_2 emission is generated not by the production of the materials used in its construction, but in the electric utilities of the building over its life-cycle (e.g. lighting, heating, and air-conditioning).

2.4 Characteristics of Concrete

Concrete is used extremely widely in building and civil engineering structures, due to its low cost, flexibility, durability, and high strength. It also has high resistance to fire. Concrete is a non-linear, non-elastic and brittle material. It is strong in compression and very weak in tension. It behaves non-linearly at all times. Because it has essentially zero strength in tension, it is almost always used as reinforced concrete, a composite material. It is a mixture of sand, aggregate, cement and water. It is placed in a mould, or form, as a liquid, and then it sets (goes off), due to a chemical reaction between the water and cement. The hardening of the concrete is called curing. The reaction is exothermic (gives off heat). Concrete increases in strength continually from the day it is cast. Assuming it is not cast under water or in constantly 100% relative humidity, it shrinks over time as it dries out, and it deforms over time due to a phenomenon called creep. Its strength depends highly on how it is mixed, poured, cast, compacted, cured (kept wet while setting), and whether or not any admixtures were used in the mix. It can be cast into any shape that a form can be made for. Its colour, quality, and finish depend upon the complexity of the structure, the material used for the form, and the skill of the worker. The elastic modulus of concrete can vary widely and depends on the concrete mix, age, and quality, as well as on the type and duration of loading applied to it. It is usually taken as approximately 25 GPa for long-term loads once it has attained its full strength (usually considered to be at 28 days after casting). It is taken as approximately 38 GPa for very short-term loading, such as footfalls. Concrete has very favourable properties in fire - it is not adversely affected by fire until it reaches very high temperatures. It also has very high mass, so it is good for providing sound insulation and heat retention (leading to lower energy requirements for the heating of concrete buildings). This is offset by the fact that producing and transporting concrete is very energy intensive.

In the study of strength of materials, the compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some material fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures and also another important parameter is flexural strength.

a) Compressive strength

Compressive strength is often measured on a universal testing machine; these range from very small table top systems to ones with over 53 MN capacity. Measurements of compressive strength are affected by the specific test method and conditions of measurement. Compressive strengths are usually reported in relationship to a specific technical standard. By definition, the ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied. As can be imagined, the specimen (usually cylindrical) is shortened as well as spread laterally. A Stress–strain curve is plotted by the instrument and would look similar to the following: true stress-strain curve for a typical specimen. The compressive strength of the material would correspond to the stress at the red point shown on the curve. In a compression test, there is a linear region where the material follows Hooke's Law. Hence for this region where this time E refers to the Young's Modulus for compression in this region, the material deforms elastically and returns to its original length when the stress is removed. This linear region terminates at what is known as the yield point. Above this point the material behaves plastically and will not return to its original length once the load is removed.

There is a difference between the engineering stress σ_c and the true stress f_c. By its basic definition the uniaxial stress is given by:

$$\sigma_c = \frac{F}{A} \quad (2.1)$$

Where,

F = Load applied [N], A = Area [m^2]

As stated, the area of the specimen varies on compression. In reality therefore the area is a some function of the applied load i.e. A = f(F). Indeed, stress is defined as the force divided by the area at the start of the experiment. This is known as the engineering stress σ_c and is defined by,A_0 = Original specimen area [m^2]. Correspondingly, the engineering strain would be defined by

$$\varepsilon = (l - l_o)/l_o \quad (2.2)$$

Where l = current specimen length [m] and l_o = original specimen length [m]

The compressive stress would therefore correspond to the point on the engineering stress strain curve defined by where F^* = load applied just before crushing and l^* = specimen length just before crushing. Experiment has shown that concrete cast and cured with seawater increases gradually for all curing days beyond the strength of control cast (Olutoge et al; 2014). In concrete in which there is a reduction in the value of ph of the water used in mixing it, the compressive strength and split tensile strength of the concrete will equally reduce (Kucche et al; 2015). The strength of concrete decreased as the percentage of replacement of the conventional material increased (Nagalakshmi; 2013)

b) Flexural strength

Flexural strength is the ability of a beam or slab to resist failure in bending, it is a measurement that indicates the resistance of a material to deformation when placed under a load (Kala; 2013). Flexural strength is very important because it gives two useful parameters which includes the first crack strength, which is primarily controlled by the matrix, and the ultimate flexural strength or modulus of rupture, which is determined by the maximum load that can be attained (Elayesh; 2009). Flexural strength is carried out in the lab by loading 150×150×500mm concrete beam with span three times the depth. It is expressed as modulus of rupture in MPa. Flexural strength is about 12 to 20% of compressive strength, and the best correlation for specific materials is obtained by laboratory test. The values needed to calculate flexural strength are measured by experimentally with rectangular samples of the material placed under load in a 3 point testing setup. The strength of the material in bending expressed as the stress on the outermost fibres of a bent test specimen at the instant of failure (Kala 2013). It is expressed mathematically as

$$\frac{Pl}{bd} \qquad (2.3)$$

where

$P =$ applied load

$L =$ length of the beam

$b =$ width of the beam

$d =$ thickness of the beam

Flexural strength can be determined in the laboratory by carrying out a four-point bending test in accordance to BS 1881: part: 1983. The specimen for flexural strength test is a $150 \times 150 \times 500mm$ beam. The arrangement is as shown below.

According to mechanics of materials, it is understandable that under the four-point bending, the middle $l/3$ portion of the beam is under the pure bending. The maximum moment can be calculated using

$$M_{max} = \frac{P}{2} \times \frac{l}{3} = \frac{Pl}{6} \quad (2.4)$$

When fracture takes place within the middle one-third, we can now apply the beam theory under pure bending directly and the maximum tension stress can be determine using

$$f_{bt} = \frac{M_{max}\, y_{max}}{I} = \frac{\frac{Pl}{6} \times \frac{d}{2}}{\frac{bd^3}{12}} = \frac{Pl}{bd^2} \qquad (2.5)$$

If the fracture occurs outside the middle one-third (pure bending), bending moment as well as shear force is carried by the cross-section. Using theory of elasticity, if the span of height (of the beam) ratio is greater than 5%, beam theory under pure bending can still be used to determine the normal stress, and this can be allowed because the error is less than 1%. In the loading arrangement in accordance with ASTM C78 and BS 1881 has the span-to-height ratio as 3, and because of the basic formula for calculating normal stress from pure bending cannot be applied in this case. BS advised that the method should not be used, but ASTM allows the result of failure outside the middle one-third to be used. The flexural strength can be calculated using the formula below when the average distance between the fracture crack and the nearest support is a.

$$f_{bt} = \frac{M_{max}\, y_{max}}{I} = \frac{\frac{Pa}{2} \times \frac{d}{2}}{\frac{bd^3}{12}} = \frac{3Pa}{bd^2} \qquad (2.6)$$

However, when the failure occurs at a section where $\left(\frac{l}{3} - a\right) > 0.05l$, the result obtained should not be use. Although the modulus of rupture is a kind of tensile strength, it is much greater than the results obtained from direct tension because of the support from the inner layer that have not reached their failure criterion (Zongjin; 2011).

2.5 Factors Influencing Concrete Strength.

i) Water- cement, w/c ratio

One property of concrete is the water/cement ratio. In contemporary concrete, *w*/*c* is frequently replaced with *w*/*b* (water/binder) or *w*/*p* (water/powder), since Portland cement is not the only binding material in such a concrete. The *w*/*c* or *w*/*b* ratio is one of the most important factors influencing concrete properties, such as compressive strength, flexural strength, permeability, and diffusivity. A lower *w*/*c* ratio will lead to a stronger and more durable concrete. The influence of *w*/*c* on the concrete compressive strength has been known since the early 1900s (Abrams; 1927), leading to Abrams's law:

$$f_c = \frac{A}{B^{w/c}} \qquad (2.7)$$

Where; f_c is the compressive strength, *A* is an empirical constant (usually 97 MPa or 14,000 psi), and *B* is a constant that depends mostly on the cement properties (usually 4). It can be seen from the formula that the higher the *w*/*c* ratio, the lower the compressive strength. In this manner; the higher the w/c ratio the lower the flexural strength of the concrete. In their work Abolfazl et al; (2012) discovered that the reduction of water cement ratio from 0.55 to 0.33 improvs the abrasive strength of concrete by 36% and reduces the hydraulic conductivity coefficient of concrete from 31.71×10^{-15} to $2.\times 10^{-15}$m/sec. In conventional methods of concrete production it is always a rule to keep the water/cement ratio constant in order to obtain concrete with high strength and also durable (Shih et al 2006; Rahmani and Ramzanianpour; 2008., Feleko et al; 2007). But research has shown that the amount of water/cement ratio in a given mix is a function of identified size of aggregate, sand and nanosilica composition (Senff et al; 2009, Popovics; 1990, Naji et al; 2010, Aiu,. and Huang; 2006).

If the water/cement ratio is kept constant at 0.5 and at mix of (1:2:4), a change in coarse aggregate size will affect the workability of concrete (Bruce and Sabelo; 2016). When the gradation of aggregates are not properly done it lead to segregation of mortar from the coarse aggregates, internal bleeding, need for workability to be restored by the addition of admixture, increase in water use and increased cement use (Loannides and Mills; 2006).The larger the aggregate percentage in concrete mix makes it to contribute a lot to its strength (Waziri et al; 2011).In their work Hassan and Mohammed; (2014) observed that curing concrete increase strength by up to 50% and also improve durability, and this make it more water tight and improve its appearance. When concrete is not cured and but only allowed to dry in air, it will gain only 50% of the strength of continuously cured concrete (Raheem; 2013). Large aggregates demand lower water on its mix thus reducing the workability and increasing the compressive strength of concrete (Adiseshu and Ganapati; 2011).

ii) Cement content

When water is added a concrete mix, cement paste will be formed. Cement paste has three functions in concrete: binding, coating, and lubricating (Zongji Li; 2011). Cement paste provides binding to individual aggregates, reinforcing bars, and fibres and glues them together to form a unique material.

Cement paste also coats the surface of the aggregates and fibbers during the fresh stage of concrete. The rest of the paste after coating can make the movement of the aggregates or fibres easier, rather like a lubrication agent. The cement content influences concrete workability in the fresh stage, heat release rate in the fast hydration stage, and volume stabilities in the hardened stage. The range of the amount of cement content in mass concrete is 160–200 kg/m^3, in normal strength concrete it is less than 400 kg/m^3, and in high strength concrete it is 400–600 kg/m^3.As cement content increases unit weight increases slightly, slump increases, K-slump values increases, and compacting factor also increases (Khaled and Ozgur; 2011).

iii) Aggregate

Aggregate is one of the constituents used in making concrete, it can either be fine or coarse aggregate, it can be in various forms, and can be local or manufactured sand. Aggregate can be source from many sources, the use of waste stone as aggregate in the construction industries is very popular (Murali et al; 2012). An investigation carried out by Rathish et al;

2012 discover that the variation in the size of aggregate changes the micro cracking of concrete which there by modifies the strength and as well as the durability as well studied by researchers.

(a) *Maximum aggregate size*: The maximum coarse aggregate size mainly influences the cement paste requirement in the concrete. For the same volume of aggregate, the ones with a large aggregate size will lead to a small total surface area and a lower amount of cement paste coating. Hence, if the same amount of cement is used, concrete with a larger maximum aggregate size will have more cement paste left as a lubricant and the fluidity of concrete can be enhanced, as compared to concrete with a smaller maximum aggregate size. For normal-strength concrete, at the same *w/c* ratio and with the same cement content, the larger the maximum sizes, the better the workability; at the same workability, the larger the maximum sizes, the higher the strength. However, a larger aggregate size has some drawbacks. First, a larger aggregate size may make the concrete appear non homogeneous. Second, a larger aggregate size may lead to a large interface that can influence the concrete transport properties and the mechanical properties. Generally, the maximum size of coarse aggregate should be the largest that is economically available and consistent with the dimensions of the structure. In choosing the maximum aggregate size, the structural member size and spacing of reinforcing steel in a member have to be taken into consideration. In no event should the maximum size exceed one-fifth of the narrowest dimension in the sizes of the forms, one-third of the depth of slabs, or three-quarters of the minimum clear spacing between reinforcing bars.

(b) *Aggregate grading*: Aggregate grading refers to the size distribution of the aggregate. The grading mainly influences the space filling or particle packing. The classical idea of particle packing is based on the Apollonian concept, in which the smaller particles fit into the interstices left by the large particles. Well-defined grading with an ideal size distribution of aggregate will decrease the voids in the concrete and hence the cement content. As the price of the aggregate is usually only one-tenth that of cement, well-defined grading not only will lead to a better compressive strength and low permeability, but also is more economical at lower cost.

(c) *Aggregate shape and texture*: The aggregate shape and texture can influence the workability, bonding, and compressive strength of concrete. At the same *w/c* ratio and with the same cement content, aggregates with angular shape and rough surface texture result in lower workability, but lead to a better bond and better mechanical properties. On the other hand, Aggregates with spherical shape and smooth surface texture result in higher workability, but lead to a lower bond and lower mechanical properties.

(d) *Sand/coarse aggregate ratio*: The fine/coarse aggregate ratio will influence the packing of concrete. It also influences the workability of concrete in the fresh stage. Increase of the sand to coarse aggregate ratio can lead to an increase of cohesiveness, but reduces the consistency. Of all the measures for improving the cohesiveness of concrete, increasing the sand/coarse aggregate ratio has been proven to be the most effective one.

(e) *Aggregate/cement ratio*: The aggregate/cement ratio has an effect on the concrete cost, workability, mechanical properties, and volume stability. Due to the price difference between the aggregate and cement, increasing the aggregate/cement ratio will decrease the cost of concrete. From a workability point of view, an increase of the aggregate to cement ratio results in a lower consistency because of less cement paste for lubrication.
As for mechanical properties, increase of the aggregate/cement ratio can lead to a high stiffness and compressive strength if proper compaction can be guaranteed. Increasing the aggregate/cement ratio will definitely improve concrete's dimension stability due to reduction of shrinkage and creep.

iv) Admixtures

Admixtures (chemical admixtures and mineral admixtures) are important and necessary components for contemporary concrete technology. Admixture can be define as material other than water, aggregates, hydraulic cement, and fibre reinforcement, used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing (ACI 212.3R-04,Anitha; 2016, Maroliya; 2012, Oyekan; 2007).The concrete properties, both in fresh and hardened states, can be modified or improved by admixtures (Mihai; 2008,Akogu; 2011, Rixom and Mailvaganam; 2007 and Naqash et al; 2014). For instance, concrete workability can be affected by air entraining agents, water reducers, and fly ash. Concrete strength can be improved by silica fume (Venu and Neelakanteswara; 2012, Nitish; 2014,Neville; 2011,Rixom and Mailvaganam; 1986, ACI Committee 212; 1963 andRamachandran; 1996).There are numerous benefits that can be derived by the use of admixtures such as: improved quality, acceleration or retardation of setting time, colouring, greater concrete strength, increased flow for the same water-to-cement ratio, enhanced frost and sulphate resistance, improved fire resistance, cracking control, lower density, improved workability and enhanced finishability (Neil and Ravindra; 1996, . Jackson and Dhir; 1996, Raheem et al; 2010).

v) Time

The rate of strength gain depends of the *w/c* ratio, low *w/c* ratio mixes gain strength faster than high *w/c* ratio mixes. As a general rule the ratio of 28-day to 7-day compressive strengths lies between 1.3 and 1.7, and is generally less than 1.5. These ratios are not valid if accelerators or extreme curing temperatures are used.

vi) The Maturity concept

The hydration of cement is greatly affected by both the time and the temperature of hydration (Powers et al; 1946), therefore, strength gain is controlled by these two factors. The concept of "maturity" is a function of the product of curing time and temperature. The assumption is that concrete of different mixes, curing times, and curing temperatures will have about the same strength at the same level of maturity. A datum or reference point below which no concrete will gain strength is commonly a value of -100C. Curing of concrete is very important, because if concrete is not cured and is allowed to dry in air, it will gain only 50% of the strength of continuously cured concrete (Mamlouk and Zaniewski; 2006). In their work Akeem et al; (2013) discovered that moist sand curing method produced specimens with the highest compressive strength while Air curing produced the lowest. The general trend is that as maturity increases compressive strength increases, especially at low maturity values. There are a number of limitations on the use of maturity for predicting compressive strength. (1) humidity of curing is not considered, (2) only ambient temperature is considered; the contribution of heat of hydration is ignored, (3) maturity functions are not useful at low values (time should be calculated from when concrete actually begins to gain strength not at mixing and casting), (4) invalid over large curing temperature variations, (5) cement characteristics and *w/c* ratio affect strength, and (6) invalid for accelerated concretes.

Nevertheless, the maturity concept may be useful in establishing "after the fact" strength estimates of concrete.

2.6 Aggregates

Aggregates constitute a skeleton of concrete. Approximately three-quarters of the volume of conventional concrete is occupied by aggregate. It is inevitable that a constituent occupying such a large percentage of the mass should contribute important properties to both the fresh and hardened product. Aggregate is usually viewed as an inert dispersion in the cement paste. However, strictly speaking, aggregate is not truly inert because physical, thermal, and, sometimes, chemical properties can influence the performance of concrete (Neville; 1990). In their work Jain and Chouhan; (2011) discovered that for all sizes of aggregates, compressive strength of pervious aggregate vary inversely with the angularity number of the aggregate. Research has shown that when low cemetitious content, uniform aggregate gradation and high compactive effort produces pervious concrete that are high in permeability, more that 3600mm/hr and high in compressive strength more than 21MPa (Tennis et al; 2004 and Schaefer et al; 2006).

Coarse aggregate: Aggregates predominately retained on a No. 4 (4.75-mm) sieve are classified as coarse aggregate. Generally, the size of coarse aggregate ranges from 5 to 150 mm and for normal concrete used for structural members such as beams and columns, the maximum size of coarse aggregate is about 25 mm. For mass concrete used for dams or deep foundations, the maximum size can be as large as 150 mm. In this work 20mm aggregate is used.

***Fine aggregate (sand)*:** Aggregates passing through a No. 4 (4.75 mm) sieve and predominately retained on a No. 200 (75 μm) sieve are classified as fine aggregate. River sand is the most commonly used fine aggregate. In addition, crushed rock fines or quarry dust can be used as fine aggregate. However, the finish of concrete with crushed rock fines is not as good as that with river sand. This is so because river sand has a larger granular size, hence binding with the cement better than the chipping dust.

Fine aggregate (chipping dust): Crushed rock aggregate quarrying generates considerable volumes of quarry fines, often termed “quarry dust”. The finer fraction is usually smaller than 5mm in size. The use of quarry dust in concrete according to Chaturanga et al; 2008, is desirable because of the benefits such as useful disposal of a by-product, reduction of river sand consumption and increase in strength. Quarry dust has rough, sharp and angular particles, and as such causes a gain in strength due to better interlocking.

2.6.1 Physical properties of aggregates and their effects on concrete

There are many physical properties of aggregate as they affect the compressive strength of concrete. They are discussed as follows:

Shape : the shape of the aggregate is an important characteristics since it affects the workability of concrete and hence mix-water requirement. May also influence concrete strength – angular particles are preferred for improved strength.

Texture : aggregate surface texture is the property, the measure of which depends upon the relative degree to which particles surfaces are polished or dull, smooth or rough. This Influences concrete workability and mix-water requirement (but lesser than shape) but rougher texture improves aggregate bond. If excessive, can cause dimensional instability in concrete and can be associated in cracking.

Absorption and moisture content: this is obtained by measuring the increase in weight of an oven dry sample when immersed in water for 24 hours. It is the ratio of the increase in weight to the weight of the dry sample expressed as percentage. It can affect the water-cement ratio and hence the workability of the concrete. It can also influence concrete strength, movement properties, and durability.

Bulk density/ specific gravity: the bulk density of an aggregate gives valuable information regarding the shape and grading of the aggregate. Its Influence relative proportions of concrete ingredients (mix proportioning calculations). High bulk density gives improved technical properties and better economy.

Particle size distribution: Grading represents the distribution of particle sizes in a mix, and is fundamental to the nature of concrete as a 'bound conglomerate, it has important influence on workability and other plastic properties of concrete. Fines content is associated (minus 75-_m fraction) with crucial to cohesiveness and control of bleeding.

2.6.2 Chemical properties of aggregates and their effects on concrete

Sulphate Soundness of aggregate: this refers to the ability of aggregate to resist excessive changes in volume as a result of changes in physical conditions. These physical conditions that affect soundness is variation in temperature, freezing and thawing, alternate wetting and drying under normal conditions etc. Unsoundness can cause disruption of concrete, ranging from superficial pop-outs to severe cracking.

Alkali aggregate reaction: some aggregate contain reactive silica, which reacts with alkalis present in cement i.e. sodium oxide and potassium oxide. This property causes expansion and cracking when sufficient moisture is present. Effects vary from minor cracking to major structural breakdown, and also unsightly staining occurs mainly with silica-bearing aggregate, but can also occur with certain carbonate rocks.

2.7 Cement

Any material that can be made plastic and that gradually hardens to form an artificial stone like substance is called a *cementitious* material. Hydraulic cements, namely Portland and natural materials, along with limes, fly ash, and silica fume, are currently the principal cementing materials used in structures. They become plastic by the addition of water; the mix then sets and hardens.

When water is added to a concrete mix, cement paste will be formed. Cement paste has three functions in concrete: binding, coating, and lubricating. Cement paste provides binding to individual aggregates, reinforcing bars, and fibres and glues them together to form a unique material. Cement paste also coats the surface of the aggregates and fibres during the fresh stage of concrete. The rest of the paste after coating can make the movement of the aggregates or fibres easier, rather like a lubrication agent. The cement content influences concrete workability in the fresh stage, heat release rate in the fast hydration stage, and volume stabilities in the hardened stage. The range of the amount of cement content in mass concrete is 160 – 200 kg/m^3, in normal strength concrete it is less than 400 kg/m^3, and in high strength concrete it is 400 – 600 kg/m^3.

2.7.1 Properties of concrete and their effects on concrete

Portland cements are commonly characterized by their physical properties for quality control purposes. When contact with water cement paste stiffens then the solid formed progressively hardens. Cement hydration may be described by the degree of hydration, which, in a given time, is equal to the percentage of hydrated cement (Jean-Pierre et al; 2012).Their physical properties can be used to classify and compare to Portland cements. These properties are listed below

- Setting Time
- Soundness
- Fineness
- Strength
- Specific density
- Bulk density

Setting Time: Cement paste setting time is affected by a number of items including: cement fineness, water-cement ratio, chemical content (especially gypsum content) and admixtures. Setting tests are used to characterize how a particular cement paste sets. For construction purposes, the initial set must not be too soon and the final set must not be too late. Normally, two setting times are defined:

Initial set; Occurs when the paste begins to stiffen considerably.

Final set; Occurs when the cement has hardened to the point at which it can sustain some load. Setting is mainly caused by C_3A and C_3S and results in temperature rise in the cement paste.

False set; No heat is evolved in a false set and the concrete can be re-mixed without adding water. It occurs due to the conversion of anhydrous/semi hydrous gypsum to hydrous gypsum ($CaSO_4.2H_2O$)

Flash Set: is due to absence of Gypsum. Specifically used for under water repair.

Soundness: When referring to Portland cement, "soundness" refers to the ability of a hardened cement paste to retain its volume after setting without delayed expansion. This expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO). Most Portland cement specifications limit magnesia content and expansion. The cement paste should not undergo large changes in volume after it has set. However, when excessive amounts of free CaO or MgO are present in the cement, these oxides can slowly hydrate and cause expansion of the hardened cement paste. Soundness is defined as the volume stability of the cement paste.

Fineness: Fineness or particle size of Portland cement affects Hydration rate and thus the rate of strength gain. The smaller the particle size, the greater the surface area-to-volume ratio, and thus, the more area available for water-cement interaction per unit volume. The effects of greater fineness on strength are generally seen during the first seven days. When the cement particles are coarser, hydration starts on the surface of the particles. So the coarser particles may not be completely hydrated. This causes low strength and low durability. For a rapid development of strength a high fineness is necessary.

Strength: Cement paste strength is typically defined in three ways: compressive, tensile and flexural. These strengths can be affected by a number of items including: water cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate, curing conditions, size and shape of specimen, loading conditions and age.

Specific Gravity: This is generally required in mix proportioning for concrete. The particle density (measured by excluding the air between particles) of Portland cement is found to be in the range of 3.1 to 3.25 mega gram per cubic metre. The relative density of cement is assumed 3.15.

Bulk density: The bulk density can be determined by dividing the mass of cement particles and air between particles by the volume of cement sample. Bulk density of cement ranges from 830kg/m^3 to 1650kg/m^3.

2.8 Water

Combining water with a cementitious material forms a cement paste by the process of hydration. The cement paste glues the aggregate together, fills voids within it, and makes it flow more freely. Lower water to concrete ratio yields a stronger, more durable concrete, while more water gives a free-flowing concrete with a higher slump. Impure water used to make concrete can cause problems when setting or in causing premature failure of the structure. Hydration involves many different reactions, often occurring at the same time. As the reactions proceed, the products of the cement hydration process gradually bond together the individual sand and gravel particles and other components of the concrete, to form a solid mass.

Reaction:

Cement chemist notation: $C_3S + H \rightarrow C\text{-}S\text{-}H + CH$

Standard notation: $Ca_3SiO_5 + H_2O \rightarrow (CaO)\cdot(SiO_2)\cdot(H_2O)(gel) + Ca(OH)_2$

Balanced: $2Ca_3SiO_5 + 7H_2O \rightarrow 3(CaO)\cdot 2(SiO_2)\cdot 4(H_2O)(gel) + 3Ca(OH)_2$

The water used for concrete should be clean and free from dirt or organic matter. Water containing even small quantities of acid can have a serious deleterious effect on concrete. The presence of oil will result in slowing the setting time and reducing the strength. Generally speaking, if water is potable, it is satisfactory for the production of a good concrete. Water is important in starting the reaction between cement and other constituent materials. The binding property of cement cannot take effect without water. Water hydrates the materials thereby providing a binding interface which affect the strength of the concrete. Also the workability of concrete cannot be achieved without water.

2.8.1 Effects of water on workability of concrete

Workability is the ability of a fresh (plastic) concrete mix to fill the form/mould properly with the desired work (vibration) and without reducing the concrete's quality. Workability depends on water content, aggregate (shape and size distribution), cementitious content and age (level of hydration) and can be modified by adding chemical admixtures, like super plasticizer. Raising the water content increases concrete workability. Excessive water leads to increased bleeding (surface water) and/or segregation of aggregates (when the cement and aggregates start to separate), with the resulting concrete having reduced quality. The use of an aggregate with an undesirable gradation can result in a very harsh mix design with a very low slump, which cannot be readily made more workable by addition of reasonable amounts of water. In their work Malliarjuna et al; (2013), discovered that minimum strengths can be achieved for a w/c ratio 0.27 with optimum slump for M70 grade high strength self compacting concrete.

2.9 Concrete made with Sand as fine aggregates

Sand as fine aggregate has always been used in the production of concrete; though sand is used in the production of conventional concrete it has its own advantages and disadvantages. Concrete with mixtures of lateritic sand and quarry dust can be used for structural construction provided the proportion of lateritic sand content is kept below 50% (Ukpata et al; 2012).

2.9.1 Advantages of concrete

(a)*Economical*: Concrete is the most inexpensive and the most readily available material in the world. The cost of production of concrete is low compared with other engineered construction materials. The three major components in concrete are water, aggregate, and cement. Compared with steels, plastics, and polymers, these components are the most inexpensive, and are available in every corner of the world. This enables concrete to be produced worldwide at very low cost for local markets, thus avoiding the transport expenses necessary for most other materials.

(b) *Ambient temperature-hardened material* : Because cement is a low-temperature bonded inorganic material and its reaction occurs at room temperature, concrete can gain its strength at ambient temperature. No high temperature is needed.

(c) *Ability to be cast*: Fresh concrete is flowable like a liquid and hence can be poured into various formworks to form different desired shapes and sizes right on a construction site. Hence, concrete can be cast into many different configurations.

(d) *Energy efficient*: Compared with steel, the energy consumption of concrete production is low. The energy required to produce plain concrete is only 450–750 kWh/ton and that of reinforced concrete is 800–3200 kWh/ton, while structural steel requires 8000 kWh/ton or more to make.

(e) *Excellent resistance to water*: Unlike wood (timber) and steel, concrete can be hardened in water and can withstand the action of water without serious deterioration, which makes concrete an ideal material for building structures to control, store, and transport water, such as pipelines, dams, and submarine structures. A typical example of a pipeline application is the Central Arizona Project, which provides water from the Colorado River to central Arizona. The system contains 1560 pipe sections, each 6.7m long, 7.5m outside diameter, and 6.4m inside diameter. Contrary to popular belief, water is not deleterious to concrete, even to reinforced concrete; it is the chemicals dissolved in water, such as chlorides, sulphates, and carbon dioxide that cause deterioration of concrete structures.

(f) *High-temperature resistance*: Concrete conducts heat slowly and is able to store considerable quantities of heat from the environment. Moreover, the main hydrate that provides binding to aggregates in concrete, calcium silicate hydrate (C–S–H), will not be completely dehydrated until 910^{o}C. Thus, concrete can withstand high temperatures much better than wood and steel. Even in a fire, a concrete structure can withstand heat for 2–6 hours, leaving sufficient time for people to be rescued. This is why concrete is frequently used to build up protective layers for a steel structure**.**

(g) *Ability to consume waste*: With the development of industry, more and more by-products or waste has been generated, causing a serious environmental pollution problem. To solve the problem, people have to find a way to consume such wastes. It has been found that many industrial wastes can be recycled as a substitute (replacement) for cement or aggregate, such as fly ash, slag (GGBFS = ground granulated blast-furnaces slag), waste glass, and ground vehicle tires in concrete. Production of concrete with the incorporation of industrial waste not only provides an effective way to protect our environment, but also leads to better performance of a concrete structure. Due to the large amount of concrete produced annually, it is possible to completely consume most of industry waste in the world, provided that suitable techniques for individual waste incorporation are available.

(h) *Ability to work with reinforcing steel*: Concrete has a similar value to steel for the coefficient of thermal expansion (steel 1.2×10^{-5}; concrete $1.0–1.5 \times 10^{-5}$). Concrete produces a good protection to steel due to existence of CH and other alkalis (this is for normal conditions). Therefore, while steel bars provide the necessary tensile strength, concrete provides a perfect environment for the steel, acting as a physical barrier to the ingress of aggressive species and giving chemical protection in a highly alkaline environment (Ph value is about 13.5), in which black steel is readily passivated.

(i) *Less maintenance required*: Under normal conditions, concrete structures do not need coating or painting as protection for weathering, while for a steel or wooden structure, it is necessary. Moreover, the coatings and paintings have to be replaced few years. Thus, the maintenance cost for concrete structures is much lower than that for steel or wooden structures.

2.9.2 Disadvantages of concrete

(a) *Low toughness (ductility)*: Toughness is usually defined as the ability of a material to consume energy. Toughness can be evaluated by the area of a load–displacement curve. Compared to steel, concrete has very low toughness, with a value only about 1/50 to 1/100 of that of steel. Adding fibres is a good way to improve the toughness of concrete.

(b) *Low specific strength (strength/density ratio)*: For normal-strength concrete, the specific strength is less than 20, while for steel it is about 40. There are two ways to increase concrete specific strength: one is to reduce its density and the other is to increase its strength. Hence, lightweight concrete and high-strength concrete have been developed.

(c) *Formwork is needed*: Fresh concrete is in a liquid state and needs formwork to hold its shape and to support its weight. Formwork can be made of steel or wood, as shown in. The formwork is expensive because it is labour intensive and time-consuming. To improve efficiency, precast techniques have been developed.

(d) *Long curing time*: The design index for concrete strength is the 28-day compression strength. Hence, full strength development needs a month at ambient temperature. The improvement measure to reduce the curing period is steam curing or microwave curing.

(e) *Working with cracks*: Even for reinforced concrete structure members, the tension side has a concrete cover to protect the steel bars. Due to the low tensile strength, the concrete cover cracks. To solve the crack problem, prestressed concrete is developed, and it is also realized as a third-generation concrete.

2.10 Concrete Made With Quarry Dust As Fine Aggregate

Due to the rate of development in developing countries natural sands are in high demand and there is no enough to satisfy the construction industries (Amnon and Hadassa; 2006). The acute shortage of river sand, huge short coming on quality of river sand, high cost, greater impact on road damages and environmental effects (Kanawade et al; 2014) are some of the factors responsible for looking for an alternative to river sand.

Quarry dust as defined by BS EN standards, are the inherent fraction of an aggregate passing 0.063 mm (63 microns); fine material obtained from the crushing process during quarrying activity at the quarry site. Quarry dust has been use for different activities in the construction industry such as for road construction and manufacture of building materials such as lightweight aggregates, bricks, tiles and autoclave blocks (Safiuddin et al; 2012). In this context, quarry dust is used as a fine aggregate in concrete production. A lot of work has been carried out on the effect of quarry dust on concrete and the results obtained are satisfactory (Safiuddin et al; 2007, Venkat et al; 2007, Baali et al; 2007). The partial replacement of quarry dust with river sand has been investigated on (Divakar et al; 2012, Seeni et al; 2012, Shanmugapriya et al; 2012, Saeed et al; 2012 and Shyam et al; 2007) and in one of the work it was discovered that the compressive strength and flexural strength increased by 3.985% and 2.18% respectively for M30 mix (Wakchaure et al; 2012).

In a study in Thailand by Khamput; (2012) on the compressive strength of concrete using quarry dust as fine aggregate and mixing with admixture type E, it was found that with 70% quarry dust the concrete produced compared well with normal concrete. He recommended quarry dust for replacement with sand in general concrete structures. Ilangovana et al; (2006) studied the strength and durability properties of concrete containing quarry dust as fine aggregate and found that the compressive, flexural strength and durability studies of concrete made with quarry rock dust were nearly 10% more than the conventional concrete. Their workability results showed slump values ranging between 60 - 90mm and compacting factor 0.87 - 0.90 for grade 20 concrete. The range of 28 - day's compressive and flexural strengths for grade 20 concrete were found to be 23.7 - 34.50 N/mm^2 and 3.45 - 6.40 N/mm^2 respectively. In their separate works Balamurugan and Perumal; 2013 and Nimithal and Wayal; 2013 respectively discovered that the maximum compressive strength and flexural strength of concrete made with quarry dust as fine aggregate are discovered at 50% replacement. The more the water content in a mix, the less the compressive strength of concrete made with quarry dust, this is because of the increase in free water content and this does not hold for conventional concrete (Chijioke et al; 2015). When quarry dust is incorporated into concrete in the same proportion as that of cement it reduces the super plasticizer needed and this improves the compressive strength at 28 days (Felekoglu et al; 2015), also the compressive strength of concrete can be increased if the quarry dust and river sand are in a ratio of 60:40 (Hamir; 2006; Sukumar; 2008). Aginam et al;(2015) during their investigation observed that the density of concrete made with replacing quarry dust with coarse aggregates increases as the compressive strength increases. Granite powder has been used in the production of concrete by partial replacement of river sand with it as fine aggregate (Arivumangai and Flixkala; 2014, Felixkala et al; 2011and kanmalai et al; 2008) and the result has been satisfactory. In their work 'Durability studies of concrete made by using artificial sand with dust and natural sand' it was discovered that in a given mixes that contained artificial sand with dust as fine aggregates, the concrete gives higher strength that is consistent than mixes containing natural sand (Shaikh et al; 2011).

Fly ash is one of the residues generated during combustion of coal and comprises of the fine particles that rise with the flue gases (Madhavi et al; 2014), and it has been used in the production of concrete by either partially or completely replacing cement with it. Fly ash reacts and hardens if mixed with water, and this is due to the formation of a hydration product that is cementitious in nature. In his work Mehta; (2004) discovered that fly ash can reduce the water content of concrete by up to 50% and this can improve concrete workability, reduce thermal and drying shrinkage and also increase durability. Hence, concrete made with fly ash is sustainable, durable and economical (Aggarwal et al; 2010, Malhotra et al; 2002).

2.10.1 Advantages of concrete made with quarry Dust

a) Extraction – The ingredients in concrete are in abundant supply and easy extraction minimizes depletion of our natural resources. Most quarries are reclaimed for recreational use or returned to their natural state.

b) Processing – Concrete requires very low energy input for manufacture.

c) Construction – Ready mixed concrete is produced locally, keeping fuel requirements minimal. Ingredients are almost always produced and procured locally. There is very little waste in using concrete; it is ordered and used on an as-needed basis. Even leftover concrete is reclaimed and/or reused.

d) Operation – There are significant sustainable advantages to concrete buildings and pavements. Concrete's rigid design means heavy vehicles consume less fuel than when travelling over asphalt. Concrete's high thermal mass delivers year round energy savings in buildings by reducing temperature swings. Concrete is a durable material that actually gains strength over time, extending the life of structures and delaying the need for reconstruction. Concrete walls do not require paints or sealants. Concrete does not sustain the growth of mould and it is easily cleaned. Concrete's reflectance is high, reducing lighting requirements and keeping surfaces cool.

e) Demolition – Concrete is relatively easy to rubberize and can be easily stored near a reclaiming operation.

f) Recycling –solid waste minimization and waste recovery; Concrete is a nearly inert material which makes it an ideal medium for recycled waste or industrial by products such as quarry dust, or some aggregates. Concrete can be 100% recycled as aggregates for new concrete, for base layers, or for fill, thus reducing landfill use.

2.10.2 Disadvantages of concrete made with quarry dust

a) A lightweight concrete with low strength may be produced if not properly handled.

b) Fine aggregate may not be readily available when needed during concrete production.

c) Concrete production may be expensive due to the unavailability of the fine aggregate.

d) Possible loss of workability and increase shrinkage may occur.

2.11 Optimization

Optimization can be said to be the process of choosing the best elements from some set of available alternatives (Anukworji and others; 2011). The application of optimizing or linear programming can be found very important in areas such as mathematics, computer science, engineering and economics. Since optimization is the process of selecting the best from a given alternative, it is geared towards solving problems in order to minimize or maximize a real function by systematically selecting the value of real or integer variable from within an allowable set. In his work Chinneck; (2008) defined optimization as the art of allocating scarce resources to the best possible effect. The application of optimization can be found very useful in areas like transportation, industrial scheduling, decision making etc. The main aim of optimizing is to find the best setting which minimizes or maximizes a given response or responses or to meet a set of specification; (Simon 2003).

Optimization can be carried out by using mathematical (numerical) or graphical (contour plot) approach/model. The graphical method of optimization is limited to only cases where there are few responses. The mathematical method of optimization method of optimization require that the objective of the function must be defined, in order that it reflects the level of each response in term of minimizing (zero) or maximizing (one) desirability (Simeon and others 2003). In this thesis, mathematical optimization is used. Optimization process can be summarized in a chart as shown below;

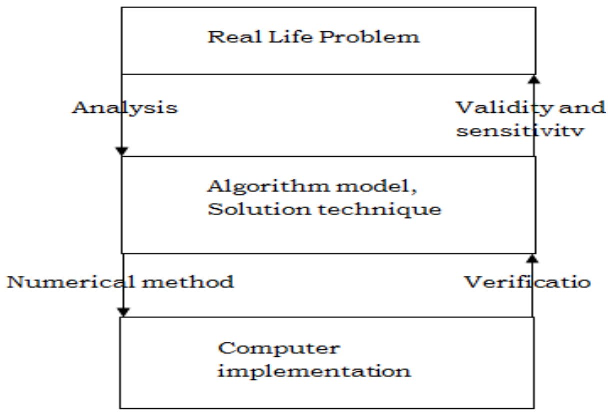

Fig. 2.1 optimization process

2.11.1 Optimization processes

From figure 2.1 the optimization cycle can be seen, it started from real life problem to analysis which is the algorithm or model technique. Here, irrelevant details are not used rather more attention is given to important major factor which is relevant in the solution of the problem.

From the algorithm techniques, the next stage is the computer implantation as seen in figure 2.1, which is generally the province of numerical methods. The accuracy in calculation when using digital computer, efficient in implementation of matrix inversion techniques, the movement from computer implementation back to algorithm, model or solution techniques is known as verification. Verification process is carried out in order to make sure that the computer implementation actually carried out the algorithm process as expected. The next stage is the process of moving from the algorithm process to the real life problem which is known as validation and sensitivity analysis. The validation process is aim at making sure that the model or solution technique is adequate for the real life situation, while the sensitivity analysis is employed to look at the effects of the specific data on the result.

2.11.2 Optimization methods

During the Second World War (1947), an American mathematician George Dantzig developed an optimization technique which was used in dealing with the massive logistical issues caused by large armies having millions of men and machines (Chenneck; 2000). This techniques developed during world war 11 is the origin of optimization process. Immediately after world war 11, when the firs electric computers were developed, optimization process were made more perfect than what it was used to be before. Today various optimization technique are available, often stimulated by fascinating insight from other fields, but for this thesis only statistical experimental design approach will be used. In recent times various optimization methods have been used in concrete mix design to predict and optimize certain desired qualities (compressive strength, flexural strength, slump, etc) without the conventional methods which involve trial and error (Onuamah; 2015, Obam and Osadebe; 2007, Orie and Osadebe; 2009, Ukamaka; 2007). There are various type of optimization processes which include;

a) Statistical experimental design process

In the industries were products such as gasoline, food, detergent etc is to be optimized, the statistical experimental design approach is used. In the case of concrete which is the combination of several components, the performance criteria include setting time, temperature, viscosity, mechanical properties such as strength, elastic modulus, creep and shrinkage etc (Simon; 2003). The application involves the use of theory of statistics (ANOVA) and some specified laboratory results from practical experiment to formulate the mathematical model (equation) which will be used later to predict the strength and other parameters with assumed mix ratio (Anukworji et al; 2011).

b) The mixture approach

George Dantzig is the first man to introduce the mixture approach during the Second World War, but Scheffes; (1958) improved the method by introducing the simplex lattice design and later in 1963 introduced the simplex centroid design. Most real-world linear programming problems have more than two variables and thus too large for a graphical solution procedure, so simplex method is used instead to find the optimal solution. The simplex method is actually an algorithm (or et of instruction) which examines corner points in a methodical fashion until the best solution-higher profit or lower cost is found. The use of mixture experiment in the design of concrete mix is relatively a new area in concrete production (Özlem et al; 2008), various work have been done on the use of factorial and statistical experiment to develop rapid-set high strength cement and medium strength self-compacting concrete (Srinivasan, et al; 2002, Bajorski, et al; 2007, Snobi;2003, Anyaogu and Ezeh;2013, Umeonyiagu and Adinna; 2014). Simplex centroid design by Scheffes have been the most used mathematical method by researchers in the determination of the compressive strength of concrete and other desired parameters (Mbadike and Osadebe; 2013, Eze and Ibearugbulem; 2009, Anya and Osadebe; 2015, Gamil and Bakar; 2016).

c) Mathematical independent variable

The mathematical independent variable approach is also known as factorial design method. In this type of design approach, if there exist q components materials (where q is the number of component material) the q components of a mixture are reached to $q-1$ independent variable using the two components as an independent variables (Simon and others; 1997). In the case of concrete, water/cement ratio is a natural choice of this ratio variable. For the situation with $q-1$ independent variable, a $2^{(q-1)}$ factorial design forms the backbone of the experiment (Anukworji and others 2011). Further more in mixture approach, empirical models are fit to the data and polynomial model (linear or quadratic) are used.

d) Regression method

For a given mixture a set of parameters $X_1, X_2, X_3, \ldots \ldots \ldots \ldots \ldots \ldots, X_n$ known as predictors can be used to predict the probable value of a dependent variable Y with a particular degree of certainty (Mandenball; 2003). Osadebe in 2003 assumed that the response function $F_{(Z)}$ is continuous and differentiable with respect to its predictors Z_i. The two researchers presumed that so long as the values of the predictors are known, the corresponding value of the dependent variable can be predicted with some degree of certainty (compressive strength, cost etc). In this design approach few points of observation will be used to formulate a model. Once the model have been formulated and validated it can be used to predict the future values of independent variables. Regression method have been used extensively in mix design for concrete production (Okere et al; 2013, Okere; 2006, Chijioke et al; 2015, Onwuka et al; 2013, Egbe and Orie; 2016).

e) Neural network approach

The use of computers in recent times has been very useful in the scientific world, especially in the area of accuracy and precision. The use of computer in the implementation of different complex statistical method cannot be over emphasis. With the increasing accuracy and precision of analytical measuring method, it become clear that all effects that are of interest cannot be described by simple uni-variant and even not by the linear multi-variant correlation precise, a set of methods that have recently found very intensive use among engineers are the artificial Neural Networks (Zupan; 1994). These methods have been used in the development of simulator and intelligent system to predict the compressive strength and the workability of high performance concrete. In this type of method, the problem to be solved is first identified; this will determine the type of network topology to be selected (Vijay and Yogesh; 2013, Acuña-Pinaud et al; 2017, Vahid and Mohammad 2013, Rasa et al; 2009, Alilou; 2009, Teshnehlab and Alilou;2008). The neural network is defined by its topology, leaning paradigm and learning topology, then effort is made to identify the types of input data whether it's is all binary (0/1), bipolar (-1/+1) or the data contains real-value inputs. These types of data might disqualify some of the network architecture which use certain function in their learning algorithm, and finally the number of input and output units and the hidden nodes that gives the best performance is determined. The network has to map the features of the inputs and produce the desired output and also solve the problem of classification assuming the study is to classify the mixture proportioning of high performance concrete that can give the best strength based on various factors (Struchenkov; 1999, Struchenkov; 2009, Adulhaq; 2015). Neural network has is used in the prediction of compressive strength of concrete and other desired parameter in concrete (Bilgehan and Turgut; 2010, Kewalramani and Gupta; 2006, Kisi; 2005).

f) Genetic algorithm method

Genetic algorithm methods are family of computational modes inspired by evolution. These algorithms encode a potential solution to a specific problem on simple chromosome-like data structure and apply recombination operators to these structures so as to preserve critical information. Genetic algorithms are often viewed as function optimizers, although the range of problems to which genetic algorithms have been applied is quite broad (Whitley; 2012).

These methods was developed by John Holland in the 1970s with the aim of

i) Understanding the adaptive processes of natural systems

ii) Designing artificial system software that retain the robustness of natural systems

ii) Providing efficient, effective techniques for optimization and machine learning application.

Genetic algorithm therefore identifies the individuals with optimum fitness value and those with lower fitness will naturally get discarded from the population. Ultimately the search procedure finds a set of variable that optimizes the fitness of individual or of the whole population. This method has advantages over traditional non-linear solution techniques that cannot always achieve an optimal solution. The process involved in solving problem using genetic algorithm is achievable through the process of evaluation, the process of selection, the process of cross-over and mutation process. Genetic algorithm has been used in the prediction of various desired parameter like compressive strength, flexural strength etc in concrete productions and concrete structures (Ahsanul et al; 2012, Hasan and Kabir; 2011, Garg; 2003, Hasan; 2012,Hamid-Zadeh et al; 2006). It has also been used in the design of low-cost reinforced frames structures (Camp et al; 2003,Ghodrati et al; 2008, Aggarwal et al; 2015). The use of conventional linear regression cannot give satisfactory solution to predicting some desired parameters in concrete, this is where genetic algorithm method comes in, to takes care of these anomalies (Juncai et al; 2017).

2.11.3Statistical method

There are so many statistical methods used in the analysis of concrete parameters and this is called Response Surface Methodology (RSM). Response surface methodology is a collection of mathematical and statistical methods used to develop, improve or optimize products to achieve the desired parameter needed (Simon et al; 1999). The RSM is used effective when it comes to products in which every component has an effect on the product. This objective of this method is to be used for the optimization of one or more response like compressive strength, flexural strength etc (Simon; 2003). Concrete is a mixture of various components like water, cement, fine aggregate, coarse aggregate and sometimes admixtures are added to achieve the desired parameter needed. The various components that made up concrete have a direct influence on it. There are three types of procedures used in RSM method they are; experimental design, modelling and optimization.

2.11.2.1 Design experiments

Design experiments is an important aspect of RSM, and were initially developed to used in model fitting of physical experiments, although it can sometimes be used in numerical experiments. Let us look at q component materials say concrete, here q is the total number of components in the mixture. There two experimental design approach that can be used in this case namely the classic mixture approach, in which the *q* mixture components are the variables and the mathematically independent variable (MIV) approach, in which *q* mixture components are transformed into *q-1* independent mixture-related variables ( ). The mixture approach the total amount of product is fixed and the settings of each of the *q* components are proportions. The q-l of the factors can be chosen independently due to the total amount is constrained to sum up to one. For the mathematical independent variable approach the *q* components of a mixture are reduced to *q-1* independent variables by means of the ratio of two components as an independent variable. Relating this to concrete, w/c is a natural choice for this ratio variable. For the situation with *q-1* independent variables, a 2^{q-l} factorial design forms the backbone of the experiment. This design consists of several factors (variables) set at two different levels (Simon; 2003).

2.11.1.2 Modelling

Modelling is a theoretic framework that allows us to define a process or relationships existing between various representative elements of a system. Here we are dealing with concrete, the responses and all the components that made up the product.. The scales of modelling are multiple (Torrenti et al; 2010). A model ca be inform of linear, polynomial or quadratic in nature. For polynomial models can be fit to data by the means of variance (ANOVA) and least square methods. Presently there are many statistical software packages that can be used to carry out these entire tasks as describe above. Once a model has been fit, it is important to verify the adequacy of the chosen model quantitatively and graphically (Simon; 2003).

2.11.2.3 Optimization

Concrete mixture optimization involves the adaptation of available resources to meet varying engineering criteria, construction operations, and economic needs. Economic considerations include materials, delivery, placement, and progress time related costs. A lot of responses can be optimized simultaneously any time the appropriate models have been developed. This can be done by the use of mathematical (numerical) or graphical (contour plots) methods. The problem with graphical approach is that it deals with few responses. In numerical optimization the function objective have to be define, that reflects the levels of each response in terms of minimum (zero) to maximum (one) desirability (Simon; 2003)

2.11.4 Summary of literature/Knowledge gap

From the literature review, it can be seen that a lot of work have been done on the use of quarry dust as a replacement (partially or total) for river sand in the production of concrete. But no work has been carried out on modelling and optimization of concrete made with quarry dust as fine aggregate.Current research is designed to address this issue so that it can contribute significantly to the existing knowledge of the use of quarry dust as fine aggregate in the production of concrete. After developing these models, computer programs will be written based on these models and these computer programs, it will be easy to predict various mixes given a particular compressive strength or flexural strength. Also it will easy to predict compressive strength or flexural strength expected given a particular mix ratio. Hence eliminating the conventional methods used in the determination of various mixes and strengths which is laborious, time wasting and expensive due to wastages. Also mos optimization techniques such as Scheffes, Osadebe and Ibearugbulem regression models assume linear models in optimization which is over assumption. Responses could be nonlinear. This research was designed to take care of this shortfall by considering response surface method that can deal with interaction and order effects. Another knowledge gap is that there is absence of prediction software for the prediction of compressive and flexural strengths of concrete made with quarry dust.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Material

3.1.1 Material Preparation

Sand, one of the fine aggregates used in this research work was obtained from Otamiri River, near Nekede in Owerri west local government area of Imo state. Quarry dust, the second fine aggregate used in this study was procured from the abundant deposits at Umuoghara, Ezza north in Abakaliki, Ebonyi state. The coarse aggregate used was crushed granite chippings of 20mm nominal size produced in Abakiliki quarry site. Ordinary Portland cement (Dangote cement) conforming to BS12 was used. The cement was well protected from dampness to avoid lumps. Portable tap water supplied by Federal Polytechnic Nekede bore hole, for domestic consumption was used throughout the research experiments.

Thus the materials used for this research were cement, sharp sand, quarry dust, coarse aggregate (crushed granite) and water. Cement was purchased and taken to the laboratory in sealed 50kg bags, while the fine and coarse aggregate were obtained from piles of each material, quarry site- for quarry dust and coarse aggregate and sand site and transported to the laboratory. Water was obtained directly from the tap in the concrete laboratory. The water was fit for drinking. The concrete samples were 150mm cubes. The tests were carried out at the concrete laboratory of Federal Polytechnic Nekede Owerri Imo state.

The materials were air dried in the laboratory. The coarse aggregate (granite chippings) was passed through sets of sieves, the portion passing through sieve (25mm) and retained on sieve (20mm) was used. The sharp sand and quarry dust used in the experiments were those passing sieve (2mm) and retained on sieve (150µm). All tests were conducted according to the relevant British Standard (BS).

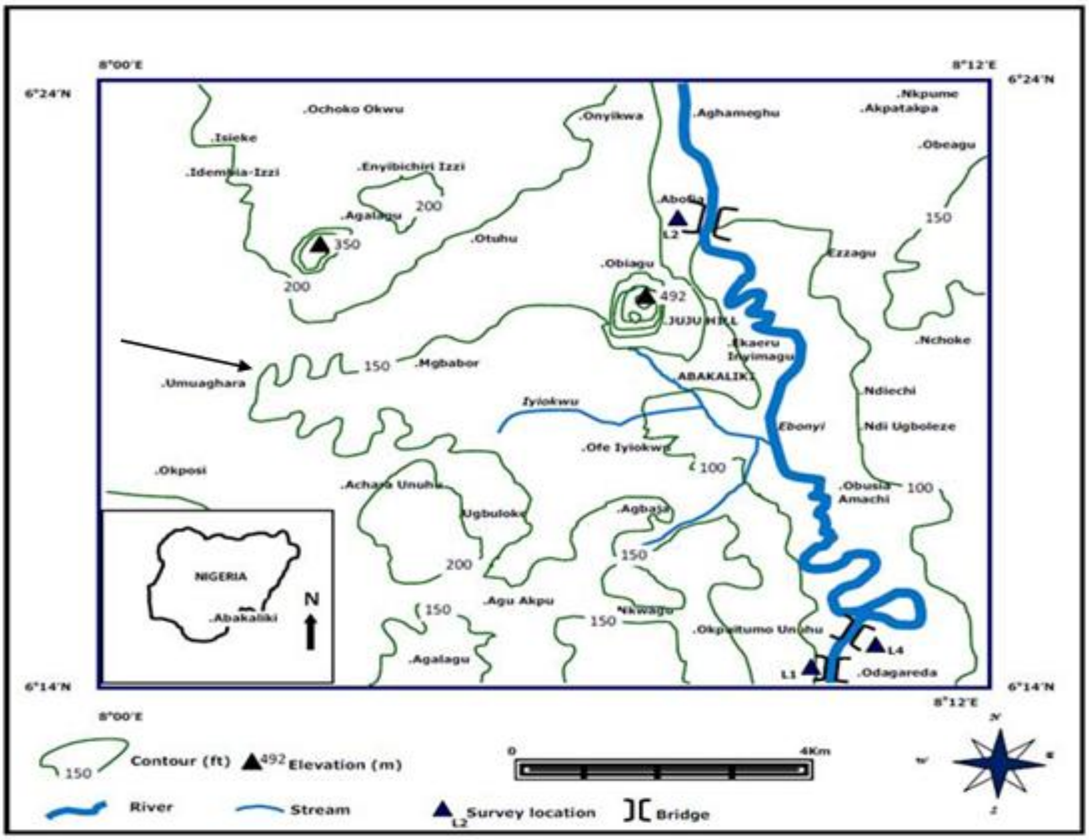

Figure 3.1Map of Umuoghara in Abakaliki Ebonyi state

Table 3.1Values of mix ratios and water cement ratios

Specimens	w/c ratio	Cement	Fine aggregate	Coarse agg.
R1	0.6	1	1.5	3
R2	0.5	1	1.75	4
R3	0.55	1	2	3
R4	0.56	1	2	5
R5	0.575	1	1.75	3
R6	0.55	1	1.625	3.5
R7	0.58	1	1.75	4
R8	0.53	1	1.875	4.5
R9	0.555	1	2	4
R10	0.525	1	1.875	3.5

Table 3.2 Control value of mix ratios

Specimens	w/c ratio	Cement	Fine aggregate	Coarse agg.
C1	0.563	1	1.688	3.25
C2	0.578	1	1.75	3.5
C3	0.567	1	1.688	3.75
C4	0.553	1	1.813	3.75
C5	0.555	1	1.813	4.25
C6	0.538	1	1.75	3.5
C7	0.575	1	1.563	3.25
C8	0.558	1	2	4.5

3.1.2 Tools and instruments used

Concrete moulds (150×150×150 in mm and 150× 150 × 500 in mm), weighing balance, spade, trowel, spanner and pinches, sieve, weighing pan, head pan and bucket, tapping rod and rule, slump test cone (Abram's cone), curing tank, and universal compressive Machine.

3.2 Specimen preparation (procedure)

The batching of concrete was done by weighing the different constituent materials based on ten different mix ratios for the real mix and eight for the control mix as stated above. The materials were then mixed thoroughly before adding the prescribed quantity of water and then mixed further to produce fresh concrete. The freshly mixed concrete was then filled into a cone and the slump obtained. The fresh concrete was remixed and then filled into moulds in approximately 50mm layers with each layer given 25 strokes of the tamping rod. The concrete was towelled off level with the top of the mould and the specimen stored under damp sacking for 24hours in the laboratory before de-moulding and storing in water for the required curing age.

This same exercise was also done for another concrete samples using quarry dust as the fine aggregate with their mix ratios. Each of the samples produced has a control. A total of 120 cubes were produced.

3.2.1 Slump test

Workability of a concrete can be measured by the use of slump test, which is a simplistic measure of the plasticity of a fresh batch of concrete, and this can be done using the ASTM C 143 or EN 12350-2 test standards. A relatively dry sample slumps vary little, having a slump value of one or two inches (25 or 50 mm) out of one foot (305 mm). A relatively wet concrete sample may slump as much as eight inches.

Procedure

The slump was measured by filling an "Abram's cone" with a sample from a fresh batch of concrete. The cone was placed with the wide end down onto a level, non-absorptive surface. It was then filled in three layers of equal volume, with each layer being tamped with a steel rod to consolidate the layer in 25 number of time. When the cone was carefully lifted off, the enclosed material slumps a certain amount due to gravity. The slump was measured with a rule calibrated in cm and values recorded.

The slump is then interpreted by the following shapes:

- **True Slump** – the only slump that can be measured in the test. The measurement is taken between the top of the cone and the top of the concrete after the cones removal
- **Zero Slump** – Very dry mixes aim to have zero slumps, and are used in road making.
- **Collapsed Slump** – This is an indication that the mix is too wet or that it is a high workability mix, for which a clump test is not appropriate
- **Shear Slump** – This result is incomplete, and should be retested

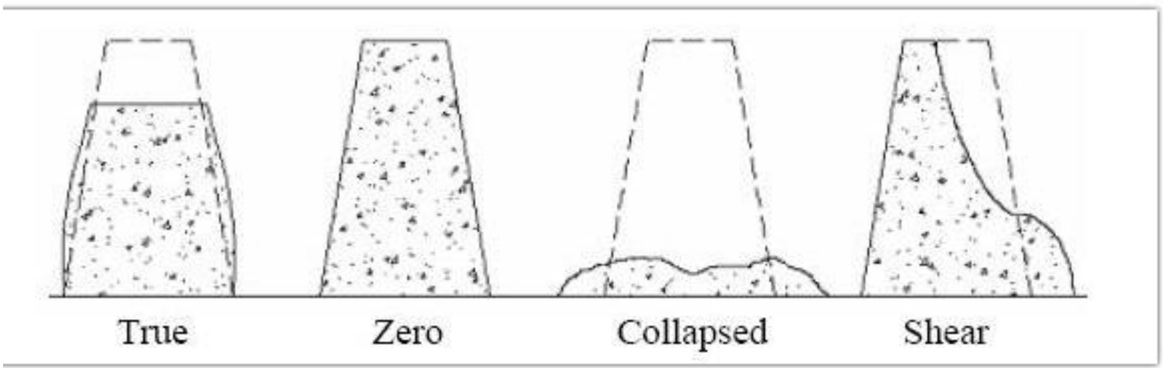

Fig 3.2 Shape of slump

The results of the slump test are as presented in table 4.9 to 4.12.

3.2.2 Testing of sample (compressive strength)

Testing of the hardened cubes were carried out after 28days curing, using a compression testing machine. The cube samples were weighed and placed between hardened steel bearing plates on a universal compression machine and load applied at the rate of 15N/mm^2 per minutes as specified in BS1881. The sample was wiped off from grit and placed centrally with load applied steadily to destruction and the highest load reached was determined. This is used to compute the compressive strength which is the ratio of the highest load to the cross sectional area of the sample expressed in N/mm^2. Three samples were used for each test and the average results adopted as the compressive strength.

Calculation :

Mean strength,

$\dot{X} = \sum x/n$

Standard deviation,

$\sigma = \sqrt{\frac{\sum(X-\dot{X})^2}{n-1}}$

$$f_k = f_{ck} + k_\sigma$$

Where f_k is characteristic strength, f_{ck} is minimum characteristic strength and k_σ is constant usually 1.64.The results of the compressive test are as presented in table 4.13 to 4.16

3.2.3 Flexural strength (BS EN 12390-5:2009)

Equipment and Materials

Rigid steel forms 50 cm long by 15 cm in the other two dimensions, point loading apparatus capable of maintaining the specified span length and distance between load applying blocks and support blocks to within $\pm$0.13 cm, a suitable loading machine capable of applying the loads at a uniform rate without interruption.

Procedure

The specimens were prepared in accordance with the concrete batch procedure, slump test was carried out on the fresh concrete. Fill the beam forms with three lifts of concrete, tamping each lift 25 times with the 16mm tamping rod or fill the form in one lift and consolidate the concrete with a mechanical vibrating table. Care was taken not to over vibrate since that would cause segregation. After the beams have been demoulded curing was carried out. The specimens are removed from the curing facility, mark the beam where it will be in contact with the supports and at the opposite side where it will be in contact with the third-point loading. Remember that none of these contact points should be on the top or hand-finished surface of the specimen. In other words the beam was tested 90° to its casting position. This was done to assure proper contact at the load points. However, this should be checked. 6.4-mm thick leather shims, 3 cm long, was used for the full width of the specimen, whenever a gap in excess of 0.10 mm exists between the loading and support points and the specimen. The test was carried out as soon as possible, while the specimen is still moist from the curing room. An initial load of 2300 kg was apply rapidly; loading continued at a rate of 450 kg per minute until failure occur. The ultimate load was recorded, the exact location of fracture, and the type of failure. If the failure occurs more than 5% of the length, 2.25 cm outside the middle third of the beam in the tension surface, the results was discarded. After the test, the cross section at each end and at the centre was measured and the average height and depth was computed (Kett 2010).The results of the flexural test are as presented in table 4.17 to 4.20.

3.3 Material grading (BS 1377: Part 2 1990)

3.3.1 Grading and size distribution

The particle size distribution of aggregates is called grading. Grading determines the paste requirement for a workable concrete since the amount of voids among aggregate particles requires the same amount of cement paste to fill out in the concrete mixture. The river sand were obtained from Otamiri river in Owerri Imo state. To obtain a grading curve for an aggregate, the sieve analysis must has been conducted.

Apparatus

Electric Sieve shaker

Sieves of various sizes (1.18mm-750μm)

Electronic weighing balance

Hand brush

Procedure

The sieve sizes were arranged from the highest sieve size (1.18mm) to the lowest size (750μm) and to the pan. The fine aggregate (sand or quarry dust), was poured into the arranged sieves from the top, fixed into the sieve shaker, power switched on. After a period of 15minutes the machine was stopped and the sieves removed from the machine. The aggregates in the sieves were weighed and recorded. This would be used for the analysis. The coarse aggregate was also graded using the same method.

Calculation:

Mass of soil retained, D = C − B

Mass of soil passing,   E = Total mass retained-mass retained

% passing F = mass of soil passing (E)/total mass retained ×100

The results of the grading and size distribution are as presented in table 4.94 to 4.50 and figure 4.11 to 4.12.

3.3.2 Density / specific gravity

Density/specific density is very important because it is used to calculate the volume of aggregates in any type of concrete mixture, and can be define as the mass of aggregates to mass of water in a given batched concrete.

Apparatus

Density bottle

Weighing balance

Funnel

Procedure (quarry dust)

The density bottle was thoroughly clean, weighed and recorded. The fine aggregate was obtained and put into the density bottle through a funnel and the mass recorded. The sample was removed from the bottle and the bottle properly cleaned. Water was poured into the bottle and the mass obtained. The same procedure was adopted for the density of sand, coarse aggregate and cement and the results are as presented in table 4.1 to 4.4.

3.3.3 Bulk density of soil samples

The mass of aggregates needed to fill the container of a unit volume of concrete after aggregates are batched based on volume is called the bulk density of the aggregates. Packing of the aggregates, shapes of the aggregates and sizes of the aggregates are factors that effects the bulk density of aggregates.

Apparatus

Weighing balance, Measuring can, oven.

Procedure

The weight of the weighing can is determined and the result recorded. Oven dry soil is weighed with the weighing can. The weight of the sample is weighed together with the can and the weight recorded. The weight of the sample is later determined. The volume of the can is also determined. The bulk density is determined by dividing the mass of the oven dry soil and the volume of the can. The results of the bulk density of each sample is as presented in table 4.5 to 4.8.

3.3.4 XRF Test

This experimental method was used to determine the metallic oxides present in a sand and quarry dust.

Method

Metallic Oxide determination in Sand and Quarry Dust

Metallic Oxides in the sample were determined using X-ray fluorescence spectrometer (XRF) in accordance with ISO 18227. Samples were reduced to <2μm diameter by crushing. Crushed samples were further pulverized for thorough homogeneity of sample. It was then processed into pressed pellets, transferred to clean prolene foil and then into a sample vial, labelled, arranged in the sample tray and finally transferred to the sample compartment of the X-ray fluorescence equipment for screening of metallic Oxides. The concentration of the oxides was obtained via a previously stored calibration with certified reference materials.

Result was calculated automatically as the necessary sample details were computed in the software.

Model: **Xepos 03 STD Gas**

Serial Number: **Spetro- 11001700**

TEST METHOD: ISO 18227

EQUIPMENT/APPARATUS:

- X-Ray Fluorescence (XRF) Spectro Xepos
- Mixer mill MM400
- Grinding Jars, Balls and Screen Insert ring
- Analytical Balance, precise to within 0.1mg
- Crucibles
- Evacuable Pellet Die:(Plunger, Base, Pair of Stainless Steel Pellets, Extractor Rings)
- Hydraulic Press
- Sample Cups (32mm, 40mm)
- Prolene Film 4µm Roll and Precutted
- Dust Protection Foil
- Sample Cup Liquid Protect
- Tool Snap Ring Sample Cup
- Handling Tool
- Cotton Wool
- Scissors
- Glass Beads (FLX-SP1&2)

<u>Loss on Ignition</u>

a. Oven-dry a representative sample as in moisture content determination for about 4hrs and cool in a desiccators.

b. Ignite a clean crucible at 550 ± 25^{o}C for 1 hour in a muffle furnace and cool to room temperature in a desiccators.

c. Weigh the empty crucible to the nearest (0.001g) and record the weight, Ma

d. Weigh approximately 0.5 - 5g of the oven-dried sample into the crucible.

e. Record the weight of the crucible and the sample, Mb.

f. Place crucible and its contents in the muffle furnace and allow the temperature to rise slowly to 550^{o}C.

g. Allow to remain at that temperature for 1 hour.

h. Remove and cool to room temperature in desiccators for 30 minutes.

i. Record the weight of the crucible and its content, Mc.

j. Calculate the percentage loss-on-ignition from the weight loss during combustion.

Loss-on-ignition at 550^{o}C (%) =$[(M_b - M_c) \times 100]/(M_b - M_a)$

Equipment/ Apparatus

a. Drying oven (105± 5^{o}C)
b. Muffle furnace, for operation at 550 ± 25^{o}C
c. Weighing balance, resolution 0.01g
d. Crucible
e. Desiccators

The results of the grading and size distribution are as presented in table 4.55 to 4.56.

3.4 Methods of Testing and analysis

3.4.1 Introduction

A mixture design experiment involves mixing various proportions of two or more components to make different composition of an end product (Aggarwal 2002). Mixture design are type of factorial design used to determine the best composition when there is a mixture of ingredients; example like in concrete we have water, cement, fine aggregates (sand) and coarse aggregates. For a mixture design the percentages of the component making up the mixture must add up to 100%, because of this anytime the percentage of one ingredient in the mixture is altered, it must reduce or increase the percentage of another ingredient in the mixture.

To plan for a mixture experiment the following steps must be followed (Rasch et al, 2011);

a) Define the objectives of the experiment. Select the mixture components.
b) Identify any constraints on the mixture components to specify the experimental region.
c) Identify the response variable to be measured.
d) Define an optimality criterion for the construction of the design.
e) Propose an appropriate model for modelling the response data as function of the mixture component.
f) Select an experimental design which suffices points (c) and (d) above.

In the general mixture problem, the measured response is assumed to depend on the proportions of the ingredients present in the mixture and not on the amount of the mixture (Cornell 2002). For mixture components where x_i is subject to constraints,

$$0 \leq x_i \leq 1 \quad (3.1)$$

Where

$$i = 1,2, - - - - - - - -, q$$

$$\sum x_i = 1$$

From equation 3.1 q is the number of components. As a result the factor space reduces to regular $(q-1)$dimensional simplex S_{q-1}. For $q = 2$a straight line is obtained and for $q = 3$ an equilateral triangle is obtained and for $q = 4$ a tetrahedron is obtained.

For a given experimental mixture, the components proportions are often subjected to constraints (singular or multiple constraints). In equation 3.1, due to the constraints, the equation yields a simple experimental region. A single or multiple components constraints generally yield a polyhedral constrained region.

Scheffe (1958, 1963) was the first to introduce the (q, m) simplex lattice design and simplex centroid design, while Cornell (2002) discussed experimental design method for simplex and constrained region mixture experiment.

3.4.2 Simplex lattice design

The (q, m) simplex lattice designs are characterized by the symmetric arrangement of points within the experimental region and a well chosen polynomial equation to represent the response surface over the entire simplex region. The polynomial has exactly as many parameters as the number of points in the associated simplex lattice design.

The (q, m) simplex lattice design given by Scheffe in 1958 consist of ${}^{q+m-1}C_m$ points, where each components proportion take $(m+1)$ equally spaced value

$$x_i = 0, \frac{1}{m}, \frac{2}{m}, \dots \dots \dots \dots \dots \dots, 1 \quad (3.2)$$

where

$i = 1,2, \dots \dots \dots \dots \dots \dots \dots \dots .., q$ ranges between 0 and 1and all possible mixture with these components proportions are used.

Consider a (2,2) simplex lattice. This can be written as $^{2+1-1}C_2 = {}^2C_2 =$ 3 points. x_i can be taken as $m+1=2$ possible values; $x_i = 0, \frac{1}{2}, 1$ with which possible design points are $(1,0), (1,0), (\frac{1}{2}, \frac{1}{2})$, as shown in the straight line in Fig 3.1 below.

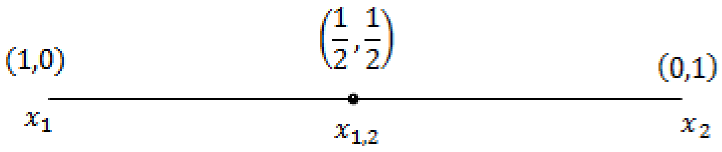

Fig. 3.3 A straight line simplex lattice.

We can carry out the same calculation for (3,2) simplex lattice, this can be written as

$^{3+2-1}C_2 = {}^4C_2 =$ 6 points. x_i can be taken as $m+1=3$ possible values; $x_i = 0, \frac{1}{2}, 1$ with which possible design points $(1,0,0), (0,1,0), (0,0,1), \left(\frac{1}{2}, \frac{1}{2}, 0\right), \left(0, \frac{1}{2}, \frac{1}{2}\right), (\frac{1}{2}, 0, \frac{1}{2})$. These points can be represented in a triangular form as shown in Fig. 3.2 below.

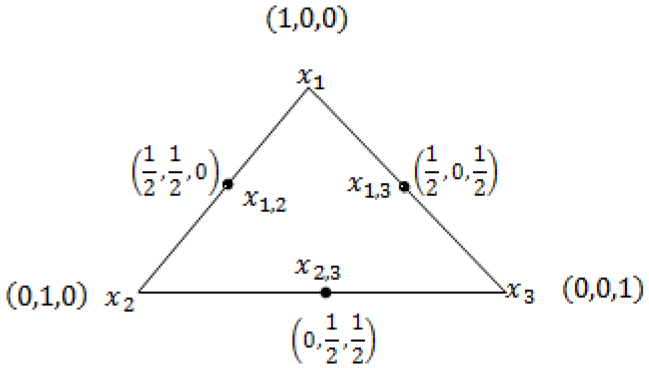

Fig 3.4 Triangular simplex lattice.

For (4,2) simplex lattice, it can be written in the form $^{4+2-1}C_2 = {}^5C_2 =$ 10 points. x_i can be taken as $m+1=4$ possible values; $x_i = 0, \frac{1}{2}, 1$ with which possible design points $(1,0,0,0), (0,1,0,0), (0,0,1,0), (0,0,0,1), \left(\frac{1}{2}, \frac{1}{2}, 0,0\right), \left(\frac{1}{2}, 0, \frac{1}{2}, 0\right),$

$\left(\frac{1}{2}, 0,0, \frac{1}{2}\right), \left(\frac{1}{2}, \frac{1}{2}, 0,0\right), \left(0, \frac{1}{2}, 0, \frac{1}{2}\right), \left(0,0, \frac{1}{2}, \frac{1}{2}\right)$. These points can be represented in a tetrahedron form as shown in Fig. 3.3 below.

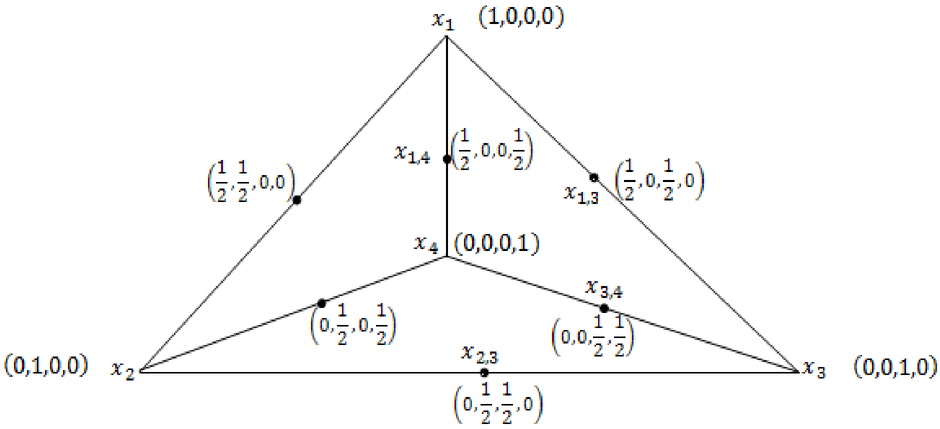

Fig 3.5 Tetrahedron simplex lattice

3.4.3 The Canonical Polynomials

The concept of canonical polynomial was first introduced by Scheffe (1958) to be used with his simplex lattice. These polynomials are obtained by modifying the usual polynomial model in x_i by using the restriction $\sum x_i = 1$.

The number of terms in (q, m) polynomial or canonical polynomial is $^{q+m-1}C_m$ and this number is equal to the number of points that make up the associated (q, m) simplex lattice design (Aggarwal 2002). For a linear canonical model where $m = 1$ then

$$Y = \sum \beta_i x_i \qquad (3.3)$$

For the above equation the number of term is q, which is the number of points in the $(q, 1)$ lattice. For $m = 2$, the second degree canonical polynomial is given as

$$Y = \sum \beta_i x_i + \sum \sum_{i<j} \beta_{ij} x_i x_j \ (3.4)$$

From equation 3.4 above the number of terms is given as

$$q + \frac{q(q-1)}{2} = \frac{q(q+1)}{2} \ (3.5)$$

3.4.4 Responses

The property of fresh and hardened concrete are called responses (Simeon et at, 1997), and these include compressive strength, modulus of rapture, shear modulus, slump, elastic modulus etc. These responses can be put in a polynomial function of pseudo component of the mixture as proposed by Scheffes (1958) and Simon et al (1997) as shown below;

$$Y = b_o + \sum b_i X_i + \sum b_{ij} X_i X_j + \sum b_{ijk} X_i X_j X_k + \ldots . + \sum b_{i1,i2}, \ldots \ldots \ldots , in X_i, X_{12}, \ldots \ldots . . X_{in} + e \tag{3.6}$$

Where

$1 \leq i \leq q$, $1 \leq i \leq j \leq q$, $1 \leq i \leq j \leq k \leq q$, and $1 \leq i_1 \leq i_2 \ldots \ldots . . \leq in \leq q$ respectively.

b_o = arbitrary constant

e =random error

Y = the response

The equation of the response for a two-pseudo component mixture cab be written as

$$Y = b_o + b_1 X_1 + b_2 X_2 + b_{11} X_1^2 + b_{12} X_1 X_2 + b_{22} X_2^2 + e \tag{3.7}$$

For three pseudo component mixture the response equation is

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{11} X_1^2 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{22} X_2^2 + b_{23} X_2 X_3 + b_{33} X_3^2 + e \tag{3.8}$$

For four pseudo component mixture the response equation cab be written as

$$Y = b_o + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_{11} X_1^2 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{14} X_1 X_4 + b_{22} X_2^2 + b_{23} X_2 X_3 + b_{24} X_2 X_4 + b_{33} X_3^2 + b_{34} X_3 X_4 + b_{44} X_4^2 + e \tag{3.9}$$

The term e which is the random error, that represent the combined effects of the variable will not be used in the formation of the model. For the components that is expected to make up the mixture, we have for mixture 1; water, cement, fine aggregate (sand) and coarse aggregate. For mixture 2; water, cement, quarry dust, coarse aggregate. So for all the mixtures, there are four components that make up each mixture. Equation 3.9 will be used in the formation of the final Scheffes equation for the two mixtures.

3.4.5 Scheffes Simplex Design for the two mixtures

The two mixtures comprise of four components each and equation 3.9 will be used to optimize the response based on Scheffes simplex design.

$$Y = b_o + bX_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{33}X_3^2 + b_{34}X_3X_4 + b_{44}X_4^2 + e \qquad (3.9)$$

Using the equation

$$\sum_{i=1}^{q} X_1 = 1(3.10)$$

where

$q = 4$

Equation 3.10 can now be written as

$$\sum_{i=1}^{4} X_1 = 1 \qquad (3.11)$$

Since the total component in the mixture cannot be more than 1, equation 3.10 can be written as

$$X_1 + X_2 + X_3 + X_4 = 1 \qquad (3.12)$$

Multiplying equation 3.12 by b_o yields

$$b_oX_1 + b_oX_2 + b_oX_3 + b_oX_4 = b_o \qquad (3.13)$$

Multiplying equation 3.12 by X_1 yields

$$X_1^2 + X_1X_2 + X_1X_3 + X_1X_4 = X_1 \qquad (3.14)$$

In like manner equation 3.12 can be multiply by X_2, X_3 and X_4 to give their respective values as follows

$$X_1X_2 + X_2^2 + X_2X_3 + X_2X_4 = X_2 \qquad (3.15)$$

$$X_1X_3 + X_2X_3 + X_3^2 + X_3X_4 = X_3 \qquad (3.16)$$

$$X_1X_4 + X_2X_4 + X_3X_4 + X_4^2 = X_4 \qquad (3.17)$$

Making X_i^2 the subject of the formulas in equations 3.14 to 3.17 give respectively the following;

$$X_1^2 = X_1 - X_1X_2 - X_1X_3 - X_1X_4 \qquad (3.18)$$

$$X_2^2 = X_2 - X_1X_2 - X_2X_3 - X_2X_4 \qquad (3.19)$$

$$X_3^2 = X_3 - X_1X_3 - X_2X_3 - X_3X_4 \qquad (3.20)$$

$$X_4^2 = X_4 - X_1X_4 - X_2X_4 - X_3X_4 \qquad (3.21)$$

Substituting equation 3.13 and equations 3.18, 3.19, 3.20 and 3.21 into equation 3.9 yields

$$\begin{aligned} Y = b_oX_1 + b_oX_2 + b_oX_3 + b_oX_4 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 \\ + b_{11}(X_1 - X_1X_2 - X_1X_3 - X_1X_4) + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 \\ + b_{22}(X_2 - X_1X_2 - X_2X_3 - X_2X_4) + b_{23}X_2X_3 + b_{24}X_2X_4 \\ + b_{33}(X_3 - X_1X_3 - X_2X_3 - X_3X_4) + b_{34}X_3X_4 \\ + b_{44}(X_4 - X_2X_4 - X_1X_3 - X_3X_4) \end{aligned} \qquad (3.22)$$

Equation 3.22 can be expanded and rearranged by bringing likes terms together to give

$$\begin{aligned} Y = X_1(b_o + b_1 + b_{11}) + X_2(b_o + b_2 + b_{22}) + X_3(b_o + b_3 + b_{33}) + X_4(b_o + b_4 + b_{44}) \\ + X_1X_2(b_{12} - b_{11} - b_{22}) + X_1X_3(b_{13} - b_{11} - b_{33}) + X_1X_4(b_{14} - b_{11} - b_{44}) \\ + X_2X_3(b_{23} - b_{22} - b_{33}) + X_2X_4(b_{24} - b_{22} - b_{44}) \\ + X_3X_4(b_{34} - b_{33} - b_{44}) \end{aligned} \qquad (3.23)$$

The constants in parenthesis can be sum up to give other constants say β and let

$$\left.\begin{aligned}
\beta_1 &= b_o + b_1 + b_{11} \\
\beta_2 &= b_o + b_2 + b_{22} \\
\beta_3 &= b_o + b_3 + b_{33} \\
\beta_4 &= b_o + b_4 + b_{44} \\
\beta_{12} &= b_{12} - b_{11} - b_{22} \\
\beta_{13} &= b_{13} - b_{11} - b_{33} \\
\beta_{14} &= b_{14} - b_{11} - b_{44} \\
\beta_{23} &= b_{23} - b_{22} - b_{33} \\
\beta_{24} &= b_{24} - b_{22} - b_{44} \\
\beta_{34} &= b_{34} - b_{33} - b_{44}
\end{aligned}\right\} \tag{3.24}$$

Substituting equation 3.24 into equation 3.23 yields

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{14} X_1 X_4 + \beta_{23} X_2 X_3 + \beta_{24} X_2 X_4 + \beta_{34} X_3 X_4 + e \tag{3.25}$$

Equation 3.25 can be written as

$$Y = \ddot{Y} + e \tag{3.26}$$

Where

$e =$ standard error or standard deviation

$$\ddot{Y} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{14} X_1 X_4 + \beta_{23} X_2 X_3 + \beta_{24} X_2 X_4 + \beta_{34} X_3 X_4 + e \tag{3.27}$$

Equation 3.27 can be written in the form

$$\ddot{Y} = \sum_{i=1}^{4} \beta_i X_i + \sum_{1 \le i \le j \le 4} \beta_{ij} X_i X_j \quad + \quad e \tag{3.28}$$

Equation 3.27 has ten coefficients which is in agreement with Scheffes Simplex equation.

3.4.5.1 Mixture model optimization equation

The coefficients of (4,2) polynomial is as given in fig. 3.6

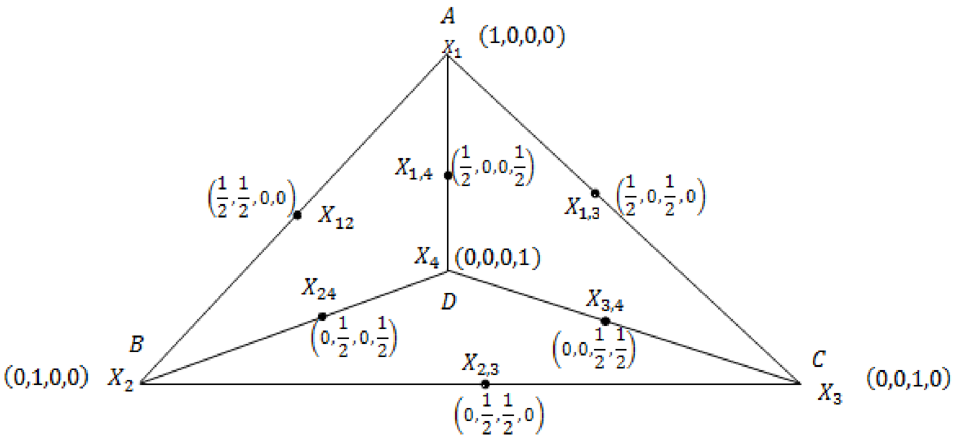

Fig 3.6 Coefficients of 4,2 polynomial

At the vortex A the value of $X_1 = 1$, and $X_2 = X_3 = X_4 = 0$ and similarly

$$\left.\begin{array}{l} At\ B\ X_2 = 1, and\ X_1 = X_3 = X_4 = 0 \\ At\ C\ X_3 = 1, and\ X_1 = X_2 = X_4 = 0 \\ At\ D\ X_4 = 1, and\ X_1 = X_2 = X_3 = 0 \end{array}\right\} \quad (3.28a)$$

While at the midpoint between vortex A and B, X_1,X_2,X_3 and X_4 is $1/2$,$1/2$, 0,0 respectively. Similarly at midpoints between A and C, A and D, B and C, B and D, C and D, give respectively

$$\left.\begin{array}{l} A\ and\ C\ X_1, X_2, X_3\ and\ X_4\ is\ \ 1/2\,, 0\ 1/2\,, 0 \\ A\ and\ D\ X_1, X_2, X_3\ and\ X_4\ is\ \ 1/2\,, 0{,}0, 1/2 \\ B\ and\ C\ X_1, X_2, X_3\ and\ X_4\ is\ 0, 1/2\,, 1/2\,, 0 \\ B\ and\ D\ X_1, X_2, X_3\ and\ X_4\ is\ \ 0{,}1/2\,, 0, 1/2 \\ C\ and\ D\ X_1, X_2, X_3\ and\ X_4\ is\ 0{,}0, 1/2\,, 1/2 \end{array}\right\} \quad (3.28b)$$

Now let's designate Y_i as n_i and Y_{ij} as n_{ij}, where n_i is the response to pure components and n_{ij} is the response to mixture components i and j. From equation 3.28, if $X_i = 1$ and $X_j = 0$, since $j \neq i$ then

$$n_i = \beta_i \quad (3.29)$$

Equation 3.29 implies that the coefficient β_i and n_i are the responses to the pure components which means that equation 3.28 can be written as

$$\sum_{i=1}^{4} \beta_i X_i = \sum_{i=1}^{4} n_i X_i \quad (3.30)$$

Now substituting the response values into equation 3.28 give respectively

$$\left.\begin{aligned} n_1 &= \beta_1 \\ n_2 &= \beta_2 \\ n_3 &= \beta_3 \\ n_4 &= \beta_4 \end{aligned}\right\} \tag{3.31}$$

In general equation 3.31 can be summary and written as

$$n_i = \beta_1 \tag{3.32}$$

In a similar manner, the values of the midpoints between X_1,X_2,X_3 and X_4 can be substitute into equation 3.32 to give respectively

$$\left.\begin{aligned} n_{12} &= \frac{1}{2}\beta_1 + \frac{1}{2}\beta_2 + \frac{1}{4}\beta_{12} \\ n_{13} &= \frac{1}{2}\beta_1 + \frac{1}{2}\beta_3 + \frac{1}{4}\beta_{13} \\ n_{14} &= \frac{1}{2}\beta_1 + \frac{1}{2}\beta_4 + \frac{1}{4}\beta_{14} \\ n_{23} &= \frac{1}{2}\beta_2 + \frac{1}{2}\beta_3 + \frac{1}{4}\beta_{23} \\ n_{24} &= \frac{1}{2}\beta_2 + \frac{1}{2}\beta_4 + \frac{1}{4}\beta_{24} \\ n_{34} &= \frac{1}{2}\beta_3 + \frac{1}{2}\beta_4 + \frac{1}{4}\beta_{34} \end{aligned}\right\} \tag{3.33}$$

Equation 3.33 can be summarized and be written as

$$n_{ij} = \frac{1}{2}\beta_i + \frac{1}{2}\beta_j + \frac{1}{4}\beta_{ij} \tag{3.34}$$

Rearranging equation 3.32 and equation 3.34 give

$$\beta_i = n_i \tag{3.35}$$

$$\beta_{ij} = 4n_{ij} - 2\beta_i - 2\beta_j \tag{3.36}$$

Equation 3.36 can further be written as

$$\beta_{ij} = 4n_{ij} - 2n_i - 2n_j \tag{3.37}$$

Substituting equation 3.35 and equation 3.37 into equation 3.25 yields

$$Y = n_1X_1 + n_2X_2 + n_3X_3 + n_4X_4 + X_1X_2(4n_{12} - 2n_1 - 2n_2) + X_1X_3(4n_{13} - 2n_1 - 2n_3) + X_1X_4(4n_{14} - 2n_1 - 2n_4) + X_2X_3(4n_{23} - 2n_2 - 2n_3) + X_2X_4(4n_{24} - 2n_2 - 2n_4) + X_3X_4(4n_{34} - 2n_3 - 2n_4) \quad (3.38)$$

Expanding equation 3.38 and rearranging yields

$$Y = n_1X_1(1 - 2X_2 - 2X_3 - 2X_4) + n_2X_2(1 - 2X_1 - 2X_3 - 2X_4) + n_3X_3(1 - 2X_1 - 2X_2 - 2X_4) + n_4X_4(1 - 2X_1 - 2X_2 - 2X_3) + 4X_1X_2n_{12} + 4X_1X_3n_{13} + 4X_1X_4n_{14} + 4X_2X_3n_{23} + 4X_2X_4n_{24} + 4X_3X_4n_{34} \quad (3.39)$$

Recalling equation 3.12 gives

$$X_1 + X_2 + X_3 + X_4 = 1 \quad (3.12)$$

Multiplying equation 3.12 by 2 gives

$$2\mathrm{X}_1 + 2\mathrm{X}_2 + 2\mathrm{X}_3 + 2\mathrm{X}_4 = 2 \quad (3.40)$$

Subtracting 1 from equation 3.40 (both RHS and LHS) gives

$$2\mathrm{X}_1 + 2\mathrm{X}_2 + 2\mathrm{X}_3 + 2\mathrm{X}_4 - 1 = 1 \quad (3.41)$$

Rearranging equation 3.41 gives

$$2\mathrm{X}_1 - 1 = 1 - 2\mathrm{X}_2 - 2\mathrm{X}_3 - 2\mathrm{X}_4 \quad (3.42)$$

Similarly

$$\left.\begin{array}{l} 2\mathrm{X}_2 - 1 = 1 - 2\mathrm{X}_1 - 2\mathrm{X}_3 - 2\mathrm{X}_4 \\ 2\mathrm{X}_3 - 1 = 1 - 2\mathrm{X}_1 - 2\mathrm{X}_2 - 2\mathrm{X}_4 \\ 2\mathrm{X}_4 - 1 = 1 - 2\mathrm{X}_1 - 2\mathrm{X}_2 - 2\mathrm{X}_3 \end{array}\right\} \quad (3.43)$$

Substituting equation 3.42 and 3.43 into equation 3.39 yields

$$Y = n_1X_1(2X_1 - 1) + n_2X_2(2X_2 - 1) + n_3X_3(2X_3 - 1) + n_4X_4(2X_4 - 1) + 4X_1X_2n_{12} + 4X_1X_3n_{13} + 4X_1X_4n_{14} + 4X_2X_3n_{23} + 4X_2X_4n_{24} + 4X_3X_4n_{34} \quad (3.44)$$

Equation 3.43 is the mixture model for the optimization of concrete mixture for both concrete produced with river sand as fine aggregates and concrete produced with quarry dust as fine aggregates. All the concrete mixtures have four components. n_i and n_{ij} are responses which are constants at the points i and j and can only be determined in the laboratory.

3.4.5.2 Relationship between Pseudo and Actual Components

In lattice mixture design introduction by Scheffes (1958) the pseudo components have relationship with the actual components. Scheffes shows that the actual components can be derived from the pseudo components in the mixture from the following relationship

$$Z = A * X \tag{3.45}$$

Where

$A =$ coefficient of the relationship

$X =$ pseudo component (coded variables used to simplify design construction and model fitting, and reduce the correlation between component bounds in constrained designs)

$Z =$ actual component

Equation 3.45 can be rearranged to give

$$X = ZA^{-1} \tag{3.46}$$

At the vortices of the tetrahedron in Fig.3.5 the actual mixture proportions are given below

$N_1(0.6,1,1.5,3)$, $N_2(0.5,1,1.75,4)$, $N_3(0.55,1,2,3)$, $N_4(0.56,1,2,5)$

The proportions above correspond to water, cement, fine aggregate/quarry dust and coarse aggregate.

Equation 3.45 and equation 3.46 can be put in a matrix form as shown below

$$\begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{bmatrix} = \begin{pmatrix} a_{11} & a_{12} a_{13} & a_{14} \\ a_{21} & a_{22} a_{23} & a_{24} \\ a_{31} & a_{32} a_{33} & a_{34} \\ a_{41} & a_{42} a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{pmatrix} \tag{3.47}$$

$$\begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{pmatrix} = \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{bmatrix} \begin{pmatrix} a_{11} & a_{12} a_{13} & a_{14} \\ a_{21} & a_{22} a_{23} & a_{24} \\ a_{31} & a_{32} a_{33} & a_{34} \\ a_{41} & a_{42} a_{43} & a_{44} \end{pmatrix}^{-1} \tag{3.48}$$

Where

$a_{11} = 0.6$, $a_{12} = 0.5$, $a_{13} = 0.55$, $a_{14} = 0.56$

$a_{21} = 1$, $a_{22} = 1$, $a_{23} = 1$, $a_{24} = 1$

$a_{31} = 1.5$, $a_{32} = 1.75$, $a_{33} = 2$, $a_{34} = 2$

$a_{41} = 3$, $a_{42} = 4$, $a_{43} = 3$, $a_{44} = 5$

$$A = \begin{pmatrix} a_{11} & a_{12}a_{13} & a_{14} \\ a_{21} & a_{22}a_{23} & a_{24} \\ a_{31} & a_{32}a_{33} & a_{34} \\ a_{41} & a_{42}a_{43} & a_{44} \end{pmatrix} = \begin{pmatrix} 0.6 & 0.500.55 & 0.56 \\ 1.0 & 1.01.0 & 1.0 \\ 1.5 & 1.752.0 & 2.0 \\ 3.0 & 4.03.0 & 5.0 \end{pmatrix} A^{-1}$$

$$= \begin{pmatrix} 0.6 & 0.500.55 & 0.56 \\ 1.0 & 1.01.0 & 1.0 \\ 1.5 & 1.752.0 & 2.0 \\ 3.0 & 4.03.0 & 5.0 \end{pmatrix}^{-1} = \begin{pmatrix} 6.25 & -0.59375-1.375 & -0.03125 \\ -12.5 & 9.1875-1.25 & 0.0625 \\ 0 & -1.52 & -0.5 \\ 6.25 & -6.093750.625 & 0.46875 \end{pmatrix}$$

The pseudo components are derived from equation 3.45 using

$$\begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{bmatrix} = \begin{pmatrix} 0.6 & 0.500.55 & 0.56 \\ 1.0 & 1.01.0 & 1.0 \\ 1.5 & 1.752.0 & 2.0 \\ 3.0 & 4.03.0 & 5.0 \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \end{pmatrix} \quad (3.49)$$

The pseudo components will now be determined using equation 3.49 as follows

For N_{12}

$$\begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \end{bmatrix} = \begin{pmatrix} 0.6 & 0.500.55 & 0.56 \\ 1.0 & 1.01.0 & 1.0 \\ 1.5 & 1.752.0 & 2.0 \\ 3.0 & 4.03.0 & 5.0 \end{pmatrix} \begin{pmatrix} 0.5 \\ 0 \\ 0.5 \\ 0 \end{pmatrix}$$, so solving gives

$Z_1 = 0.575$, $Z_2 = 1.0$, $Z_3 = 1.75$, and $Z_4 = 3.0$ respectively.

Similarly the values of other mid points will be

For N_{13} : $Z_1 = 0.55$, $Z_2 = 1.0$, $Z_3 = 1.625$, and $Z_4 = 3.5$ respectively

For N_{14} : $Z_1 = 0.58$, $Z_2 = 1.0$, $Z_3 = 1.75$, and $Z_4 = 4.0$ respectively

For N_{23} : $Z_1 = 0.53$, $Z_2 = 1.0$, $Z_3 = 1.875$, and $Z_4 = 4.5$ respectively

For N_{24} : $Z_1 = 0.555$, $Z_2 = 1.0$, $Z_3 = 2.0$, and $Z_4 = 4.0$ respectively

For N_{34} : $Z_1 = 0.525$, $Z_2 = 1.0$, $Z_3 = 1.875$, and $Z_4 = 3.5$ respectively.

All the pseudo components and all the actual components at different points on the factor space is given in table 3.3.

Table 3.3 Mixture proportions for actual and pseudo components.

N	X_1	X_2	X_3	X_4	RESPONSE	Z_1	Z_2	Z_3	Z_4
N_1	1	0	0	0	n_1	0.6	1	1.5	3
N_2	0	1	0	0	n_2	0.5	1	1.75	4
N_3	0	0	1	0	n_3	0.55	1	2	3
N_4	0	0	0	1	n_4	0.56	1	2	5
N_{12}	0.5	0	0.5	0	n_{12}	0.575	1	1.75	3
N_{13}	0.5	0.5	0	0	n_{13}	0.55	1	1.625	3.5
N_{14}	0.5	0	0	0.5	n_{14}	0.58	1	1.75	4
N_{23}	0	0.5	0	0.5	n_{23}	0.53	1	1.875	4.5
N_{24}	0	0	0.5	0.5	n_{24}	0.555	1	2	4
N_{34}	0	0.5	0.5	0	n_{34}	0.525	1	1.875	3.5

3.4.5.3 Control points for test of adequacy

The ten coefficients of the model will be determined using table 3.3, to confirm the adequacy of the model another ten points other than the one in table 3.1 is required. These sets of mixture proportions that are needed to test the adequacy of the model are called the control mixture proportions. Here, ten control points will be used and they are C_1, C_2,C_3,C_4,C_5,C_6,C_7,C_8,C_9, and C_{10}. For the control mixture proportion the actual and the corresponding pseudo components of the control points are as shown in table 3.4.

Table 3.4 Mixture proportions at the control points showing the actual and pseudo components.

N	X_1	X_2	X_3	X_4	RESPONSE	Z_1	Z_2	Z_3	Z_4
N_1	0.25	0.25	0.25	0.25	n_1	0.563	1	1.6875	3.25
N_2	0.4	0.4	0.2	0	n_2	0.578	1	1.75	3.5
N_3	0.4	0	0.2	0.4	n_3	0.567	1	1.6875	3.75
N_4	0	0.4	0.4	0.2	n_4	0.553	1	1.8125	3.75
N_{12}	0.2	0.4	0	0.4	n_{12}	0.555	1	1.8125	4.25
N_{13}	0.3	0.3	0.2	0.2	n_{13}	0.538	1	1.75	3.5
N_{14}	0.2	0.2	0.3	0.3	n_{14}	0.575	1	1.5625	3.25
N_{23}	0.2	0.3	0.2	0.3	n_{23}	0.558	1	2	4.5

3.4.6 Osadebe regression model

3.4.6.1 Introduction

Osadebe in 2003 showed that for a set of parameters X_1, X_2, X_3, ..., X_n which are known as predictors, can be used to predict the probable value of a dependent variable, Y, at a particular degree of certainty. The above observation can be further explain in this way, as long as the value of the predictors are known, the corresponding value of the dependant variable can be predicted with some degree of certainty.

3.4.6.2 Coefficient of the regression model

Few points of observation was used in the formulation of the model. Osadebe (2003) assumed that the response function $Y(Z)$, is continues and differentiable with respect to its prediction Z_i.

Here Taylors series is made use of, and the response function could be expanded in the neighbourhood of a chosen point, Z_0.

$$Y(Z) = \sum_{0 \le m \le \infty} F^m(Z_o) * (Z_i - Z_o)^m / m! \quad (3.50)$$

Where

Y = response function

Z_i =number of prediction

m = number of components

Expanding equation 3.50 gives

$$Y(Z) = Y^0(Z_0) \times (Z_i - Z_o)^0/0! + \sum Y^1(Z_0) \times (Z_i - Z_o)^1/1! + \sum Y^{11}(Z_0) \times (Z_i - Z_o)^2/2! + \sum Y^{11}(Z_0) \times (Z_i - Z_o)/2! \quad (3.51)$$

Equation 3.51 can be further written as

$$Y(Z) = Y^0(Z_0) + \sum Y^1(Z_0)(Z_i - Z_o) + \sum Y^{11}(Z_0)\,(Z_i - Z_o)^2/2! + \sum Y^{11}(Z_0)\,(Z_i - Z_o)/2! \quad (3.52)$$

$$1 \le i \le j \le 4$$

Lets assume that the origin Z_0 (for convenient sake) which is chosen without loss of generality of the formula is equal to zero, then

$$Y^0(0) = b_0 \quad (3.53)$$

$$Y^1(0) = b_i \quad (3.54)$$

Where

$$0 \le i \le 4$$

$$Y^{11}(0) = b_{ii} \quad (3.55)$$

Where

$$0 \le i \le 4$$

$$Y^{11}(0) = b_{ij} \quad (3.56)$$

Where

$$0 \leq i \leq j \leq 4$$

So substituting equations 3.53-3.56 into equation 3.52 gives

$$Y(Z) = b_0 + \sum b_i Z_i + \sum b_{ii} Z_i^2 + \sum b_{ij} Z_i Z_j \quad (3.57)$$

Where

$$0 \leq i \leq j \leq 4$$

The actual mixture components is designated S_i while the functional portion of the components as a ratio of the total components S is designated Z_i. That is

$$S = \sum S_i \quad (3.58)$$

$$Z_i = \frac{S_i}{S} \quad (3.59)$$

$$\sum Z_i = 1 \quad (3.60)$$

Where

$$0 \leq i \leq 4$$

If equation 3.60 is multiply by b_0 and Z_i respectively, the following equations will be generated;

$$b_0 = b_0 \sum Z_i \quad (3.61)$$

$$Z_i = Z_i \sum Z_i \quad (3.62)$$

Equation 3.61 can be further written as

$$b_0 = b_0 Z_1 + b_0 Z_2 + b_0 Z_3 + b_0 Z_4 \quad (3.63)$$

$$Z_i = Z_i Z_1 + Z_i Z_2 + Z_i Z_3 + Z_i Z_4 \quad (3.64)$$

If $i = 1$, $i = 2$, $i = 3$ and $i = 4$ the respective equations will now be

$$Z_1 = Z_1^2 + Z_1Z_2 + Z_1Z_3 + Z_1Z_4 \tag{3.65}$$

$$Z_2 = Z_1Z_2 + Z_2^2 + Z_2Z_3 + Z_2Z_4 \tag{3.66}$$

$$Z_3 = Z_1Z_3 + Z_2Z_3 + Z_3^2 + Z_3Z_4 \tag{3.67}$$

$$Z_4 = Z_1Z_4 + Z_2Z_4 + Z_3Z_4 + Z_4^2 \tag{3.68}$$

Equations 3.65-3.68 can be rearranged to give respectively

$$Z_1^2 = Z_1 - Z_1Z_2 - Z_1Z_3 - Z_1Z_4 \tag{3.69}$$

$$Z_2^2 = Z_2 - Z_1Z_2 - Z_2Z_3 - Z_2Z_4 \tag{3.70}$$

$$Z_3^2 = Z_3 - Z_1Z_3 - Z_2Z_3 - Z_3Z_4 \tag{3.71}$$

$$Z_4^2 = Z_4 - Z_1Z_4 - Z_2Z_4 - Z_3Z_4 \tag{3.72}$$

Substituting equations 3.69-3.72 into equation 3.57 gives

$$\begin{aligned} Y = {} & b_0Z_1 + b_0Z_2 + b_0Z_3 + b_0Z_4 + b_1Z_1 + b_2Z_2 + b_3Z_3 + b_4Z_4 + b_{12}Z_1Z_2 + b_{13}Z_1Z_3 \\ & + b_{14}Z_1Z_4 + b_{23}Z_2Z_3 + b_{24}Z_2Z_4 + b_{34}Z_3Z_4 \\ & + b_{11}(Z_1 - Z_1Z_2 - Z_1Z_3 - Z_1Z_4) + b_{22}(Z_2 - Z_1Z_2 - Z_2Z_3 - Z_2Z_4) \\ & + b_{33}(Z_3 - Z_1Z_2 - Z_2Z_3 - Z_3Z_4) \\ & + b_{44}(Z_4 - Z_1Z_4 - Z_2Z_4 - Z_3Z_4) \end{aligned} \tag{3.73}$$

Collecting like terms and factorizing gives

$$\begin{aligned} Y = {} & Z_1(b_0 + b_1 + b_{11})Z_2(b_0 + b_2 + b_{22}) + Z_3(b_0 + b_3 + b_{33}) + Z_4(b_0 + b_4 + b_{44}) \\ & + Z_1Z_2(b_{12} - b_{11} - b_{22}) + Z_1Z_3(b_{13} - b_{11} - b_{33}) + Z_1Z_4(b_{14} - b_{11} - b_{44}) \\ & + Z_2Z_3(b_{23} - b_{22} - b_{33}) + Z_2Z_4(b_{24} - b_{22} - b_{44}) \\ & + Z_3Z_4(b_{34} - b_{33} - b_{44}) \end{aligned} \tag{3.74}$$

Summing up the constants in equation 3.74 gives other constants and they are given respectively as

$$\beta_1 = b_0 + b_1 + b_{11} \tag{3.75}$$

$$\beta_2 = b_0 + b_2 + b_{22} \tag{3.76}$$

$$\beta_3 = b_0 + b_3 + b_{33} \tag{3.77}$$

$$\beta_4 = b_0 + b_4 + b_{44} \tag{3.78}$$

$$\beta_{12} = b_{12} - b_{11} - b_{22} \tag{3.79}$$

$$\beta_{13} = b_{13} - b_{11} - b_{33} \tag{3.80}$$

$$\beta_{14} = b_{14} - b_{11} - b_{44} \tag{3.81}$$

$$\beta_{23} = b_{23} - b_{22} - b_{33} \tag{3.82}$$

$$\beta_{24} = b_{24} - b_{22} - b_{44} \tag{3.83}$$

$$\beta_{34} = b_{34} - b_{33} - b_{44} \tag{3.84}$$

Substituting equations 3.75-3.84 into equation 3.74 gives

$$Y = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_{12} Z_1 Z_2 + \beta_{13} Z_1 Z_3 + \beta_{14} Z_1 Z_4 + \beta_{23} Z_2 Z_3 + \beta_{24} Z_2 Z_4 + \beta_{34} Z_3 Z_4 \tag{3.85}$$

Equation 3.85 is the Osadebe's regression model for the optimisation of concrete mixture. Equation 3.85 can be further written in compact form as shown in below

$$Y = \sum \beta_i Z_i + \sum \beta_{ij} Z_i Z_j \tag{3.85}$$

Since the predictor has a constant coefficient, different points of observation will have different responses. For example, the nth observation will have Y^n response corresponding with Z_i^n predictor. This means that equation 3.85 can be written in matrix form

$$[Y^n] = [Z_i^n][\beta_i] \tag{3.86}$$

Expanding equation 3.86 gives

$$\begin{bmatrix} Y^1 \\ Y^2 \\ Y^3 \\ . \\ . \\ . \\ Y^{10} \end{bmatrix} = \begin{bmatrix} Z_1^{(1)} & Z_2^{(1)} & Z_3^{(1)} & . & . & . & Z_3^{(1)} Z_4^{(1)} \\ Z_1^{(2)} & Z_2^{(2)} & Z_3^{(2)} & . & . & . & Z_3^{(2)} Z_4^{(2)} \\ Z_1^{(3)} & Z_2^{(3)} & Z_3^{(3)} & . & . & . & Z_3^{(3)} Z_4^{(3)} \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ Z_1^{(10)} & Z_2^{(10)} & Z_3^{(10)} & . & . & . & Z_3^{(10)} Z_4^{(10)} \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ . \\ . \\ . \\ \beta_{34} \end{bmatrix} \tag{3.87}$$

Where

$$[\beta]^T = [\beta_1, \beta_2, \beta_3, \beta_4, \beta_{12}, \beta_{13}, \beta_{14}, \beta_{23}, \beta_{24}, \beta_{34}] \tag{3.88}$$

$$[Y^N]^T = [Y^1, Y^2, Y^3, Y^4, Y^{12}, Y^{13}, Y^{14}, Y^{23}, Y^{24}, Y^{34}] \quad (3.89)$$

$$[Z_i^k] = [Z_1^k, Z_2^k, Z_3^k, Z_4^k, Z_5^k, Z_6^k, Z_7^k, Z_8^k, Z_9^k, Z_{10}^k,] \quad (3.90)$$

where

$1 \leq n \leq 10$ and $1 \leq k \leq 4$

The actual mix proportions, S_i^n and their corresponding fractions $Z_i^{(n)}$, are given in table 3.5 . And the value of the fractional portions, $Z_i^{(n)}$ given in table 3.5 and were used to develop the $Z^{(n)}$ matrixes presented in table 3.6, and table 3.7 respectively for $(\sum Z \leq 1)$.

Table 3.5 Values of actual mix proportion and their corresponding fractional portion $(\boldsymbol{when} \sum \boldsymbol{Z} \leq \mathbf{1})$

$$\boldsymbol{Legend\ S = \sum S_i,\ \ Z_i = S_i/S}$$

N	S_1	S_2	S_3	S_4	S	RESPONSE	Z_1	Z_2	Z_3	Z_4
N_1	0.6	1	1.5	3	6.1	n_1	0.09836066	0.1639344	0.2459016	0.491803
N_2	0.5	1	1.75	4	7.25	n_2	0.06896552	0.1379310	0.2413793	0.551724
N_3	0.55	1	2	3	6.55	n_3	0.08396947	0.1526718	0.3053435	0.458015
N_4	0.56	1	2	5	8.56	n_4	0.06542056	0.1168224	0.2336449	0.584112
N_{12}	0.575	1	1.75	3	6.325	n_{12}	0.09090909	0.1581028	0.2766798	0.474308
N_{13}	0.55	1	1.65	3.5	6.675	n_{13}	0.082397	0.1498127	0.2434457	0.524345
N_{14}	0.58	1	1.75	4	7.33	n_{14}	0.07912688	0.1364257	0.2387449	0.545703
N_{23}	0.53	1	1.85	4.5	7.905	n_{23}	0.06704617	0.1265022	0.2371917	0.569260
N_{24}	0.555	1	2	4	7.555	n_{24}	0.07346128	0.1323627	0.2647254	0.529451
N_{34}	0.525	1	1.875	3.5	6.9	n_{34}	0.07608696	0.1449275	0.2717391	0.507246

Table 3.6 Actual mix $\boldsymbol{Z^{(n)}}$ matrix

N	Z_1	Z_2	Z_3	Z_4	Z_1Z_2	Z_1Z_3	Z_1Z_4	Z_2Z_3	Z_2Z_3	Z_3Z_4
N_1	0.09836066	0.16393443	0.24590164	0.49180328	0.01612470	0.024187046	0.04837409	0.0403117	0.08062349	0.12093523
N_2	0.06896552	0.13793103	0.24137931	0.55172414	0.00951249	0.016646849	0.03804994	0.0332937	0.07609988	0.13317479
N_3	0.08396947	0.15267176	0.30534351	0.45801527	0.01281977	0.025639531	0.03845930	0.0466173	0.06992599	0.13985199
N_4	0.06542056	0.11682243	0.23364486	0.58411215	0.00764259	0.015285178	0.03821294	0.0272950	0.0682374	0.1364748
N_{12}	0.09090909	0.15810277	0.27667984	0.4743083	0.01437298	0.025152713	0.04311894	0.0437439	0.07498945	0.13123155
N_{13}	0.082397	0.14981273	0.24344569	0.52434457	0.01234412	0.020059196	0.04320442	0.0364713	0.07855349	0.12764943
N_{14}	0.07912688	0.13642565	0.23874488	0.54570259	0.01079493	0.018891137	0.04317974	0.0325709	0.07444783	0.1302837
N_{23}	0.06704617	0.12650221	0.23719165	0.56925996	0.00848147	0.015902793	0.03816670	0.0300053	0.07201265	0.13502371
N_{24}	0.07346128	0.13236267	0.26472535	0.52945069	0.00972353	0.019447064	0.03889413	0.0350398	0.07007951	0.14015902
N_{34}	0.07608696	0.14492754	0.27173913	0.50724638	0.01102710	0.020675803	0.03859483	0.0393826	0.07351397	0.13783869

Table 3.7 Actual mix inverse of $Z^{(n)}$ matrix

N	Z_1	Z_2	Z_3	Z_4	Z_1Z_2	Z_1Z_3	Z_1Z_4	Z_2Z_3	Z_2Z_4	Z_3Z_4
N_1	2907.031	16425.78	-2.0906E-10	5724.5	1.59936E-10	-13923.6328	8395.140625	-19527.8203	-4.23498E-1	6.41334E-10
N_2	48.32939453	8390.610	257.415	5888.363813	142.5200391	-972.217661	777.5999004	-13994.1242	2086.915289	-2624.50125
N_3	140.7003125	164.2578	343.22	57.245	-440.061875	306.3199219	-184.693094	-195.278203	285.390125	-476.1
N_4	0.072675781	0.410645	21.45125	32.2003125	2.500351562	-0.34809082	-3.14817773	7.322932617	-53.5106484	-5.95125
N_{12}	-3740.25908	-48305.35	-257.415	-23233.5988	-1642.73098	26452.46571	-18155.5410	66914.51728	-4227.34123	6195.25125
N_{13}	-4326.82531	-13304.88	-343.22	-4636.845	2440.343125	15288.14883	-9217.86441	15817.53445	2568.511125	-4284.9
N_{14}	-2936.17424	-16590.45	-21.45125	-4898.02531	-502.570664	14063.21723	-7804.33260	18153.54996	-659.964664	1196.20125
N_{23}	-16.3520507	-10903.84	-1201.27	-7107.68231	437.5615234	-1453.27918	1128.097021	17528.65971	-5368.90172	6957.01125
N_{24}	-44.4775781	-8273.666	-128.7075	-6792.11925	-90.0126562	914.7826758	-793.340789	14968.07427	-1498.29815	1737.765
N_{34}	-134.37751	-181.0942	-536.28125	-3.5778125	537.5755859	-314.32601	45.12388086	51.26052832	-89.1844140	624.88125

When the values of $Y^{(n)}$ and Z_i^n are known, to determine the values of the constant coefficient β will now be easier using equation 3.87. To do this $[\beta_i]$is made the subject of the formula in equation 3.88

$$[\beta_i] = [Y^n][Z_i^n]^{-1} \qquad (3.91)$$

Putting equation 3.91 in matrix form gives

$$\begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ . \\ . \\ . \\ \beta_{34} \end{bmatrix} = \begin{bmatrix} Z_1^{(1)} & Z_2^{(1)} & Z_3^{(1)} & . & . & . & Z_3^{(1)}Z_4^{(1)} \\ Z_1^{(2)} & Z_2^{(2)} & Z_3^{(2)} & . & . & . & Z_3^{(2)}Z_4^{(2)} \\ Z_1^{(3)} & Z_2^{(3)} & Z_3^{(3)} & . & . & . & Z_3^{(3)}Z_4^{(3)} \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ Z_1^{(10)} & Z_2^{(10)} & Z_3^{(10)} & . & . & . & Z_3^{(10)}Z_4^{(10)} \end{bmatrix}^{-1} \begin{bmatrix} Y^1 \\ Y^2 \\ Y^3 \\ . \\ . \\ . \\ Y^{10} \end{bmatrix} \qquad (3.92)$$

To solve the matrix of equation 3.92, the values of $Y^{(n)}$ has to be determined, and this will be done during the practical test that will be carried out in the laboratory. The method is as stated in chapter four and the analysis is carried out in chapter five of this thesis.

3.4.7 Ibearugbulem's regression model

In 2013 Ibearugbulem developed a model which is a modification of Osadebe's model. Scheffe's optimization model and Osadebe's regression models are statistical model often used in civil engineering in the optimization and design of concrete mix (Scheffe, 1958 & 1963, Obam, 1998 & 2006, Ibearugbulem, 2006, Osadebe and Ibearugbulem, 2008, 2009). Simon et al. (1997) also used a method that is close to Scheffe's method in concrete mix design. These methods have been found to be working well for mix optimizations (Ibearugbulem et al. 2013). Though these models have been tested and found to be good but they have some problems associated with them. For Scheffes optimization model and Osadebe regression model to be formulated there must be predetermined number of experiments to be carried out. Apart from having predetermined number of observation points, they determine the mix ratios that can be used in them (Ibearugbulem et al. 2013). Due to these inherent problems associated with these models, their use in the optimization of an already conducted laboratory tests is not feasible. For this to be possible there must be laboratory values already predetermined by these models. Hence the search for an alternative model that can eliminate these inherent problems and still give the expected result.

3.4.7.1 Polynomial

Osadebe and Ibearugbulem (2008) quoted Osadebe (2003) that the response function F(z) is given as

$$F(z) = \sum F^m\,(z_0).\,(z_i - z_0)^m/m! \qquad (3.93)$$

$$0 \leq m \leq \infty$$

Here $F^m\,(z_0)$ is the derivative of the function $F(z_0)$ to m degree. Hence, equation (3.93) will be rewritten as

$$F(z) = \frac{\sum d^m\,F(z_0)}{dz_0^m}.\frac{(z_i - z_0)^m}{m!} \qquad (3.94)$$

The number of terms in equation (3.94) is dependent on the degree of the polynomial, m and the number of independent variables, i. For instance let m be equal to one, hence

$$F(z) = \frac{\sum d^0\, F(z_0)}{dz_0^0} . \frac{(z_i - z_0)^0}{0!} + \frac{\sum d\, F(z_0)}{dz_0} . \frac{(z_i - z_0)}{1!} \quad (3.95)$$

If m is equal to two, then equation (3.94) will read

$$F(z) = \frac{\sum d^0 F(z_0)}{dz_0^0} . \frac{(z_i - z_0)^0}{0!} + \frac{\sum dF(z_0)}{dz_0} . \frac{(z_i - z_0)}{1!} + \frac{\sum d^2 F(z_0)}{dz_0^2} . \frac{(z_i - z_0)^2}{2!} \quad (3.96)$$

Assuming that the origin is z_0, and it is equal to zero. Now taking the products and quotients of constants to give a new constant, and that z_0 is equal to zero, then equation (3.93) will be written as

$$F(z) = \sum b_m . z_i^m \quad (3.97)$$

$0 \le m \le \infty$, $2 \le m \le \infty$

Where if m = 0 then $b_m = b$ (3.98)

if m = 1 then $b_m = b_i$ (3.99)

if m = 2 then $b_m = b_{ii}$ for z_i^2 term (3.100)

$b_m = b_{ij}$ for $z_i z_j$ term (3.101)

If m = 3 then $b_m = b_{iii}$ for z_i^3 term

if m = 3 then $b_m = b_{iii}$ for z_i^3 term (3.102)

$b_m = b_{ijk}$ for $z_i z_j z_k$ term (3.103)

$b_m = b_{iij}$ for $z_i^2 z_j$ term (3.104)

$b_m = b_{ijj}$ for $z_i z_j^2$ term (3.105)

$b_m = b_{iik}$ for $z_i^2 z_k$ term (3.106)

$b_m = b_{ikk}$ for $z_i z_k^2$ term (3.107)

$b_m = b_{jjk}$ for$z_j^2 z_k$ term (3.108)

$b_m = b_{jkk}$ for $z_j z_k^2$ term (3.109)

Now equation (5) can be written as

$$F(z) = b_0 + \sum b_m . z_i^m \qquad (3.110)$$

$1 \le m \le \infty$, $2 \le m \le \infty$

For $i = n, 1 \le m \le n$ (3.111)

The implication of equation (3.111) is that the maximum degree of polynomial one can use is equal to the number of independent variables, i.

3.4.7.2 Boundary conditions

Both Scheffe (1958) and Osadebe and Ibearugbulem (2008) restricted the summation of the independent variables to unity. That is

$$\sum z_i = 1 \qquad (3.112)$$

Scheffe (1958) also restricted the value of each arbitrary independent variable to be between zero and one. That is

$0 \le m \le 1$ (3.113)

3.1.7.3 Ibearugbulem's regression model

Multiplying equation (3.112) by b_0 will give

$$b_0 = \sum b_0 z_i \qquad (3.114)$$

Multiplying equation (3.112) by z_i will give on rearranging

$$z_i^2 = z_i - z_1 z_i - z_2 z_i - .... - z_i z_n \qquad (3.115)$$

Multiplying equation (3.112) by z_i^r will give on rearranging

$$Z_i^{r+1} = z_i^r - z_1 z_i^r - z_2 z_i^r - \cdots - z_i^r z_n \qquad (3.116)$$

$Z_i^{r+1} = z_i^r - z_1 z_i^r - z_2 z_i^r - \ldots - z_i^r z_n$

Taking the highest degree of the polynomial and substituting equations (3.114) and (3.117) into equation(3.110) and factorizing, making sure that every term has no independent variable of more than one degree will yield

$$F(z) = \sum \propto_i \, z_i + \sum \propto_{ij} \, z_i z_j + \sum \propto_{ijk} \, z_i z_j z_k + \\ ...+ \sum \propto_{ijk \,....\propto} z_i z_j z_k \ldots z_\infty \quad (3.117)$$

$1 \leq i \leq \infty$, $1 \leq i \leq j \leq \infty$, $1 \leq i \leq j \leq k \leq \infty$, … , $1 \leq i \leq j \leq k \leq \ldots \leq \infty$

If $i = 2$ then equation (3.117) becomes

$$F(z) = \propto_1 z_1 + \propto_2 z_2 + \propto_{12} z_1 z_2 \quad (3.118)$$

If $i = 3$ then equation (3.117) becomes

$$F(z) = \propto_z z_1 + \propto_2 z_2 + \propto_3 z_3 + \propto_{12} z_1 z_2 + \propto_{13} z_1 z_3 + \propto_{23} z_2 z_3 + \propto_{123} z_1 z_2 z_3 \quad (3.119)$$

If i = 4 then equation (3.117) becomes

$$F(z) \\ = \propto_1 z_1 + \propto_2 z_2 + \propto_3 z_3 + \propto_4 z_4 + \propto_{12} z_1 z_2 + \propto_{13} z_1 z_3 + \propto_{14} z_1 z_4 + \propto_{23} z_2 z_3 + \propto_{24} z_2 z_4 \\ + \propto_{34} z_3 z_4 + \propto_{123} z_1 z_2 z_3 + \propto_{124} z_1 z_2 z_4 + \propto_{134} z_2 z_3 z_4 \\ + + \propto_{1234} z_1 z_2 z_3 z_4 \quad (3.120)$$

3.4.7.4 Pseudo variables

The independent variables used in the regression function (equation 3.117) are pseudo variables. They are not the actual variables. However, a relationship exists between the pseudo variables, z_i and the actual variables, s_i

$$Z_i = s_i / S \quad (3.121)$$

$$S = \sum s_i \quad (3.122)$$

3.4.7.5 Coefficients of the regression function

Summing equation (3.117) for n observation points gives

$$\sum_r F(z) = \sum_r \sum \alpha i \; zi + \sum_r \sum \alpha ij \; zi \; zj + \ldots \quad (3.123)$$

$1 \leq r \leq n$

Multiplying equation (3.123) by z_w will give

$$\sum_r z_w . F(z) = \sum_r \sum \alpha i \; zi \,. z_w + \sum_r \sum \alpha ij \; zi \; zj \,. z_w + \; ... \qquad (3.124)$$

Multiplying equation (31) by$z_q z_s z_t . . .$ will give

$$\sum_r z_q . z_s z_t \; F(z) = \sum_r \sum \alpha i \; zi \,. z_q . z_s z_t + \sum_r \sum \alpha ij \; zi \; zj \,. z_q . z_s z_t + \; ... \qquad (3.125)$$

Adding equations (3.124) and (3.125) will give n simultaneous equations with n unknowns. This is represented in matrix form as shown in equation (3.126).

$$\begin{bmatrix} \sum_r z_1 . F(z) \\ \sum_r z_2 . F(z) \\ \sum_r z_3 . F(z) \\ \vdots \\ . \\ \sum_r z_1 z_2 z_3 ... F(z) \end{bmatrix} = \begin{bmatrix} \sum_r \sum z_1 . z_1 & \sum_r \sum z_2 . z_1 & \sum_r \sum z_3 . z_1 & \cdots & \cdots & \cdots & \cdots \\ \sum_r \sum z_1 . z_2 & \sum_r \sum z_2 . z_2 & \sum_r \sum z_3 . z_2 & \cdots & \cdots & \cdots & \cdots \\ \sum_r \sum z_1 . z_3 & \sum_r \sum z_2 . z_3 & \sum_r \sum z_3 . z_3 & \cdots & \cdots & \cdots & \cdots \\ \vdots & \vdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ . & . & . & . & . & . & . \\ \sum_r \sum z_1 . z_1 . z_2 & \cdots & \sum_r \sum z_2 . z_1 . z_2 & . & . & . & . \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \vdots \\ . \\ \alpha_{123..} \end{bmatrix} - \quad (3.126)$$

Equation 3.126 is a simultaneous equation and solving it will give the coefficients of regression function of equation 3.117. This equation (3.126) can be written in a form shown below

$$[F(z).Z] = [CC] \; [\alpha]$$

$$[\alpha] = [CC]^{-1}[F(z).Z] \qquad (3.127)$$

CC is always a symmetric matrix and $[CC]^{-1}$ is the inverse.

For a mixture of four components, CC is a 14 x 14 matrix.

Table 3.8 Z formation for actual and control mix (Ibearugbulem model)

$$\boldsymbol{Legend\ S = \sum S_i,\ \ Z_i = S_i/S}$$

Points	S1	S2	S3	S4	S	Z1	Z2	Z3	Z4
N1	0.6	1	1.5	3	6.1	0.098361	0.163934	0.245902	0.491803
N2	0.5	1	1.75	4	7.25	0.068966	0.137931	0.241379	0.551724
N3	0.55	1	2	3	6.55	0.083969	0.152672	0.305344	0.458015
N4	0.56	1	2	5	8.56	0.065421	0.116822	0.233645	0.584112
N12	0.575	1	1.75	3	6.325	0.090909	0.158103	0.27668	0.474308
N13	0.55	1	1.625	3.5	6.675	0.082397	0.149813	0.243446	0.524345
N14	0.58	1	1.75	4	7.33	0.079127	0.136426	0.238745	0.545703
N23	0.53	1	1.875	4.5	7.905	0.067046	0.126502	0.237192	0.56926
N24	0.555	1	2	4	7.555	0.073461	0.132363	0.264725	0.529451
N34	0.525	1	1.875	3.5	6.9	0.076087	0.144928	0.271739	0.507246
c1	0.563	1	1.688	3.25	6.5005	0.086609	0.153834	0.259595	0.499962
c2	0.578	1	1.75	3.5	6.828	0.084651	0.146456	0.256298	0.512595
c3	0.567	1	1.688	3.75	7.0045	0.080948	0.142765	0.240917	0.53537
c4	0.553	1	1.813	3.75	7.1155	0.077718	0.140538	0.254726	0.527018
c5	0.555	1	1.813	4.25	7.6175	0.072859	0.131277	0.237939	0.557926
c6	0.538	1	1.75	3.5	6.788	0.079258	0.147319	0.257808	0.515616
c7	0.575	1	1.563	3.25	6.3875	0.09002	0.156556	0.244618	0.508806
c8	0.558	1	2	4.5	8.058	0.069248	0.1241	0.248201	0.558451

Table 3.9 Z matrix for actual mix (Ibearugbulem model)

Points	Z1	Z2	Z3	Z4	Z1Z2	Z1Z3	Z1Z4	Z2Z3	Z2Z4	Z3Z4	Z1Z2Z3	Z1Z2Z4	Z2Z3Z4	Z1Z2Z3Z4
N1	0.098361	0.163934	0.245902	0.491803	0.016125	0.024187	0.048374	0.040312	0.080623	0.120935232	0.003965	0.007930179	0.019825448	0.00195
N2	0.068966	0.137931	0.241379	0.551724	0.009512	0.016647	0.03805	0.033294	0.0761	0.133174792	0.002296	0.005248268	0.018368937	0.001267
N3	0.083969	0.152672	0.305344	0.458015	0.01282	0.02564	0.038459	0.046617	0.069926	0.13985199	0.003914	0.005871648	0.021351449	0.001793
N4	0.065421	0.116822	0.233645	0.584112	0.007643	0.015285	0.038213	0.027295	0.068237	0.136474801	0.001786	0.004464129	0.015943318	0.001043
N5	0.090909	0.158103	0.27668	0.474308	0.014373	0.025153	0.043119	0.043744	0.074989	0.131231546	0.003977	0.006817223	0.02074807	0.001886
N6	0.082397	0.149813	0.243446	0.524345	0.012344	0.020059	0.043204	0.036471	0.078553	0.127649427	0.003005	0.006472573	0.01912351	0.001576
N7	0.079127	0.136426	0.238745	0.545703	0.010795	0.018891	0.04318	0.032571	0.074448	0.130283702	0.002577	0.005890824	0.017774038	0.001406
N8	0.067046	0.126502	0.237192	0.56926	0.008481	0.015903	0.038167	0.030005	0.072013	0.13502371	0.002012	0.004828172	0.017080798	0.001145
N9	0.073461	0.132363	0.264725	0.529451	0.009724	0.019447	0.038894	0.03504	0.07008	0.140159019	0.002574	0.005148131	0.018551823	0.001363
N10	0.076087	0.144928	0.271739	0.507246	0.011027	0.020676	0.038595	0.039382	0.073514	0.137838689	0.002996	0.005593454	0.019976622	0.00152
N11	0.086609	0.153834	0.259595	0.499962	0.013323	0.022483	0.043301	0.039935	0.076911	0.129787724	0.003459	0.006661185	0.019965806	0.001729
N12	0.084651	0.146456	0.256298	0.512595	0.012398	0.021696	0.043392	0.037536	0.075073	0.131376918	0.003177	0.006354997	0.019240908	0.001629
N13	0.080948	0.142765	0.240917	0.53537	0.011557	0.019502	0.043337	0.034395	0.076432	0.128979524	0.002784	0.00618704	0.018413809	0.001491
N14	0.077718	0.140538	0.254726	0.527018	0.010922	0.019797	0.040959	0.035799	0.074066	0.134245098	0.002782	0.005756256	0.018866573	0.001466

The matrix CC was formed using equation 3.127 as shown below.

$$\begin{bmatrix} \sum_r \sum z_1 . z_1 & \sum_r \sum z_2 . z_1 & \sum_r \sum z_3 . z_1 & \dots & \dots & \dots & \dots \\ \sum_r \sum z_1 . z_2 & \sum_r \sum z_2 . z_2 & \sum_r \sum z_3 . z_2 & \dots & \dots & \dots & \dots \\ \sum_r \sum z_1 . z_3 & \sum_r \sum z_2 . z_3 & \sum_r \sum z_3 . z_3 & \dots & \dots & \dots & \dots \\ \vdots & \vdots & \dots & \dots & \dots & \dots & \dots \\ . & . & . & . & . & . & . \\ \sum_r \sum z_1 . z_1 . z_2 & \dots & \sum_r \sum z_2 . z_1 . z_2 & . & . & . & . \end{bmatrix} \quad (3.127)$$

Table 3.10 CC Matrix (Ibearugbulem model)

0.098361	0.163934	0.245902	0.491803	0.016125	0.024187	0.048374	0.040312	0.080623	0.120935232	0.003965	0.007930179	0.019825448	0.00195
0.068966	0.137931	0.241379	0.551724	0.009512	0.016647	0.03805	0.033294	0.0761	0.133174792	0.002296	0.005248268	0.018368937	0.001267
0.083969	0.152672	0.305344	0.458015	0.01282	0.02564	0.038459	0.046617	0.069926	0.13985199	0.003914	0.005871648	0.021351449	0.001793
0.065421	0.116822	0.233645	0.584112	0.007643	0.015285	0.038213	0.027295	0.068237	0.136474801	0.001786	0.004464129	0.015943318	0.001043
0.090909	0.158103	0.27668	0.474308	0.014373	0.025153	0.043119	0.043744	0.074989	0.131231546	0.003977	0.006817223	0.02074807	0.001886
0.082397	0.149813	0.243446	0.524345	0.012344	0.020059	0.043204	0.036471	0.078553	0.127649427	0.003005	0.006472573	0.01912351	0.001576
0.079127	0.136426	0.238745	0.545703	0.010795	0.018891	0.04318	0.032571	0.074448	0.130283702	0.002577	0.005890824	0.017774038	0.001406
0.067046	0.126502	0.237192	0.56926	0.008481	0.015903	0.038167	0.030005	0.072013	0.13502371	0.002012	0.004828172	0.017080798	0.001145
0.073461	0.132363	0.264725	0.529451	0.009724	0.019447	0.038894	0.03504	0.07008	0.140159019	0.002574	0.005148131	0.018551823	0.001363
0.076087	0.144928	0.271739	0.507246	0.011027	0.020676	0.038595	0.039382	0.073514	0.137838689	0.002996	0.005593454	0.019976622	0.00152
0.086609	0.153834	0.259595	0.499962	0.013323	0.022483	0.043301	0.039935	0.076911	0.129787724	0.003459	0.006661185	0.019965806	0.001729
0.084651	0.146456	0.256298	0.512595	0.012398	0.021696	0.043392	0.037536	0.075073	0.131376918	0.003177	0.006354997	0.019240908	0.001629
0.080948	0.142765	0.240917	0.53537	0.011557	0.019502	0.043337	0.034395	0.076432	0.128979524	0.002784	0.00618704	0.018413809	0.001491
0.077718	0.140538	0.254726	0.527018	0.010922	0.019797	0.040959	0.035799	0.074066	0.134245098	0.002782	0.005756256	0.018866573	0.001466

Table 3.11 Inverse of CC Matrix (Ibearugbulem model)

3932.974481	-4845.620981	798.3986762	1248.354407	690.342206	11924.63653	-5655.56368	3341.036257	289.5414888	-4896.782209	-1525.612669	5276.93771	-946.3376365	2752.697336
-3260.145199	1906.450725	-1263.583397	-1305.763638	-263.2064721	-4047.938021	6056.553689	-959.5866646	3237.283752	5281.920085	-1588.750388	-4870.336657	-2293.862863	-1019.217654
1887.346094	-2340.804409	738.3283095	16.09116503	1918.786456	5321.732109	-2459.32442	-2567.975017	3025.188767	-979.9113286	-4221.423053	-4813.36404	-73.63718361	341.8025421
1308.481423	-612.3761867	533.1804631	-90.66927972	761.2394978	-5368.599043	-122.2920252	-239.9401894	650.9585062	-303.6457832	-930.944225	168.519237	-1.526767762	1950.045817
-321.6436809	1256.321233	2274.864622	1261.444541	-7005.125518	-8844.890344	3000.658237	3518.007293	-6383.939674	-8098.197281	899.7898725	3609.256883	7088.383411	2908.822811
-2717.938153	-2561.736685	-3606.120446	1091.504926	4240.004023	26206.53341	2911.112272	5567.682651	-8850.886879	2577.847194	8127.997577	11362.55387	13137.83659	1326.334243
-3457.58874	9826.371272	1623.259485	-940.5828964	-1512.110792	-33965.1803	7341.591972	-5876.364695	-7048.875359	1213.521995	8624.87551	1628.708871	-4802.64765	-9115.696112
4758.426653	3624.184665	1543.301068	-685.9843548	-766.1804222	-38094.12682	-2891.953754	-595.6231921	-2336.576437	1134.152178	2867.985573	8948.016943	-3193.41094	9831.804079
-2571.900399	-4622.765392	-4317.456054	1604.291641	1375.433989	66422.43909	-11141.70173	-1090.617881	2423.224998	48.69629232	-2883.22838	-5910.655485	6809.572129	-6661.543359
-6422.977952	5347.191134	-1972.025746	366.2916207	-6677.145406	3405.67311	4932.874723	5604.890189	-7635.270242	1302.729446	9152.83042	7231.490601	-528.6374655	-6075.629305
1810.613924	6297.10873	3461.532085	-2090.939538	-7331.09389	-67828.7511	11624.57762	272.44998	-576.0487858	1424.47294	6645.537859	1263.959217	-1376.298927	-4939.603554
9737.419434	5962.004623	5657.167822	-1371.41327	-7579.814721	-92860.12928	6040.010711	5736.254392	-3347.708439	-3379.465208	1872.240074	-5071.076912	-7063.414886	12340.6994
-608.9827554	5687.899378	5637.661119	153.6329059	1670.419337	-60893.52253	5460.484211	2966.831696	-5923.339402	-8225.85441	13741.32989	13087.10507	642.4638743	1420.72027
4816.289078	1699.479047	3611.144272	1150.663377	-804.2376994	-25716.42023	-10253.35917	6296.223067	-1337.879647	-8777.629661	-9482.722792	5890.375035	-8389.541876	-5906.65411

3.4.8 Test for adequacy of the model

After the determination of β_i and β_{ij} the final model equations will be written for concrete made with sand as fine aggregate and concrete made with quarry dust as fine aggregate. It is expected that the result of the models will be accepted with about 95% risk of being correct or 5% risk of being incorrect. For the result to be correct it means that there is no difference between the models results and the experimental results. For the models to be accepted it will be wise to state the statistical hypothesis for accepting or rejecting the adequacy of the models results:

a) Null Hypothesis (H_0), there is no significant difference between the model's result and experiment test result.
b) Alternative Hypothesis (H_i) there is a significant difference between the model's results and experimental results.
c) The risk involved is that 5% or below model's result will be incorrect.

For this thesis, two statistical methods were used to test the hypothesis; they are Fish Statistical test and Student t-test methods. If (H_0) is not true, the results expected based on the model may not exactly the same with experimental values, due to the fluctuation from both the derivation of the model and the actual experimentation. However if the difference is marginal significant the Null hypothesis is accepted (Crammer, 1946).

3.4.8.1 Fisher test

A sample of Fisher test is given below in table 3.10 and the values presented in the table are obtained using the following equations. The variances S_c^2 and S_m^2 of the predicted responses are given by the following;

$$S_c^2 = \frac{\sum(y_e - \bar{y}_e)^2}{(N-1)} \qquad (3.128)$$

Where

$y_e =$ The responses generated from the control points (the actual results), when the compressive strengths have been determined.

$\bar{y}_e =$ The mean, determine from

$$\frac{\sum y_e}{N} \tag{3.129}$$

$N = 10 =$ total number of experimental points.

$$S_m^2 = \frac{\sum(y_m - \bar{y}_m)^2}{(N-1)} \tag{3.130}$$

Where

$y_m =$ The responses generated from the mix ratios of point $n_1, n_2, n_3, \dots \dots \dots \dots, n_{34}$

$\bar{y}_m =$ The mean, determine from

$$\frac{\sum y_m}{N} \tag{3.131}$$

$$F_{cal} = \frac{S_1^2}{S_2^2} \tag{3.132}$$

Where

$S_1^2 =$ is the greater of S_e^2 and S_m^2 and S_2^2 is the lesser of the two. For Null Hypothesis to be accepted, the following condition must be satisfied;

$$\frac{1}{F_{table}} < \frac{S_1^2}{S_2^2} < F_{table} \tag{3.133}$$

Where

F given as $F_\alpha(V_1, V_2)$ is the value obtained from statistical table

$\alpha =$ Significant or risk level which the hypothesis is tested.

$V =$ Degree of freedom

$$V_1 = 5\% = 0.05$$

$$V_2 = N - 1 = 9$$

3.4.8.2 Student T-Test method

Akhnazorova and Katarao (1982) observed that experiments involving simplex design is saturated which means that they do not have any degree of freedom. To take care of this additional points are required to test the adequacy of the models. He further went ahead to say that the variance of the S_Y^2 of the predicted replica response is a result of the error accumulated. He proposed that the replica variance S_Y^2 is the same in all points of observation, and the replica values are the average values of n_i and n_{ij} replica observations. He gave the equation as

$$S^2 = S_Y^2\left(\sum \beta_i^2/n_i - \sum \beta_{ij}^2/n_{ij}\right) \tag{3.134}$$

$$1 < i \leq\leq q \; and \; 1 < j \leq\leq q$$

For this thesis the number of replicates is the same and β_i and $\beta_{ij} = n$, so equation 3.134 can be written as

$$S^2 = S_Y^2\left(\sum \beta_i^2/n + \sum \beta_{ij}^2/n\right) = \frac{S_Y^2}{n}\left(\sum \beta_i^2 + \sum \beta_{ij}^2\right) \tag{3.135}$$

$$1 < i \leq\leq q \; and \; 1 < j \leq\leq q$$

Here

$$\varepsilon = \left(\sum \beta_i^2 + \sum \beta_{ij}^2\right) \tag{3.136}$$

$$1 < i \leq\leq q \; and \; 1 < j \leq\leq q$$

Then equation 3.100 becomes

$$S^2 = S_Y^2 \frac{\varepsilon}{n} \tag{3.137}$$

Equation 3.101 can be written as

$$Y = (\sum \beta_i)n_i + \left(\sum \beta_{ij}\right)n_{ij} + e \tag{3.138}$$

Where

$$\beta_i = X_i(2X_i - 1) \tag{3.139}$$

And

$$\beta_{ij} = 4X_iX_j \tag{3.140}$$

Putting equations 3.139 and 3.140 into equation 3.136 gives

$$\varepsilon = \sum[X_i(2X_i - 1)]^2 + \sum\left[4X_iX_j\right]^2 \tag{3.141}$$

The equation for the calculation of t for t-test statistics (Paradine and others 1970) is given as

$$t = \frac{(Y_Y + Y_m)\sqrt{n}}{S_Y\left(\sqrt{(1+\varepsilon)}\right)} \tag{3.142}$$

Where

Y_P = Experimental test response

Y_m = The model response

n = Number of replicates at an observation point

S_Y = Is as given in the equation

ε = is as given in equation 3.136

3.4.8.3 Normal Probability Plot

The normal probability plot is a graphical illustration used to evaluate the fit of a distribution to data, estimate percentiles, and compare different sample distributions; it is a way of checking if the error is reasonably normally distributed or not in a linear regression model. Here a model equation is acceptable if the p - value is greater than 0.05 and rejected if the p - value is less than 0.05. In this work it was done using MINITAB 17.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

The results and analysis are as follows;

4.1 Chemical analysis

Table 4.1 XRF Test for Quarry Dust sample (Sedimentary Rock)

Parameter	Method	Date of Analysis	Quarry dust 2017 - 117
SiO_2%	ISO 18227	06/03/2017	40.50
Al_2O_3%	ISO 18227	06/03/2017	15.70
Fe_2O_3%	ISO 18227	06/03/2017	11.90
CaO%	ISO 18227	06/03/2017	6.42
MgO%	ISO 18227	06/03/2017	10.30
Na_2O%	ISO 18227	06/03/2017	3.39
K_2O%	ISO 18227	06/03/2017	0.02
TiO_2%	ISO 18227	06/03/2017	3.00
Loss in ignition	ASTM D7348	10/02/2017	2.46

Table 4.2 XRF Test for River Sand sample

Parameter	Method	Date of Analysis	River Sand 2017 - 050
SiO_2%	ISO 18227	14/02/2017	71.8
Al_2O_3%	ISO 18227	14/02/2017	3.85
Fe_2O_3%	ISO 18227	14/02/2017	0.80
CaO%	ISO 18227	14/02/2017	<0.0014
MgO%	ISO 18227	14/02/2017	<0.0034
Na_2O%	ISO 18227	14/02/2017	0.37
K_2O%	ISO 18227	14/02/2017	0.03
TiO_2%	ISO 18227	14/02/2017	0.07
Loss in ignition	ASTM D7348	10/2/2017	0.59

From the XRF (X-Ray Fluorescence) test conducted it can be seen that the quarry dust and river sand have the same parameters (oxides) but in different proportion. So quarry dust and river sand are the same in terms of what they contained, and one can be used to replace another.

4.1.1 Effects of various oxides from XRF test on the strengths of concrete

Table 4.3 XRF Test of Major Oxides in Dangote Cement (Ibrahim et al 2012)

S/N	oxide	Percentage present (%)
1	CaO	64.86
2	SiO_2	19.96
3	Al_2O_3	6.05
4	Fe_2O_3	2.99
5	MgO	1.26
6	SO_3	1.99
7	P_2O_3	0.24
8	K_2O	1.09
9	Free CaO	2.15
10	Loss in ignition	7.48

4.1.2 Silicon oxide (SiO_2)

The oxide SiO_2 is responsible for the grindability and coerciveness of the concrete materials. In cement the percentage of the oxide is about 64.86%, that of river sand is about 71.8% and that of quarry dust is about 40.5%. So river sand is coarser than quarry dust as can be seen on the two graphs in Figures 4.1 and 4.2 respectively. The oxide SiO_2 is also responsible for the strengths (compressive strength and flexural strength) of the concrete; hence the concrete made with river sand as fine aggregate has more strengths than the concrete made with quarry dust as fine aggregate as can be seen in Tables 4.18 to 4.25. This is because concrete made with rive sand as fine aggregate is coarser than concrete made with quarry dust as fine aggregate, since the coarser an aggregate is the more the bond between the aggregates and the cement past. The oxide SiO_2 is also responsible for the level of water intake, and this has effects on their slumps based on their mixed ratios, see Table 4.14 to 4.17.

4.1.3 Aluminium Oxide (Al_2O_3)

The oxides Al_2O_3 gives rise to the quantity of C_3A present in a concrete. The presence of C_3A is responsible for early setting of the concrete. Hence in a concrete with lower Al_2O_3 the setting time will be long than when the percentage of Al_2O_3 is higher (Ibrahim el at 2012). Concrete made with river sand as fine aggregate has lower setting time (long period of setting) because of lower Al_2O_3 of about 3.85% compare to that of quarry dust of about 15.7%. The concrete made with quarry dust as fine aggregate set early hence has reduced strengths (compressive strength and flexural strength). During the hydration process of the cement, the C_3A causes sudden hardening of the past, although this can be reduced by the addition of gypsum. For a given concrete, higher amount of C_3A is undesirable. The C_3S and C_2S hydrate to produce calcium silicate, this hydration is responsible for the adhesive and cohesive strengths of the concrete (Ahmed el at 2009). Concrete made with quarry dust as fine aggregate has higher amount of Al_2O_3 (15.7%) which produces much C_3A, this causes sudden hardening of the concrete. this gives rice to reduction in adhesive and cohesive strengths of the concrete. concrete made with river sand as fine aggregate has lower Al_2O_3 (3.85%) and hardened gradually, this brings about an increase in the adhesive and cohesive strengths of the concrete, hence the higher compressive strength and flexural strength compare to that made with quarry dust as fine aggregate.

4.1.4 Ion oxide (Fe_2O_3)

The oxide Fe_2O_3 is responsible for colouration. The concrete made with quarry dust as fine aggregate has darker grey colouration than that made with river sand as fine aggregate (Ibrahim et al 2012). Fe_2O_3 is also responsible for the fusion of the various components of the concrete materials.

4.1.5 Calcium Oxide (CaO)

CaO contributes to the strengths (compressive strength and flexural strength) of concrete. BS 12 (2) requires that the ratio of lime CaO to silicon dioxide (SiO_2) in Portland cement should not be less than 2. In their work “Effects of chemical composition of ordinary Portland cement on the compressive strength of concrete” by Arimanwa el at 2016, they observed that concrete strengths are higher when the combination of CaO and SiO_2 are higher. For quarry dust the combination of CaO and SiO_2 = 49.92% (CaO =40.5% and SiO_2 = 6.42%) and for river sand the combination = 71.8% (CaO = 71.8% and SiO2 = 0.0014%), from this it will adequate to predict that concrete made with river sand as fine aggregate has higher compressive strength and flexural strength than that made with quarry dusts as fine aggregate, as can be observed in tables 4.18 to 4.25.

4.1.6 Magnesium Oxide MgO

The oxide MgO is responsible for the colouration of the concrete and hardness of the concrete. for quarry dust the percentage is 10.8% and that of river sand is < 0.0034%. This is one of the oxides that are responsible for maximum compressive strength of $25.76N/mm^2$ and flexural strength of $2.63N/mm^2$ despite low combination of CaO and SiO_2 in concrete made with quarry dust as fine aggregate.

4..1.7 Residual Effect

Na_2O, K_2O, P_2O_3 and TiO_2 are called residual and are found in cement (K2O = 1.09, and P_2O_3 = 0.24% given a total of 1.33%), they exist in quarry dust and river sand in significant proportion. For quarry dust the percentages of Na_2O, K_2O and TiO_2 are 3.39%, 0.02% and 3.00% respectively and give a total of 6.32% , for river sand the percentages are 0.37%, 0.03% and 0.07% give a total of 0.47%, so from the XRF test it can be seen that the percentage of residual is higher in quarry dust than in river sand. Residuals in concrete are responsible for efflorescence and unsightly cracking when it is present in high proportion (Arimanwa el at 2016), from this it can be seen that concrete made with quarry dust as fine aggregate is more likely to be effected by these two conditions than that made with river sand as fine aggregate. BS 2 (12) recommended that the total percentage of residual present in a given cement sample should not be greater than 5%.

4.2 Mechanical Analysis

Table 4.4 Specific gravity of Quarry Dust

Soil Specimen No.	1	2	3
Specific gravity of soil particles (quarry dust) = $\frac{m_2-m_1}{(m_4-m_1)-(m_3-m_2)}$	2.60	2.56	2.50
Average S.G	2.55		

The specific gravity of quarry dust in Table 4.4 shows that the aggregate is normal weight aggregate, which means that the quarry dust has particles in it (normal weight aggregate ranges from$(2.4 \leq S > G \leq 2.9)$. This indicates that quarry dust is a crush stone and contains quartz (SiO_2).

Table 4.5 Specific gravity of River Sand

Soil Specimen No.	1	2	3
Specific gravity of soil particles (river sand) = $\frac{m_2-m_1}{(m_4-m_1)-(m_3-m_2)}$	2.70	2.74	2.53
Average S.G	2.66		

The specific gravity of river sand in Table 4.5 shows that the aggregate is normal weight aggregate, which means that the river sand has particles in it (normal weight aggregate ranges from$(2.4 \leq S > G \leq 2.9)$. This indicates that river sand contain quartz (SiO_2).

Table 4.6 Specific gravity of coarse aggregate (chippings)

Soil Specimen No.	1	2	3
Specific gravity of chippings particles $= \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$	2.67	2.53	2.60
Average S.G	2.60		

The specific gravity of chippings in table 4.6 shows that the aggregate is normal weight aggregate, this means that chippings is coarse and has particles in it (normal weight aggregate ranges from$(2.4 \leq S > G \leq 2.9)$. This indicates that chippings is a crush stone and contains quartz (SiO_2).

Table 4.7 Specific gravity of Port land Cement

Soil Specimen No.	1	2	3
Specific gravity of soil particles (Portland cement) $= \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$	3.03	3.13	
Average S.G	3.08		

The specific gravity of cement in Table 4.7 shows that is it a heavy weight particle, this means that cement comprises no less than 20 wt % of aggregate having a particle size smaller than 0.15mm and no less than 20 wt % of aggregate having a particle size from 2.5mm to less than 5mm (normal weight aggregate ranges from$(S.G > 2.9)$.

Table 4.8 Bulk Density of Quarry Dust

Soil specimen number	1	2
Bulk density $\frac{m_2 - m_1}{V_c}$ (Mg/m^3)	1.48	1.49
Average bulk density (Mg/m^3)	1.48	

The bulk density of quarry dust in Table 4.8 shows that the quarry dust contain coarse sand particles (for coarse particle $(\rho > 1.4Mg/m^2)$.

Table 4.9 Bulk Density of Sand

Soil specimen number	1	2
Bulk density $\frac{m_2 - m_1}{V_c}$ (Mg/m^3)	1.585	1.60
Average bulk density (Mg/m^3)	1.593	

The bulk density of river sand in table 4.9 shows That it is a medium sand (for medium sand ($\rho\ > 1.59Mg/m^2$).

Table 4.10 Bulk Density of Coarse Aggregate (chippings)

Soil specimen number	1	2
Bulk density $\frac{m_2 - m_1}{V_c}$ (Mg/m^3)	1.39	1.42
Average bulk density (Mg/m^3)	1.41	

The bulk density of coarse aggregate in Table 4.10 shows that the chippings contain coarse particles.

Table 4.11 Bulk Density of Cement

Soil specimen number	1	2
Bulk density $\frac{m_2 - m_1}{V_c}$ (Mg/m^3)	1.11	1.10
Average bulk density (Mg/m^3)	1.105	

The bulk density of cement in Table 4.11 shows that it is a fat clay particle (for fat clay particle ($\rho\ > 1.0Mg/m^2$).

4.1.1 Summary of specific gravity/bulk density

Tables 4.4 to 4.11 show the specific gravity of materials used namely: quarry dust, river sand, coarse aggregate and cement and were found to be 2.55, 2.66, 3.08 and 2.60, respectively. The bulk densities of the materials used were also determine as shown in table 4.5 to 4.8, for quarry dust it is 1.48, for river sand it is 1.60, for coarse aggregate it is 1.41 and for cement it is 1.105 respectively.

The specific gravity of sand is greater than that of quarry dust due to the fact that river sand used has granular particles more than quarry dust.

4.3 Particle Grading

Table 4.12 Grain size distribution for the fine aggregate

Sieve sizes	QUARRY DUST	SAND
	Percentage Passing %	Percentage Passing %
4.75mm	100	100
2.36mm	96	95
1.18mm	85	83
600µm	59	58
425µm	28	39
300µm	10	27
212µm	4	17
150µm	2	14
75 µm	1	7
PAN	0	0

Table 4.13 Grain size distribution for the Coarse aggregate

Sieve sizes	Coarse aggregate
	Percentage Passing %
25mm	100
19mm	89
13.2mm	32
9.5mm	11
6.7mm	10
PAN	0

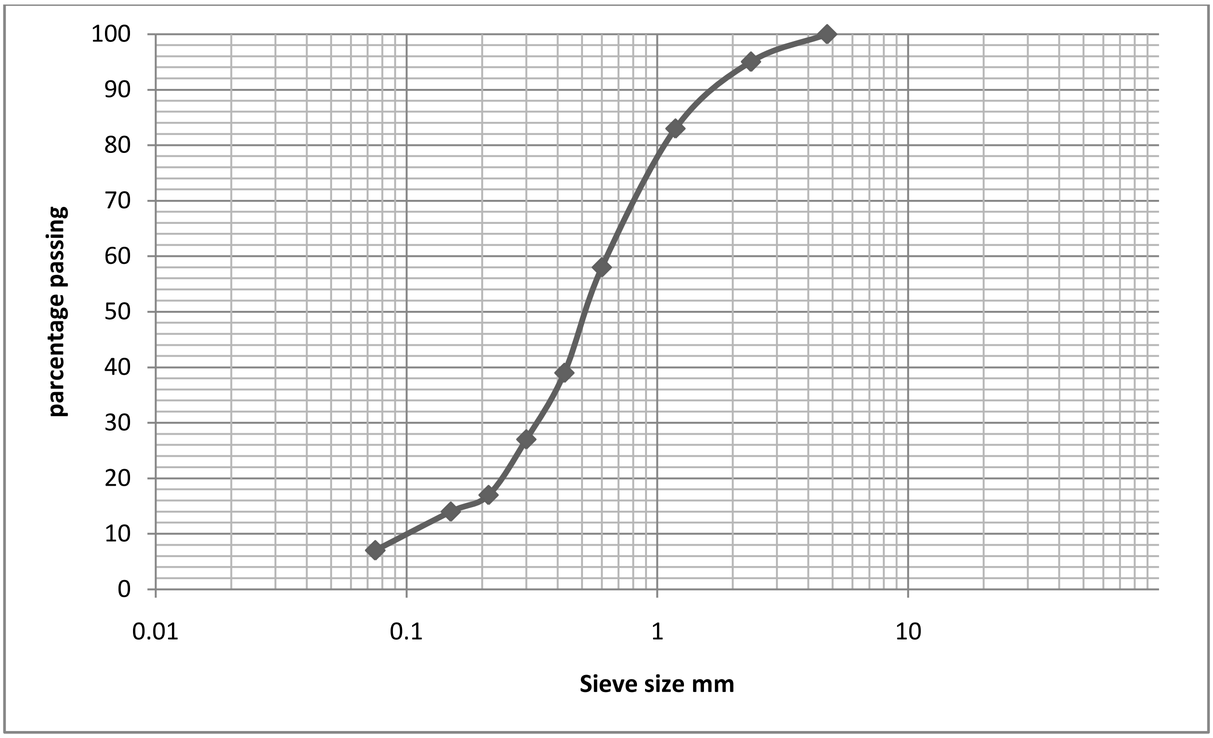

Fig. 4.1 Percentage passing against sieve sizes (River sand)

Effective size $D_{10} = 0.300mm$, $D_{30} = 0.440mm$, $D_{60} = 0.600mm$

The coefficient of uniformity C_c

$$C_c = \frac{D_{60}}{D_{10}} = \frac{0.600}{0.300} = 2$$

The coefficient of coverture C_u

$$C_u = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.4440^2}{0.600 \times 0.300} = 1.08$$

From the curve 95% of the soil is made of sand which have 25% coarse sand, 65% medium sand and 5% fine sand. From the values of C_c and C_u the soil is well graded; the soil is sand that is well graded (BS 1377: Part 2 1990).

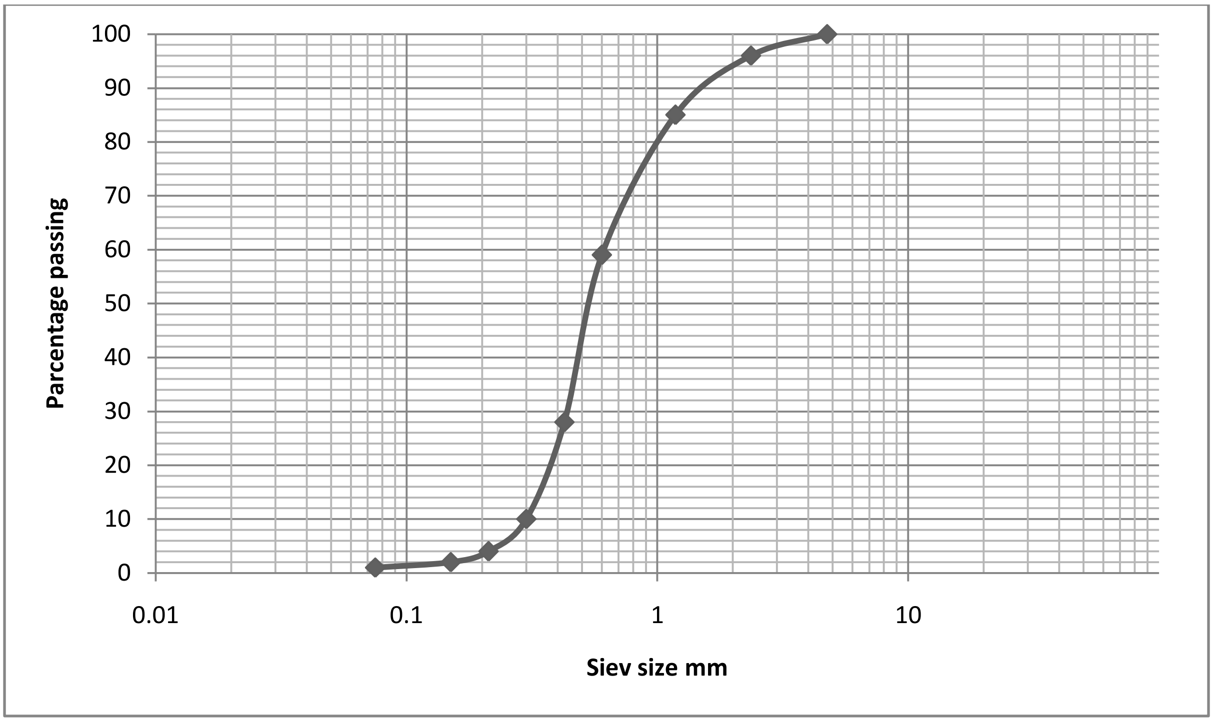

Fig. 4.2 Percentage passing against sieve sizes (quarry dust)

Effective size D_{10} = 0.100mm , D_{30} = 0.340mm, D_{60} = 0.630mm

The coefficient of uniformity C_c

$$C_c = \frac{D_{60}}{D_{10}} = \frac{0.630}{0.100} = 6.3$$

The coefficient of coverture C_u

$$C_u = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.340^2}{0.630 \times 0.100} = 1.83$$

From the curve 15%of silt, 77% of sand and 8% of gravel is present in the quarry dust. From the values of C_c and C_u the soil is well graded. The soil is well graded with mixed particles having more of sand (BS 1377: Part 2 1990).

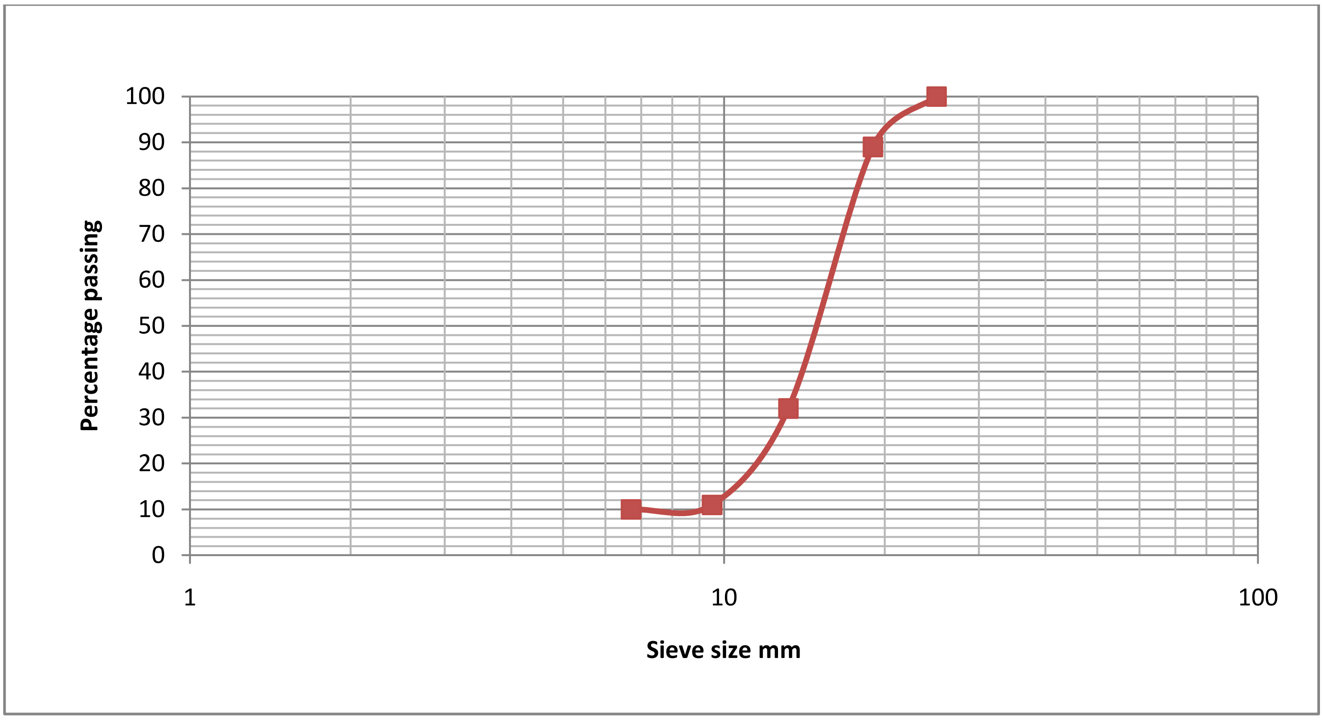

Fig. 4.3 Percentage passing against sieve sizes (Crushed Coarse aggregate)

Effective size D_{10} = 6.5 , D_{30} = 14mm, D_{60} = 17 mm

The coefficient of uniformity C_c

$$C_c = \frac{D_{60}}{D_{10}} = \frac{17}{6.5} = 2.65$$

The coefficient of coverture C_u

$$C_u = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{14^2}{17 \times 6.5} = 1.77$$

From the curve 100% of the soil is gravel, with 93% medium gravel and 7% coarse gravel. From the values of C_c and C_u the soil is uniformly graded; the soil is a uniformly graded gravel (BS 1377: Part 2 1990).

4.3.1 Summary of grain size distribution

Fig.4.1, Fig. 4.2 and Fig. 4.3 show the grain size distribution of river sand, quarry dust and coarse aggregate respectively. The curve in Fig. 4.1, vary more in uniformity than fig. 4.3. The uniformity of the curve in fig. 4.2 shows that the quarry dust used has more uniform grain in size than the river sand. It also implies that quarry dust used has more of silt than the river sand.

4.4 Fresh Concrete: Slump Test Results

Table 4.14 Slump test for concrete made with Quarry Dust (Actual value)

S/N	Mix ratio	Point of observation	Weight of sample 1 (g)	Weight of sample 2 (g))	Weight of sample 3 (g)	Average Weight of sample (g))	Slumps (cm)
1	0.6:1:1.5:3	Q_1	9460.00	8720.00	9500.00	9226.67	4.5
2	0.5:1:1.75:4	Q_2	8020.00	8080.00	7980.00	8026.67	Zero
3	0.55:1:2:3	Q_3	9700.00	7360.00	8780.00	8613.33	3.5
4	0.56:1:2:5	Q_4	8920.00	9656.00	9540.00	9372.00	Zero
5	0.575:1:1.75:3	Q_{12}	9150.00	9120.00	8600.00	8956.67	Zero
6	0.55:1:1.625:3.5	Q_{13}	10380.00	9460.00	10380.00	10073.33	1.3
7	0.58:1:1.75:4	Q_{14}	10580.00	9720.00	10580.00	10293.33	Zero
8	0.53:1:1.875:4.5	Q_{23}	8680.00	7880.00	7220.00	7926.67	Zero
9	0.555:1:2:4	Q_{24}	8860.00	8160.00	8800.00	8606.67	Zero
10	0.525:1:1.875:3.5	Q_{24}	7800.00	7640.00	8220.00	7886.67	Zero

The slump as indicated in Table 4.14 is the slump of concrete made with quarry dust (mean value $<$ 25mm), it shows dry mix and low workability. This is because quarry dust concrete required more water than conventional river sand concrete during mix to achieve high workability.

Table 4.15 Slump test for concrete made with River Sand (actual value)

S/N	Mix ratio	Point of observation	Weight of sample 1 (g)	Weight of sample 2 (g))	Weight of sample 3 (g)	Average Weight of sample (g))	Slumps (cm)
1	0.6:1:1.5:3	S_1	8120.00	8140.00	8140.00	8133.33	Zero
2	0.5:1:1.75:4	S_2	9340.00	9580.00	8720.00	9213.33	Zero
3	0.55:1:2:3	S_3	8240.00	8700.00	8840.00	8593.33	Collapse
4	0.56:1:2:5	S_4	6120.00	6120.00	6800.00	6346.67	Zero
5	0.575:1:1.75:3	S_{12}	11160.00	11380.00	11180.00	11240.00	Collapse
6	0.55:1:1.625:3.5	S_{13}	9380.00	8800.00	9540.00	9240.00	9.2
7	0.58:1:1.75:4	S_{14}	8540.00	8300.00	8740.00	8526.67	5.4
8	0.53:1:1.875:4.5	S_{23}	8680.00	8640.00	8480.00	8600.00	Zero
9	0.555:1:2:4	S_{24}	8880.00	9720.00	8460.00	9020.00	1.2
10	0.525:1:1.875:3.5	S_{24}	8240.00	9080.00	8240.00	8520.00	1.9

The slump as indicated in table 4.15 is the slump of concrete made with river sand (mean value $<$ 50mm), it shows medium workability. This is because the amount of water required to achieve workability in concrete made with river sand is lower than that required for concrete made with quarry dust.

Table 4.16 Slump test made with Quarry Dust (Control value)

S/N	Mix ratio	Point of observation	Weight of sample 1 (g)	Weight of sample 2 (g))	Weight of sample 3 (g)	Average Weight of sample (g))	Slumps (cm)
1	0.563:1:1.6875:3.25	Qc_1	10640.00	10820.00	10520.00	10660.00	Zero
2	0.578:1:1.75:3.5	Qc_2	9100.00	8780.00	8540.00	8806.67	1.3
3	0.567:1:1.6875:3.75	Qc_3	8720.00	7820.00	7920.00	8120.00	Zero
4	0.553:1:1.8125:3.75	Qc_4	9440.00	8320.00	7340.00	8366.67	Zero
5	0.555:1:1.8125:4.25	Qc_{12}	9480.00	9270.00	8900.00	9216.67	3.0
6	0.538:1:1.75:3.5	Qc_{13}	8460.00	10520.00	8620.00	9200.00	Zero
7	0.575:1:1.5625:3.25	Qc_{14}	6020.00	9760.00	9760.0	8513.33	5.8
8	0.558:1:2:4.5	Qc_{23}	9320.00	9380.00	9980.00	9560.00	Zero

The slump as indicated in Table 4.16 is the slump of concrete made with quarry dust (mean value $<$ 25mm), it shows dry mix and low workability. This is because quarry dust concrete required more water than conventional river sand concrete during mix to achieve high workability.

Table 4.17 Slump test for concrete made with Sand (Control value)

S/N	Mix ratio	Point of observation	Weight of sample 1 (g)	Weight of sample 2 (g))	Weight of sample 3 (g)	Average Weight of sample (g))	Slumps (cm)
1	0.563:1:1.6875:3.25	Sc_1	9020.00	8840.00	8420.00	8760.00	5.9
2	0.578:1:1.75:3.5	Sc_2	8720.00	10820.00	8800.00	9446.67	collapse
3	0.567:1:1.6875:3.75	Sc_3	6460.00	8220.00	8210.00	7630.00	Zero
4	0.553:1:1.8125:3.75	Sc_4	9760.00	9620.00	9140.00	9506.67	1.4
5	0.555:1:1.8125:4.25	Sc_{12}	8960.00	9220.00	8700.00	8960.00	Zero
6	0.538:1:1.75:3.5	Sc_{13}	8360.00	10240.00	9060.00	9220.00	Collapse
7	0.575:1:1.5625:3.25	Sc_{14}	8360.00	8400.00	8140.00	8300.00	Zero
8	0.558:1:2:4.5	Sc_{23}	6080.00	7920.00	7920.00	7306.67	Zero

The slump as indicated in Table 4.17 is the slump of concrete made with river sand (mean value $<$ 50mm), it shows medium workability. This is because the amount of water required to achieve workability in concrete made with river sand is lower than that required for concrete made with quarry dust.

4.4.1 Summary of workability

The variation of workability of fresh concrete is measured in terms of slump, with water/cement ratio and reported in Tables 4.14 to 4.17, respectively. The overall workability value of Quarry Rock Dust concrete is less compared to conventional concrete. Some of the fresh quarry dust concrete has zero slumps. This indicates that quarry dust absorbs water more than river sand hence requires more water to satisfy its workability, and this affects their compressive and flexural strengths.

4.5 Hardened Concrete

4.5.1.1 Compressive strength of concrete made with quarry dust as fine aggregate

Table 4.18 Compressive strength of concrete made with Quarry Dust (Actual Value)

S/N	Mix ratio	Point of observation	Replica 1 (KN)	Replica 2 (KN)	Replica 3 (KN)	Average Cube strength (KN)	Cube strength (N/mm^2)
1	0.6:1:1.5:3	Q_1	560.00	480.00	560.00	533.33	23.70
2	0.5:1:1.75:4	Q_2	300.00	380.00	320.00	333.33	14.82
3	0.55:1:2:3	Q_3	460.00	480.00	520.00	486.67	21.63
4	0.56:1:2:5	Q_4	130.00	140.00	120.00	130.00	25.76
5	0.575:1:1.75:3	Q_{12}	500.00	460.00	490.00	483.33	21.48
6	0.55:1:1.625:3.5	Q_{13}	610.00	470.00	510.00	530.00	23.56
7	0.58:1:1.75:4	Q_{14}	420.00	360.00	430.00	403.33	17.93
8	0.53:1:1.875:4.5	Q_{23}	280.00	220.00	240.00	246.67	10.96
9	0.555:1:2:4	Q_{24}	327.00	296.00	287.00	303.33	13.48
10	0.525:1:1.875:3.5	Q_{24}	140.00	110.00	170.00	140.00	6.22

Note: the cube strength in N/mm^2 is derived from dividing the force by 150×150mm^2.

Table 4.19 Compressive strength of concrete made with Quarry Dust (Control Value)

S/N	Mix ratio	Point of observation	Replica 1 (KN)	Replica 2 (KN)	Replica 3 (KN)	Average Cube strength (KN)	Cube strength (N/mm^2)
1	0.563:1:1.6875:3.25	Qc_1	403.325	419.325	417.325	413.325	18.37
2	0.578:1:1.75:3.5	Qc_2	384.048	420.0525	396.0495	400.05	17.78
3	0.567:1:1.6875:3.75	Qc_3	461.375	477.375	475.375	471.375	20.95
4	0.553:1:1.8125:3.75	Qc_4	271.296	296.73	279.774	282.6	12.56
5	0.555:1:1.8125:4.25	Qc_{12}	398.304	435.645	410.751	414.9	18.44
6	0.538:1:1.75:3.5	Qc_{13}	365.075	381.075	379.075	375.075	16.67
7	0.575:1:1.5625:3.25	Qc_{14}	479.952	524.9475	494.9505	499.95	22.22
8	0.558:1:2:4.5	Qc_{23}	288.35	304.35	302.35	298.35	13.26

From the lab results, it can be seen that for quarry dust the maximum compressive strength of 25.76N/mm^2 was obtained at a mix ratio of 0.56:1:2:5 and the lowest compressive strength of 6.22N/mm^2 was also obtained at a mix ratio of 0.525:1:1.875:3.5 (Table 4.13).The Compressive Strength is higher for the concrete made with quarry dust at some mix proportions and less at some other mix proportions compared to conventional concrete. The more the water content in the mix, the less the compressive strength of concrete made with quarry dust compared to conventional concrete, because the increase in free water content is the cause of decrease in concrete strength (Neville, 2003).

4.5.1.2 Compressive strength of concrete made with river sand dust as fine aggregate

Table 4.20 Compressive strength of concrete made with River sand (Actual Value)

S/N	Mix ratio	Point of observation	Replica 1 (KN)	Replica 2 (KN)	Replica 3 (KN)	Average Cube strength (KN)	Cube strength (N/mm^2)
1	0.6:1:1.5:3	S_1	650.00	640.00	590.00	626.67	27.85
2	0.5:1:1.75:4	S_2	765.00	830.00	700.00	765.00	34.00
3	0.55:1:2:3	S_3	580.00	550.00	570.00	566.67	25.19
4	0.56:1:2:5	S_4	640.00	560.00	660.00	620.00	27.69
5	0.575:1:1.75:3	S_{12}	480.00	470.00	500.00	483.33	21.48
6	0.55:1:1.625:3.5	S_{13}	590.00	610.00	610.00	603.33	26.82
7	0.58:1:1.75:4	S_{14}	510.00	600.00	600.00	570.00	25.33
8	0.53:1:1.875:4.5	S_{23}	640.00	560.00	660.00	620.00	27.56
9	0.555:1:2:4	S_{24}	710.00	760.00	640.00	703.33	31.26
10	0.525:1:1.875:3.5	S_{24}	430.00	540.00	610.00	526.67	23.41

Note: The cube strength in N/mm^2 is derived from dividing the force by 150×150mm^2

Table 4.21 Compressive strength of concrete made with River sand (Control Value)

S/N	Mix ratio	Point of observation	Replica 1 (KN)	Replica 2 (KN)	Replica 3 (KN)	Average Cube strength (KN)	Cube strength (N/mm^2)
1	0.563:1:1.6875:3.25	Sc_1	570.24	623.7	588.06	594	26.4
2	0.578:1:1.75:3.5	Sc_2	562.6665	596.7675	550.584	568.35	25.26
3	0.567:1:1.6875:3.75	Sc_3	608.3438	550.584	567.7898	573.525	25.49
4	0.553:1:1.8125:3.75	Sc_4	556.2	608.3438	573.5813	579.375	25.75
5	0.555:1:1.8125:4.25	Sc_{12}	628.6005	666.6975	628.6005	634.95	28.22
6	0.538:1:1.75:3.5	Sc_{13}	554.472	606.4538	571.7993	577.575	25.67
7	0.575:1:1.5625:3.25	Sc_{14}	566.352	619.4475	584.0505	589.95	26.22
8	0.558:1:2:4.5	Sc_{23}	621.432	640.8518	679.6913	647.325	28.77

For river sand a maximum compressive strength of 34.0N/mm^2 at a mix ratio of 0.5:1:1.75:4 was obtained and a lower compressive strength of 21.48N/mm^2 at a mix ratio of 0.575:1:1.75:3 was obtained (Table 4.15). But Table 4.13 and Table 4.15 show increase in compressive Strength of river sand concrete with corresponding decrease in quarry dust content at 0.5 water/cement ratio. This may be due to the high water absorption property of quarry dust which left insufficient water in the mix for the complete hydration of cement.The quantity of coarse aggregate affected the strength of the concretes. The more the coarse aggregate in the mix, the lesser the compressive strength in the quarry dust concrete as compared to river sand concrete. The reason for this is that as aggregate quantity increases, the quantity of fine aggregate in the concrete is decreasing thereby reducing the aggregate surface area to absorb water, with consequence of increasing the free water content in the concrete.

Generally, concrete having sand as fine aggregate is stronger than the corresponding one with quarry dust as fine aggregate. This can be seen from the results obtained because river sand concrete has greater number of concretes with higher compressive strength than quarry dust concrete. Theoretically, this is true because river sand has more granular particles than quarry dust hence less cement is needed for its bonding with coarse aggregate. Although from researches carried out (Sahu et al 2003), it was found that crushed stone dust can be used effectively in the replacement of natural sand in concrete and that concrete made with this replacement can attain the same compressive strength, in this case however, replacement of natural sand with quarry dust is not only effective, it also caused increase in strength, though marginal. For example, for concrete made with river sand, the compressive strength is 21.48N/mm^2 at water/cement ratio of 0.575 and a mix ratio of 1:1.75:3, while complete replacement of this sand with quarry dust, the compressive strength is the same with a value of 21.48 N/mm^2, this shows that the same compressive strength or even higher compressive can be obtained if river sand is completely replaced with quarry dust. Though in some other mix proportions, the compressive strength of concrete made with river sand has greater compressive strengths than the concrete made with quarry dust. For instance, from table 4.15 the compressive strength of most concrete made with river sand has greater value than their quarry dust counterpart of the same mix proportion. Also theoretically, it is clearly shown that the difference in texture between sand and quarry dust affect the strength. This also affected the variation of strength between the two fine aggregates.

4.5.2 Flexural Strength

4.5.2.1 Flexural strength of concrete made with quarry dust as fine aggregate

Table 4.22 Flexural strength of concrete made with Quarry Dust (Actual Value)

S/N	Mix ratio	Point of observation	Replica 1 (KN)	Replica 2 (KN)	Replica 3 (KN)	Average strength (KN)	Average Flexural strength (N/mm^2)
1	0.6:1:1.5:3	S_1	15.02415	16.96275	16.4781	16.155	2.393333
2	0.5:1:1.75:4	S_2	13.66542	14.98788	15.4287	14.694	2.176889
3	0.55:1:2:3	S_3	16.11225	18.19125	17.6715	17.325	2.566667
4	0.56:1:2:5	S_4	13.97232	15.7752	15.32448	15.024	2.225778
5	0.575:1:1.75:3	S_{12}	16.27002	16.74855	14.83443	15.951	2.363111
6	0.55:1:1.625:3.5	S_{13}	13.7547	15.5295	15.0858	14.79	2.191111
7	0.58:1:1.75:4	S_{14}	15.38685	17.37225	16.8759	16.545	2.451111
8	0.53:1:1.875:4.5	S_{23}	18.1152	18.648	16.5168	17.76	2.631111
9	0.555:1:2:4	S_{24}	14.80653	16.71705	16.23942	15.921	2.358667
10	0.525:1:1.875:3.5	S_{24}	17.49825	15.49845	16.9983	16.665	2.468889

Note: the cube strength in N/mm^2 is derived from dividing the force by $(F \times L)/(b \times d^2)$

Table 4.23 Flexural strength of concrete made with Quarry Dust (Control Value)

S/N	Mix ratio	Point of observation	Replica 1 (KN)	Replica 2 (KN)	Replica 3 (KN)	Average strength (KN)	Average Flexural strength (N/mm^2)
1	0.563:1:1.6875:3.25	Sc_1	15.03085	16.48544	16.97031	16.1622	2.3944
2	0.578:1:1.75:3.5	Sc_2	16.92353	14.98941	16.440	16.11765	2.3878
3	0.567:1:1.6875:3.75	Sc_3	17.29084	15.76518	17.79939	16.9518	2.511378
4	0.553:1:1.8125:3.75	Sc_4	17.14874	15.63562	17.65312	16.8125	2.49074
5	0.555:1:1.8125:4.25	Sc_{12}	17.10927	15.59052	17.09928	16.764	2.483556
6	0.538:1:1.75:3.5	Sc_{13}	16.62044	15.15393	17.10927	16.29455	2.414007
7	0.575:1:1.5625:3.25	Sc_{14}	17.77149	18.29418	16.20342	17.42303	2.58119
8	0.558:1:2:4.5	Sc_{23}	16.53928	15.07994	17.02573	16.21499	2.40222

Note: The cube strength in N/mm^2 is derived from dividing the force by $(F \times L)/(b \times d^2)$

The flexural strength of concrete made with quarry dust has its highest value of 2.63N/mm^2 at 1:1.875:4.5 at water cement ratio of 0.53 and the lowest value of 2.18N/mm^2 at mix ration of 1:1.75:4 at water cement ratio of 0.53.

4.5.2.2 Flexural strength of concrete made with river sand as fine aggregate

Table 4.24 Flexural strength of concrete made with River sand (Actual Value)

S/N	Mix ratio	Point of observation	Replica 1 (KN)	Replica 2 (KN)	Replica 3 (KN)	Average strength (KN)	Average Flexural strength (N/mm^2)
1	0.6:1:1.5:3	Q_1	23.22954	26.2269	25.47756	24.978	3.700444
2	0.5:1:1.75:4	Q_2	37.13535	32.89131	36.07434	35.367	5.239556
3	0.55:1:2:3	Q_3	33.74226	38.0961	37.00764	36.282	5.375111
4	0.56:1:2:5	Q_4	25.88283	29.22255	28.38762	27.831	4.123111
5	0.575:1:1.75:3	Q_{12}	31.37076	35.4186	34.40664	33.732	4.997333
6	0.55:1:1.625:3.5	Q_{13}	30.79602	33.77628	34.7697	33.114	4.905778
7	0.58:1:1.75:4	Q_{14}	16.53912	18.6732	18.13968	17.784	2.634667
8	0.53:1:1.875:4.5	Q_{23}	13.90815	15.70275	15.2541	14.955	2.215556
9	0.555:1:2:4	Q_{24}	18.39672	18.9378	16.77348	18.036	2.672
10	0.525:1:1.875:3.5	Q_{24}	19.33191	21.82635	21.20274	20.787	3.079556

Note: the cube strength in N/mm^2 is derived from dividing the force by $(F \times L)/(b \times d^2)$

Table 4.25 Flexural strength of concrete made with River sand (Control Value)

S/N	Mix ratio	Point of observation	Replica 1 (KN)	Replica 2 (KN)	Replica 3 (KN)	Average strength (KN)	Average Flexural strength (N/mm^2)
1	0.563:1:1.6875:3.25	Qc_1	31.41464	27.82439	30.51707	29.9187	4.4324
2	0.578:1:1.75:3.5	Qc_2	22.95321	20.92793	23.62831	22.50315	3.3338
3	0.567:1:1.6875:3.75	Qc_3	26.28555	23.96624	27.05866	25.77015	3.8178
4	0.553:1:1.8125:3.75	Qc_4	17.09991	18.75474	19.30635	18.387	2.724
5	0.555:1:1.8125:4.25	Qc_{12}	24.39769	22.24495	25.11527	23.9193	3.5436
6	0.538:1:1.75:3.5	Qc_{13}	24.06101	24.76869	21.93798	23.58923	3.4947
7	0.575:1:1.5625:3.25	Qc_{14}	30.1625	27.5011	31.04963	29.57108	4.3809
8	0.558:1:2:4.5	Qc_{23}	24.24563	21.4747	23.5529	23.09108	3.4209

Note: the cube strength in N/mm^2 is derived from dividing the force by $(F \times L)/(b \times d^2)$

The flexural strength of concrete made with river sand has its highest value of 5.375N/mm^2 at 1:2:3 at water cement ratio of 0.55 and the lowest value of 2.216N/mm^2 at mix ration of 1:1.875:4.5 at water cement ratio of 0.53.

MODEL EQUATIONS FOR COMPRESSIVE STRENGTH

4.6 Modelling

4.6.1 Osadebe's Regression Model for Quarry Dust concrete.

$$Y = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_{12} Z_1 Z_2 + \beta_{13} Z_1 Z_3 + \beta_{14} Z_1 Z_4 + \beta_{23} Z_2 Z_3 + \beta_{24} Z_2 Z_4 + \beta_{34} Z_3 Z_4$$

To write the Osadebe's Regression model for Quarry Dust Concrete the values of the coefficients of the Regression $\beta_1, \beta_2, \dots \dots \dots \dots \dots \dots \dots \dots, \beta_{34}$ is generated by substituting the values of the compressive strengths in table 4.1 into equation 3.87. After the computation the values are as given as;

$$\beta_1 = 68249.01, \quad \beta_2 = 135277.6, \quad \beta_3 = 7865.667, \beta_4 = 612.2575,$$
$$\beta_{12} = -431256, \quad \beta_{13} = 2069.578, \beta_{14} = -63985.5,$$
$$\beta_{23} = -212660, \beta_{24} = -141363, \beta_{34} = -9363.45$$

Substituting values of the coefficients into equation 3.85 gives

$$Y = 68249.01Z_1 + 135277.6Z_2 + 7865.667Z_3 + 612.2575Z_4 - 431256Z_1Z_2 + 2069.578Z_1Z_3 - 63985.5Z_1Z_4 - 212660Z_2Z_3 - 141363Z_2Z_4 - 9363.45Z_3Z_4 \qquad (4.1)$$

Table 4.26 F-Statistical Test for Osadebe's Regression Model for Quarry Dust concrete.

$LEGEND$: $\ddot{Y}_P = \sum Y_P/N$, $\ddot{Y}_M = \sum Y_M/N$, where $N = 8$ (Y_p = laboratory value, Y_m = model vaues)

$Response$	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	18.37	19.254	0.83875	2.103433	0.703502	4.424428
C2	17.78	16.178	0.24875	-0.97253	0.061877	0.94581
C3	20.95	17.201	3.41875	0.050352	11.68785	0.002535
C4	12.56	11.851	-4.97125	-5.29996	24.71333	28.08955
C5	18.44	15.147	0.90875	-2.0036	0.825827	4.014403
C6	16.67	14.352	-0.86125	-2.79866	0.741752	7.832484
C7	22.22	25.015	4.68875	7.864383	21.98438	61.84851
C8	13.26	18.208	-4.27125	1.056573	18.24358	1.116345
Total	140.25	137.2077			78.96209	108.2741
Mean	17.53125	17.15096				

$$S_P^2 = \frac{\sum(Y_P - \ddot{Y}_P)^2}{N-1} = 11.2803$$

$$S_M^2 = \frac{\sum(Y_M - \ddot{Y}_M)^2}{N-1} = 15.46772$$

S_1^2 is the greater of S_P^2 and S_M^2, and S_2^2 is the smaller of the two values. So $S_1^2 = 15.46772$and $S_2^2 = 11.2803$. The $F_{calculated} = S_1^2/S_2^2 = 15.46772/11.2803 = 1.371216$. From statistical tables $(V_1, V_2) = t_\alpha(7,7)$, from Appendix G, $F_{0.05(7,7)} = 3.79$. $1/F_{table} = 1/3.79 = 0.264$. The Null Hypothesis will be accepted if $1/F_{table} < F_{calculated} < F_{table}$;

$0.264 < 1.371216 < 3.79$. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.27 Student-Statistical T-Test for Osadebe's Regression Model for Quarry Dust (Two-Tailed T-Test)

$Response$	Y_M	Y_E	$D_i = Y_M - Y_E$	$D_A - D_i$	$(D_A - D_i)^2$
C1	18.37	19.25439	0.88439	-1.2646825	1.5994
C2	17.78	16.17843	-1.60157	1.60157	2.565
C3	20.95	17.20131	-3.74869	3.74869	14.053
C4	12.56	11.851	-0.709	0.709	0.5027
C5	18.44	15.14736	-3.29264	3.29264	10.841
C6	16.67	14.3523	-2.3177	2.3177	5.3717
C7	22.22	25.01534	2.79534	-2.79534	7.8139
C8	13.26	18.20753	4.94753	-4.94753	24.478
		$\sum D_i$	-3.04234	$\sum (D_A - D_i)^2$	67.225
		$D_A = \sum D_i / N$	-0.3802925	$S^2 = \sum (D_A - D_i)^2 / (N-1)$	9.6036
				$S = \sqrt{S^2}$	3.099
				$T = D_A \times N^{0.5} / S$	0.347

t from the table (Appendix F) is given as $t_\alpha(V) = t_{0.05(7)} = 1.893$, and calculated t =0.347. Therefore, t from the table is higher than t calculated; so the difference between the lab result and the model result is insignificant. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.28 Residual for compressive strength (Osadebe Model for Quary Dust Concrete)

Obs	lab	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI
1	18.37	18.72	1.11	(16.00; 21.43)	-0.35	-0.14	-0.13	0.165857
2	17.78	16.98	1.00	(14.54; 19.42)	0.80	0.31	0.29	0.133739
3	20.95	17.56	0.96	(15.20; 19.92)	3.39	1.33	1.44	0.125023
4	12.56	14.55	1.69	(10.41; 18.68)	-1.99	-0.93	-0.92	0.384415
5	18.44	16.40	1.10	(13.72; 19.09)	2.04	0.82	0.79	0.162083
6	16.67	15.95	1.21	(12.99; 18.92)	0.72	0.29	0.27	0.197346
7	22.22	21.96	2.28	(16.39; 27.53)	0.26	0.17	0.16	0.696214
8	13.26	18.13	1.00	(15.67; 20.58)	-4.87	-1.92	-2.82	0.135324

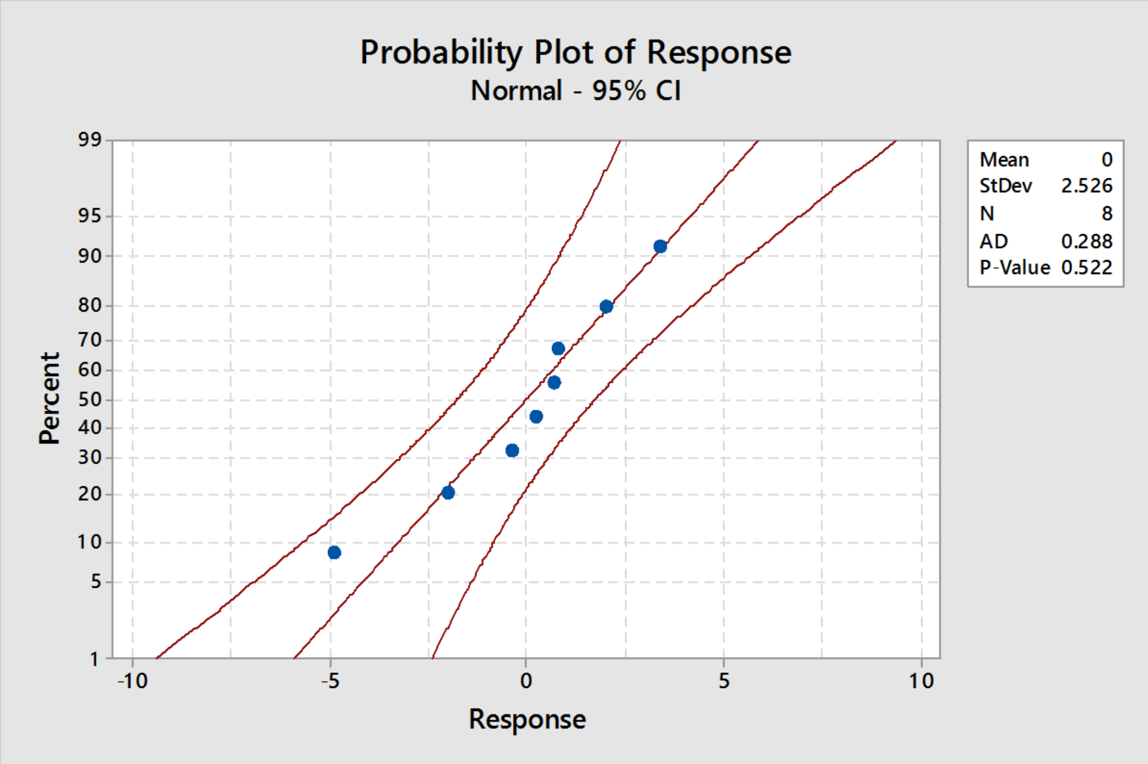

Fig 4.4 Normal Distribution plot for 28 days Compressive Strength

(Osadebe Model for Quarry Dust Concrete)

From the normal distribution plot (Fig. 4.4) it can be seen that p-value is greater than 0.05 (p-value = 0.522 > 0.05). There is no significant difference between the laboratory results and the model results, so the Null Hypothesis is accepted. The Osadebe's regression equation can be used to predict 28th day compressive strength for concrete made with quarry dust as fine aggregate.

4.6.2 Osadebe's Regression Model for River Sand concrete.

$$Y = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_{12} Z_1 Z_2 + \beta_{13} Z_1 Z_3 + \beta_{14} Z_1 Z_4 + \beta_{23} Z_2 Z_3 + \beta_{24} Z_2 Z_4 + \beta_{34} Z_3 Z_4$$

To write the Osadebe's Regression model for Quarry Dust Concrete the values of the coefficients of the Regression $\beta_1, \beta_2, \dots \dots \dots \dots \dots \dots \dots \dots, \beta_{34}$ is generated by substituting the values of the compressive strengths in table 4.3 into equation 3.87. After the computation the values are as given below;

$\beta_1 = 98979.14$, $\beta_2 = 70965.23$, $\beta_3 = 6212.717$, $\beta_4 = -197.644$, $\beta_{12} = -325033$, $\beta_{13} = -65036.4$, $\beta_{14} = -105633$, $\beta_{23} = -121140$, $\beta_{24} = -64989.2$, $\beta_{34} = -5994.42$.

Substituting values of the coefficients into equation 3.85 gives

$$Y = 98979.14Z_1 + 70965.23Z_2 + 6212.717 - 197.644Z_4 - 325033Z_1Z_2 - 65036.4Z_1Z_3 - 105633Z_4 - 121140Z_2Z_3 - 64989.2Z_2Z_4 - 5994.42Z_3Z_4 \quad (4.2)$$

Table 4.29 F-Statistical Test for Osadebe's Regression Model for River Sand

$LEGEND$: $\ddot{Y}_P = \sum Y_P/N$, $\ddot{Y}_M = \sum Y_M/N$, where $N = 8$

$Response$	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	26.4	22.439	-0.0725	-3.00325	0.005256	9.019511
C2	25.26	25.102	-1.2125	-0.34025	1.470156	0.11577
C3	25.49	25.061	-0.9825	-0.38125	0.965306	0.145352
C4	25.75	25.047	-0.7225	-0.39525	0.522006	0.156223
C5	28.22	25.633	1.7475	0.19075	3.053756	0.036386
C6	25.67	23.956	-0.8025	-1.48625	0.644006	2.208939
C7	26.22	26.016	-0.2525	0.57375	0.063756	0.329189
C8	28.77	30.284	2.2975	4.84175	5.278506	23.44254
Total	211.78	203.538			12.00275	35.45391
Mean	26.4725	25.44225				

$$S_P^2 = \frac{\sum(Y_P - \ddot{Y}_P)^2}{N-1} = 1.714679$$

$$S_M^2 = \frac{\sum(Y_M - \ddot{Y}_M)^2}{N-1} = \frac{10.93105683}{7} = 5.064283$$

S_1^2 is the greater of S_P^2 and S_M^2, and S_2^2 is the smaller of the two values. So $S_1^2 = 5.064283$and $S_2^2 = 1.714679$. The $F_{calculated} = S_1^2/S_2^2 = 5.064283/2.181821 = 2.953816.$ From statistical tables $(V_1, V_2) = t_\alpha(7,7)$, from Appendix G, $F_{0.05(7,7)} = 3.79$. $1/F_{table} = 1/3.79 = 0.264$. The Null Hypothesis will be accepted if $1/F_{table} < F_{calculated} < F_{table}$;

$0.264 < 2.953816 < 3.79$. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.30 Student-Statistical T-Test for Osadebe's Regression Model for River Sand (Two-Tailed T-Test)

$Response$	Y_M	Y_E	$D_i = Y_M - Y_E$	$D_A - D_i$	$(D_A - D_i)^2$
C1	26.4	22.439	-3.961	2.93075	8.5893
C2	25.26	25.102	-0.158	0.158	0.025
C3	25.49	25.061	-0.429	0.429	0.184
C4	25.75	25.047	-0.703	0.703	0.4942
C5	28.22	25.633	-2.587	2.587	6.6926
C6	25.67	23.956	-1.714	1.714	2.9378
C7	26.22	26.016	-0.204	0.204	0.0416
C8	28.77	30.284	1.514	-1.514	2.2922
		$\sum D_i$	-8.242	$\sum (D_A - D_i)^2$	21.257
		$D_A = \sum D_i / N$	-1.03025	$S^2 = \sum (D_A - D_i)^2 / (N-1)$	3.0367
				$S = \sqrt{S^2}$	1.7426
				$T = D_A \times N^{0.5} / S$	1.672

t from the table (Appendix F) is given as $t_\alpha(V) = t_{0.05(7)} = 1.893$, and calculated $t = 1.672$. Therefore, t from the table is higher than t calculated; so the difference between the lab result and the model result is insignificant. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.31 Residual for compressive strength (Osadebe Model for River Sand Concrete)

Obs	lab	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI
1	26.400	25.304	0.648	(23.719; 26.889)	1.096	1.32	1.44	0.379401
2	25.260	26.340	0.377	(25.419; 27.262)	-1.080	-1.10	-1.12	0.128265
3	25.490	26.324	0.378	(25.400; 27.249)	-0.834	-0.85	-0.83	0.12910
4	25.750	26.319	0.378	(25.393; 27.244)	-0.569	-0.58	-0.54	0.129406
5	28.220	26.547	0.373	(25.633; 27.460)	1.673	1.70	2.16	0.126026
6	25.670	25.894	0.455	(24.781; 27.008)	-0.224	-0.24	-0.22	0.187305
7	26.220	26.696	0.385	(25.753; 27.639)	-0.476	-0.49	-0.45	0.134285
8	28.770	28.356	0.932	(26.075; 30.638)	0.414	0.85	0.83	0.786212

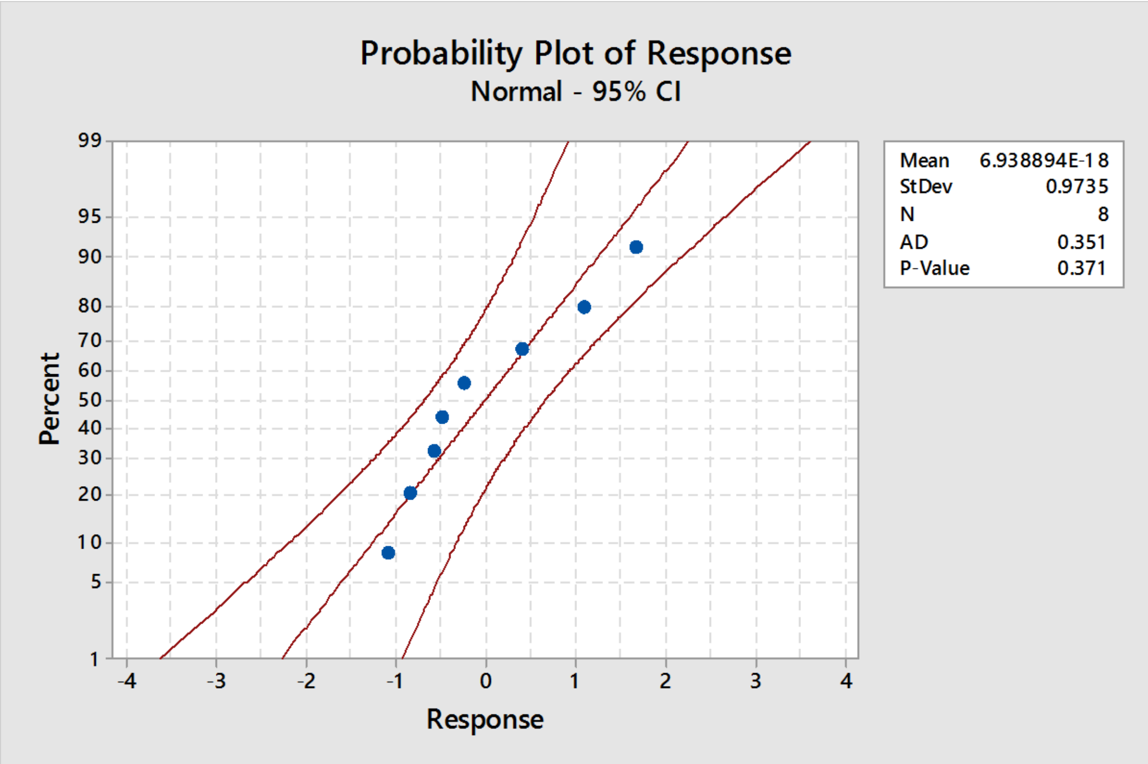

Fig 4.5 Normal Distribution plot for 28 days Compressive Strength

(Osadebe Model for River Sand Concrete)

From the normal distribution plot (Fig. 4.5) it can be seen that p-value is greater than 0.05 (p-value = 0.371 > 0.05). There is no significant difference between the laboratory results and the model results, so the Null Hypothesis is accepted. The Osadebe's regression equation can be used to predict 28th day compressive strength for concrete made with river sand as fine aggregate.

4.6.3 Ibearugbulems Model for Quarry Dust Concrete

$$F(z) = \propto_1 z_1 + \propto_2 z_2 + \propto_3 z_3 + \propto_4 z_4 + \propto_{12} z_1 z_2 + \propto_{13} z_1 z_3 + \propto_{14} z_1 z_4 + \propto_{23} z_2 z_3 + \propto_{24} z_2 z_4 + \propto_{34} z_3 z_4 + \propto_{123} z_1 z_2 z_3 + \propto_{124} z_1 z_2 z_4 + \propto_{234} z_2 z_3 z_4 + \propto_{1234} z_1 z_2 z_3 z_4$$

To write the Ibearugbulem model for Quarry Dust Concrete the values of the coefficients of the Regression $\propto_1, \propto_2, \dots \dots \dots \dots \dots \dots \dots \dots, \propto_{1234}$ is generated by substituting the values of the compressive strengths in Table 4.13 into equation 3.127. After the computation the values are as given below;

$\propto_1 = 1458.13766$, $\propto_2 = 1353.701119$, $\propto_3 = 416.3867364$, $\propto_4 = 698.4274022$, $\propto_{12} = -567.1331822$, $\propto_{13} = -1350.896081$, $\propto_{14} = -2766.855982$, $\propto_{23} = -249.8445373$,

$\propto_{24} = -4260.586756, \quad \propto_{34} = -2458.531967, \quad \propto_{123} = 4340.760331,$
$\propto_{124} = -1087.614608, \propto_{234} = 1455.050407, \propto_{1234} = 2148.252844,$

$$F(z) = 1458.13766z_1 + 1353.70119z_2 + 416.3867364z_3 + 698.4274022z_4 - 567.1331822z_1z_2 - 1350.896081z_1z_3 - 2766.855982z_1z_4 - 249.8445373z_2z_3 - 4260.586756z_2z_4 - 2458.531967z_3z_4 + 4340.760331z_1z_2z_3 - 1087.614608z_1z_2z_4 + 1455.050407z_2z_3z_4 + 2148.252844z_1z_2z_3z_4 \quad (4.3)$$

Table 4.32 F-Statistical Test for Ibearugbulems Model for Quarry Dust.

$LEGEND$: $\ddot{Y}_P = \sum Y_P/N$, $\ddot{Y}_M = \sum Y_M/N$, where $N = 8$

$Response$	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	18.37	19.6	0.83875	0.7475	0.703502	0.558756
C2	17.78	20.13	0.24875	1.2775	0.061877	1.632006
C3	20.95	19.87	3.41875	1.0175	11.68785	1.035306
C4	12.56	17.87	-4.97125	-0.9825	24.71333	0.965306
C5	18.44	17.87	0.90875	-0.9825	0.825827	0.965306
C6	16.67	17.33	-0.86125	-1.5225	0.741752	2.318006
C7	22.22	21.68	4.68875	2.8275	21.98438	7.994756
C8	13.26	16.47	-4.27125	-2.3825	18.24358	5.676306
Total	140.25	150.82			78.96209	21.14575
Mean	17.53125	18.8525				

$$S_P^2 = \frac{\sum(Y_P - \ddot{Y}_P)^2}{N-1} = 11.2803$$

$$S_M^2 = \frac{\sum(Y_M - \ddot{Y}_M)^2}{N-1} = 3.020821$$

S_1^2 is the greater of S_P^2 and S_M^2, and S_2^2 is the smaller of the two values. So $S_1^2 = 11.2803$and $S_2^2 = 3.020821$. The $F_{calculated} = S_1^2/S_2^2 = 11.2803/3.020821 = 3.73$

From statistical tables $(V_1, V_2) = t_\alpha(7,7)$, from Appendix G, $F_{0.05(7,7)} = 3.79$. $1/F_{table} = 1/3.79 = 0.264$. The Null Hypothesis will be accepted if $1/F_{table} < F_{calculated} < F_{table}$;

$0.264 < 3.73 < 3.79$. The Null Hypothesis is accepted and the model is adequate for use

Table 4.33 Student-Statistical T-Test for Ibearugbulems Model for Quarry Dust Concrete (Two-Tailed T-Test)

$Response$	Y_E	Y_M	$D_i = Y_E - Y_M$	$D_A - D_i$	$(D_A - D_i)^2$
C1	18.37	19.6	1.23	0.09125	0.0083
C2	17.78	20.13	2.35	-2.35	5.5225
C3	20.95	19.87	-1.08	1.08	1.1664
C4	12.56	17.87	5.31	-5.31	28.196
C5	18.44	17.87	-0.57	0.57	0.3249
C6	16.67	17.33	0.66	-0.66	0.4356
C7	22.22	21.68	-0.54	0.54	0.2916
C8	13.26	16.47	3.21	-3.21	10.304
		$\sum D_i$	10.57	$\sum (D_A - D_i)^2$	46.25
		$D_A = \sum D_i/N$	1.32125	$S^2 = \sum (D_A - D_i)^2/(N -$	6.6071
				$S = \sqrt{S^2}$	2.5704
				$T = D_A \times N^{0.5}/S$	1.4539

t from the table (Appendix F) is given as $t_\alpha(V) = t_{0.05(7)} = 1.893$, and calculated $t = 1.4539$. Therefore, t from the table is higher than t calculated; so the difference between the lab result and the model result is insignificant. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.34 Residual for compressive strength(Ibearugbulem Model for Quary Dust Concrete)

Obs	lab	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI
1	18.37	18.70	0.82	(16.68; 20.72)	-0.33	-0.17	-0.16	0.151424
2	17.78	19.53	0.95	(17.20; 21.87)	-1.75	-0.93	-0.91	0.202179
3	20.95	19.13	0.88	(16.96; 21.29)	1.82	0.95	0.94	0.173960
4	12.56	15.99	0.88	(13.85;18.13)	-3.43	-1.78	-2.36	0.170650
5	18.44	15.99	0.88	(13.85; 18.13)	2.45	1.27	1.35	0.170650
6	16.67	15.14	1.03	(12.63; 17.66)	1.53	0.82	0.80	0.234620
7	22.22	21.97	1.50	(18.29; 25.64)	0.25	0.17	0.16	0.503079
8	13.26	13.80	1.33	(10.54; 17.05)	-0.54	-0.32	-0.30	0.393437

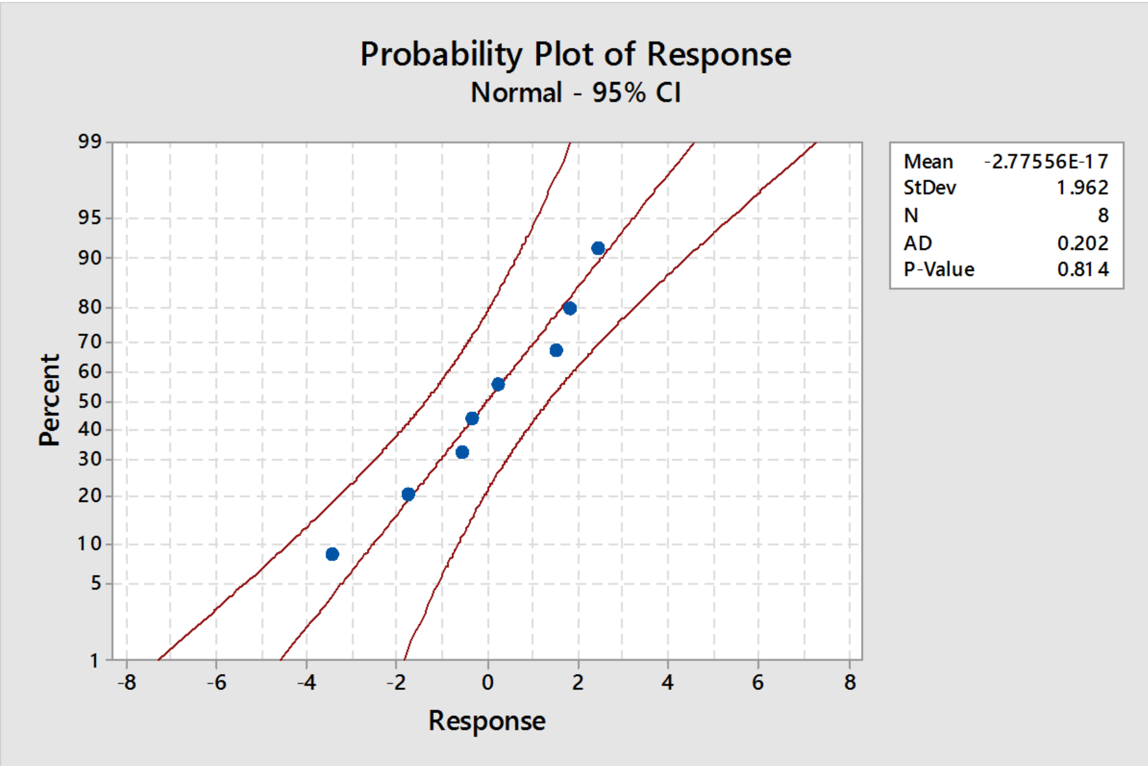

Fig 4.6 Normal Distribution plot for 28 days Compressive Strength

(Ibearugbulem Model for Quarry Dust Concrete)

From the normal distribution plot (Fig. 4.6) it can be seen that p-value is greater than 0.05 (p-value = 0.814 > 0.05). There is no significant difference between the laboratory results and the model results, so the Null Hypothesis is accepted. The Ibearugbulem regression equation can be used to predict 28th day compressive strength for concrete made with quarry dust as fine aggregate.

4.6.4 Ibearugbulems Model for River Sand Concrete

$$F(z) = \propto_1 z_1 + \propto_2 z_2 + \propto_3 z_3 + \propto_4 z_4 + \propto_{12} z_1 z_2 + \propto_{13} z_1 z_3 + \propto_{14} z_1 z_4 + \propto_{23} z_2 z_3 + \propto_{24} z_2 z_4 + \propto_{34} z_3 z_4 + \propto_{123} z_1 z_2 z_3 + \propto_{124} z_1 z_2 z_4 + \propto_{234} z_2 z_3 z_4 + \propto_{1234} z_1 z_2 z_3 z_4$$

To write the Ibearugbulem model for Quarry Dust Concrete the values of the coefficients of the Regression $\propto_1, \propto_2, \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots, \propto_{1234}$ is generated by substituting the values of the compressive strengths in Table 4.15 into equation 3.127. After the computation the values are as given below;

$\propto_1 = -1199.096105$, $\propto_2 = -1003.07614$, $\propto_3 = -791.3479956$, $\propto_4 = 43.64860808$,

$\propto_{12} = 1129.101465$, $\propto_{13} = 1396.008983$, $\propto_{14} = 1997.568957$, $\propto_{23} = 4733.539218$,

$\propto_{24} = 636.7868614$, $\propto_{34} = 643.2539974$, $\propto_{123} = -1918.276883$, $\propto_{124} = -1220.816509$,

$\propto_{234} = 1829.011132$, $\propto_{1234} = -4265.149944$,

$$F(z) = -1199.096105z_1 - 1003.07614z_2 - 791.3479956z_3 + 43.64860808z_4 + 1129.101465z_1z_2 + 1396.008983z_1z_3 + 1997.568957z_4 + 4733.539218z_2z_3 + 636.7868614z_2z_4 + 643.2539974z_3z_4 - 1918.276883z_1z_2z_3 - 1220.816509z_1z_2z_4 + 1829.011132z_1z_3z_4 - 4265.149944z_1z_2z_3z_4 \quad (4.4)$$

Table 4.35 F-Statistical Test for Ibearugbulems Model for River Sand Concrete

$LEGEND$: $\ddot{Y}_P = \sum Y_P/N$, $\ddot{Y}_M = \sum Y_M/N$, where $N = 8$

$Response$	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	26.4	26.14	-0.0725	-1.07875	0.005256	1.163702
C2	25.26	26.4	-1.2125	-0.81875	1.470156	0.670352
C3	25.49	27.51	-0.9825	0.29125	0.965306	0.084827
C4	25.75	27.27	-0.7225	0.05125	0.522006	0.002627
C5	28.22	28.49	1.7475	1.27125	3.053756	1.616077
C6	25.67	27.05	-0.8025	-0.16875	0.644006	0.028477
C7	26.22	26.44	-0.2525	-0.77875	0.063756	0.606452
C8	28.77	28.45	2.2975	1.23125	5.278506	1.515977
Total	211.78	217.75			12.00275	5.688487
Mean	26.4725	27.21875				

$$S_P^2 = \frac{\sum(Y_P - \ddot{Y}_P)^2}{N-1} = 1.714679$$

$$S_M^2 = \frac{\sum(Y_M - \ddot{Y}_M)^2}{N-1} = 0.812641$$

S_1^2 is the greater of S_P^2 and S_M^2, and S_2^2 is the smaller of the two values. So $S_1^2 = 1.714679$and $S_2^2 = 0.812641$. The $F_{calculated} = S_1^2/S_2^2 = 1.714679/0.812641 = 2.110$. From statistical tables $(V_1, V_2) = t_\alpha(7,7)$, from Appendix G, $F_{0.05(7,7)} = 3.79$. $1/F_{table} = 1/3.79 = 0.264$. The Null Hypothesis will be accepted if $1/F_{table} < F_{calculated} < F_{table}$;

$0.264 < 2.110 < 3.79$. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.36 Student-Statistical T-Test for Ibearugbulems Model for River Sand

(Two-Tailed T-Test)

$Response$	Y_E	Y_M	$D_i = Y_M - Y_E$	$D_A - D_i$	$(D_A - D_i)^2$
C1	26.4	26.14	-0.26	1.00625	1.0125
C2	25.26	26.4	1.14	-1.14	1.2996
C3	25.49	27.51	2.02	-2.02	4.0804
C4	25.75	27.27	1.52	-1.52	2.3104
C5	28.22	28.49	0.27	-0.27	0.0729
C6	25.67	27.05	1.38	-1.38	1.9044
C7	26.22	26.44	0.22	-0.22	0.0484
C8	28.77	28.45	-0.32	0.32	0.1024
		$\sum D_i$	5.97	$\sum(D_A - D_i)^2$	10.831
		$D_A = \sum D_i/N$	0.74625	$S^2 = \sum(D_A - D_i)^2/(N -$	1.5473
				$S = \sqrt{S^2}$	1.2439
				$T = D_A \times N^{0.5}/S$	1.6968

t from the table (Appendix F) is given as $t_\alpha(V) = t_{0.05(7)} = 1.893$, and calculated $t = 1.6968$. Therefore, t from the table is higher than t calculated; so the difference between the lab result and the model result is insignificant. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.37 Residual for compressive strength(Ibearugbulem Model for River Sand Concrete)

Obs	lab	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI
1	26.400	25.310	0.544	(23.978; 26.642)	1.090	1.40	1.56	0.329571
2	25.260	25.590	0.467	(24.447; 26.734)	-0.330	-0.40	-0.37	0.242844
3	25.490	26.786	0.355	(25.918; 27.654)	-1.296	-1.47	-1.68	0.139912
4	25.750	26.528	0.336	(25.706; 27.350)	-0.778	-0.88	-0.86	0.125462
5	28.220	27.842	0.607	(26.358; 29.327)	0.378	0.52	0.48	0.409096
6	25.670	26.291	0.342	(25.454; 27.127)	-0.621	-0.70	-0.67	0.130006 7
7	26.220	25.633	0.456	(24.516; 26.750)	0.587	0.71	0.67	0.231610
8	28.770	27.799	0.593	(26.347; 29.251)	0.971	1.31	1.42	0.391499

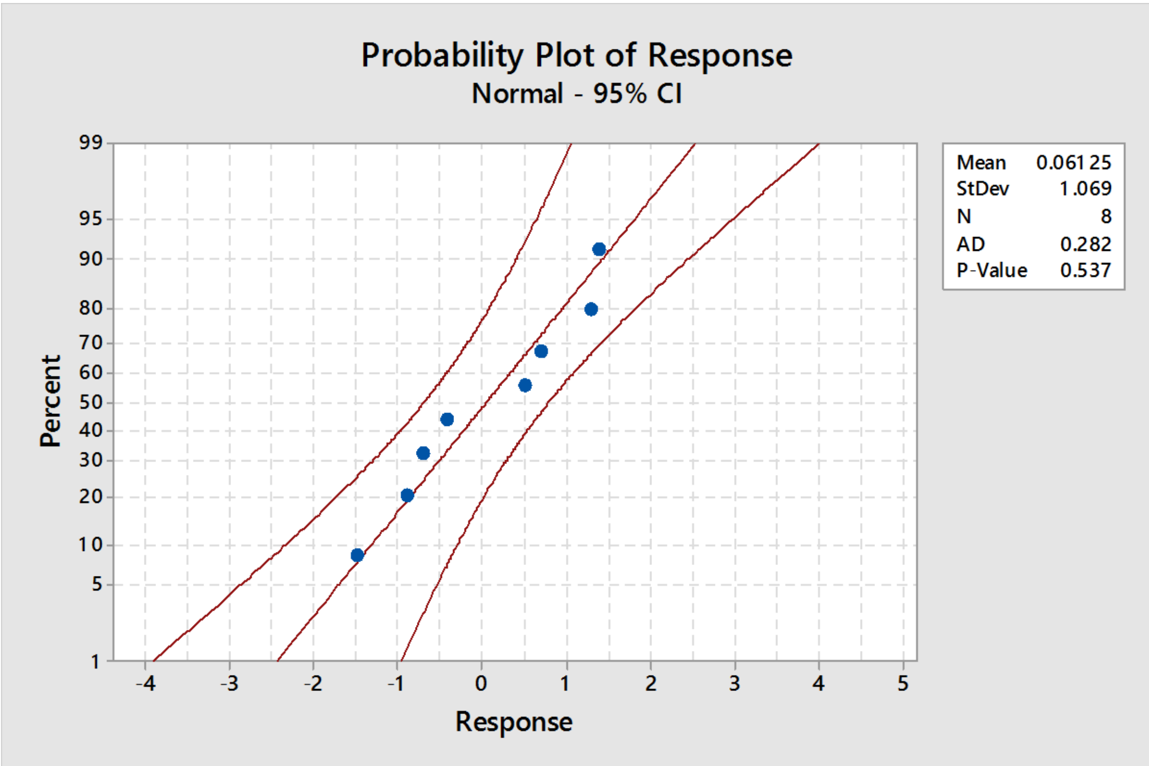

Fig 4.7 Normal Distribution plot for 28 days Compressive Strength

(Ibearugbulem Model for River sand Concrete)

From the normal distribution plot (Fig. 4.7) it can be seen that p-value is greater than 0.05 (p-value = 0.537 > 0.05). There is no significant difference between the laboratory results and the model results, so the Null Hypothesis is accepted. The Ibearugbulem regression equation can be used to predict 28th day compressive strength for concrete made with river sand as fine aggregate.

MODEL EQUATIONS FOR FLEXURAL STRENGTH

4.6.5 Osadebe's Regression Model for Quarry Dust concrete.

$$Y = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_{12} Z_1 Z_2 + \beta_{13} Z_1 Z_3 + \beta_{14} Z_1 Z_4 + \beta_{23} Z_2 Z_3 + \beta_{24} Z_2 Z_4 + \beta_{34} Z_3 Z_4$$

To write the Osadebe's Regression model for Quarry Dust Concrete the values of the coefficients of the Regression $\beta_1, \beta_2, \dots\dots\dots\dots\dots\dots\dots, \beta_{34}$ is generated by substituting the values of the compressive strengths in table 4.1 into equation 3.87. After the computation the values are as given below;

$\beta_1 = -5854.6$, $\beta_2 = -6116.64$, $\beta_3 = -134.874$, $\beta_4 = 3.586869$, $\beta_{12} = 24480.51$, $\beta_{13} = 3247.527$, $\beta_{14} = 5558.025$, $\beta_{23} = 8568.311$, $\beta_{24} = 6420.74$, $\beta_{34} = 59.25848$

Substituting values of the coefficients into equation 3.85 gives

$$Y = -5854.6Z_1 - 6116.64Z_2 - 134.874 + 3.586869 + 24480.51Z_1Z_2 + 3247.527Z_1Z_3 + 5558.025Z_1Z_4 + 8568.311Z_2Z_3 + 6420.74Z_2Z_4 + 59.25848Z_3Z_4 \quad (4.5)$$

Table 4.38 F-Statistical Test for Osadebe's Regression Model for Quarry Dust concrete(Flexural Strength)

$LEGEND$: $\ddot{Y}_P = \sum Y_P/N$, $\ddot{Y}_M = \sum Y_M/N$, where $N = 8$

$Response$	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	2.3944	2.3095	-0.06376137	-0.08639	0.004066	0.007464
C2	2.3878	2.4153	-0.07036138	0.019395	0.004951	0.000376
C3	2.511378	2.4746	0.053216625	0.078669	0.002832	0.006189
C4	2.49074	2.4794	0.032578625	0.083488	0.001061	0.00697
C5	2.483556	2.5342	0.025394625	0.138305	0.000645	0.019128
C6	2.414007	2.3122	-0.04415438	-0.08372	0.00195	0.007009
C7	2.58119	2.2631	0.123028625	-0.13283	0.015136	0.017645
C8	2.40222	2.279	-0.05594138	-0.01691	0.003129	0.000286
Total	19.665291	19.167446			0.03377	0.065068
Mean	2.45816138	2.39593075				

$$S_P^2 = \frac{\sum(Y_P - \ddot{Y}_P)^2}{N-1} = 0.00482423$$

$$S_M^2 = \frac{\sum(Y_M - \ddot{Y}_M)^2}{N-1} = \frac{0.02222}{7} = 0.00929537$$

S_1^2 is the greater of S_P^2 and S_M^2, and S_2^2 is the smaller of the two values. So $S_1^2 = 0.004131704$ and$S_2^2 = 0.00482423$

The $F_{calculated} = S_1^2/S_2^2 = 0.004131704/0.00482423$ =1.92681119.

From statistical tables $(V_1, V_2) = t_\alpha(7,7)$, from Appendix G, $F_{0.05(7,7)} = 3.79$. $1/F_{table} = 1/3.79 = 0.264$. The Null Hypothesis will be accepted if $1/F_{table} < F_{calculated} < F_{table}$;

$0.264 <$ 1.92681119 < 3.79. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.39 Student-Statistical T-Test for Osadebe's Regression Model for Quarry Dust concrete (Flexural Strength) (Two-Tailed T-Test)

$Response$	Y_E	Y_M	$D_i = Y_M - Y_E$	$D_A - D_i$	$(D_A - D_i)^2$
C1	2.3944	2.3095	-0.084864	0.010133375	0.0001
C2	2.3878	2.4153	0.027526	-0.027526	0.0008
C3	2.511378	2.4746	-0.036778	0.036778	0.0014
C4	2.49074	2.4794	-0.011321	0.011321	0.0001
C5	2.483556	2.5342	0.05068	-0.05068	0.0026
C6	2.414007	2.3122	-0.101799	0.101799	0.0104
C7	2.58119	2.2631	-0.318092	0.318092	0.1012
C8	2.40222	2.279	-0.123197	0.123197	0.0152
		$\sum D_i$	-0.597845	$\sum(D_A - D_i)^2$	0.1316
		$D_A = \sum D_i/N$	-0.0747306	$S^2 = \sum(D_A - D_i)^2/(N -$	0.0188
				$S = \sqrt{S^2}$	0.1371
				$T = D_A \times N^{0.5}/S$	1.541

t from the table (Appendix F) is given as $t_{\alpha}(V) = t_{0.05(7)} = 1.893$, and calculated $t = 1.541$. Therefore, t from the table is higher than t calculated; so the difference between the lab result and the model result is insignificant. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.40 Residual for Flexural Strength(Osadebe Model for Quary Dust Concrete)

Obs	lab	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI
1	2.3944	2.4501	0.0327	(2.3700; 2.5302)	-0.0557	-0.84	-0.82	0.195771
2	2.3878	2.4617	0.0275	(2.3944; 2.5290)	-0.0739	-1.08	-1.09	0.138172
3	2.5114	2.4682	0.0357	(2.3808; 2.5555)	0.0432	0.67	0.63	0.232718
4	2.4907	2.4687	0.0366	(2.3792; 2.5582)	0.0221	0.34	0.32	0.244357
5	2.4836	2.4747	0.0479	(2.3574; 2.5920)	0.0089	0.16	0.14	0.419543
6	2.4140	2.4504	0.0323	(2.3713; 2.5294)	-0.0363	-0.55	-0.51	0.190695
7	2.5812	2.4450	0.0414	(2.3438; 2.5462)	0.1362	2.22	4.80	0.312516
8	2.4022	2.4467	0.0382	(2.3533; 2.5401)	-0.0445	-0.70	-0.67	0.266229

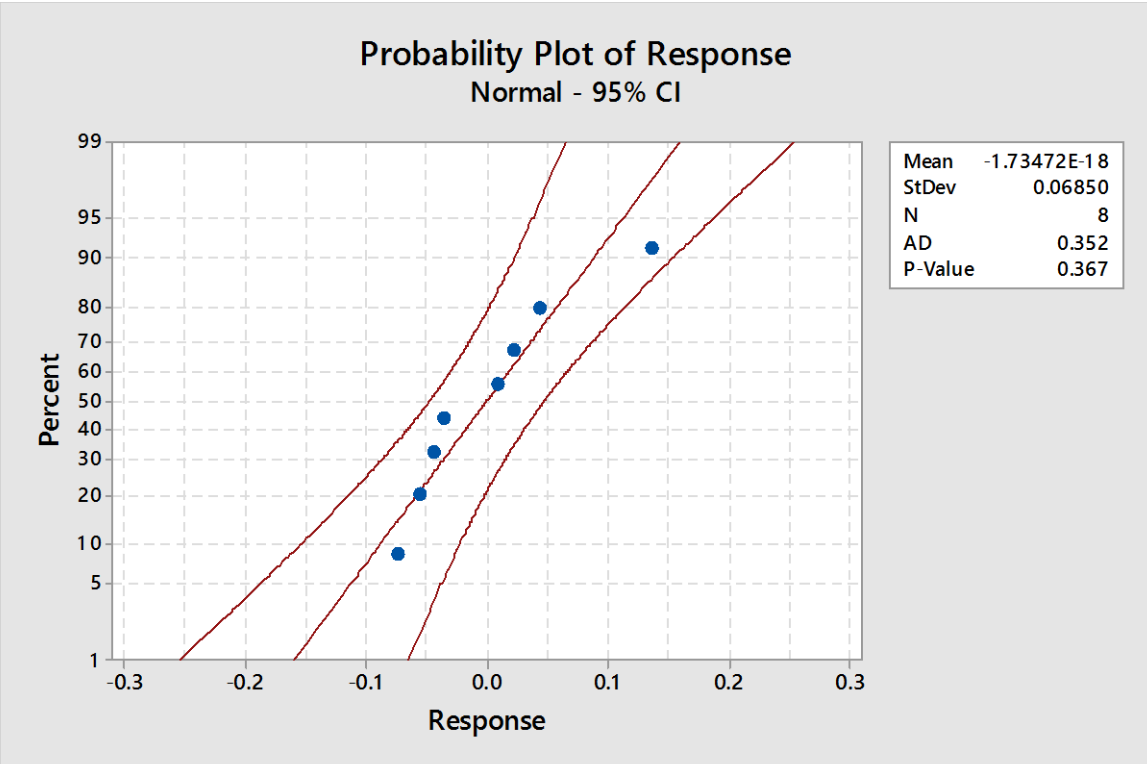

Fig 4.8 Normal Distribution plot for 28 days Flexural Strength

(Osadebe Model for Quarry Dust Concrete)

From the normal distribution plot (Fig. 4.8) it can be seen that p-value is greater than 0.05 (p-value = 0.367 > 0.05). There is no significant difference between the laboratory results and the model results, so the Null Hypothesis is accepted. The Osadebe's regression equation can be used to predict 28th day flexural strength of concrete made with quarry dust as fine aggregate.

4.6.6 Osadebe's Regression Model for River Sand concrete.

$$Y = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_{12} Z_1 Z_2 + \beta_{13} Z_1 Z_3 + \beta_{14} Z_1 Z_4 + \beta_{23} Z_2 Z_3 + \beta_{24} Z_2 Z_4 + \beta_{34} Z_3 Z_4$$

To write the Osadebe's Regression model for Quarry Dust Concrete the values of the coefficients of the Regression $\beta_1, \beta_2, \dots\dots\dots\dots\dots\dots\dots\dots, \beta_{34}$ is generated by substituting the values of the compressive strengths in table 4.3 into equation 3.87. After the computation the values are as given below;

Substituting values of the coefficients into equation 3.85 gives

$\beta_1 = 30971.02$, $\beta_2 = 34285.02, \beta_3 = 1142.898$, $\beta_4 = 107.8986$, $\beta_{12} = -134355 \beta_{13} - 15064.4$, $\beta_{14} = -30043.9$, $\beta_{23} = -49010.7$, $\beta_{24} = -35753, \beta_{34} = -1280.49$

$$Y = 30971.02 Z_1 + 34285.02 Z_2 + 1142.898 Z_3 + 107.8986 Z_4 - 134355 Z_1 Z_2 - 15064.4 Z_1 Z_3 - 30043.9 Z_1 Z_4 - 49010.7 Z_2 Z_3 - 35753 Z_2 Z_4 - 1280.49 Z_3 Z_4 \quad (4.6)$$

Table 4.41 F-Statistical Test for Osadebe's Regression Model for River Sand concrete (Flexural Strength).

$LEGEND$: $\ddot{Y}_P = \sum Y_P / N$, $\ddot{Y}_M = \sum Y_M / N$, where $N = 8$

$Response$	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	4.4324	4.2903	0.788943625	0.945305	0.622432	0.893601
C2	3.3338	3.0465	-0.30972238	-0.29852	0.095928	0.089112
C3	3.8178	2.8413	0.174279625	-0.50367	0.030373	0.25368
C4	2.724	2.584	-0.91950038	-0.76097	0.845481	0.579079
C5	3.5436	2.4591	-0.09994437	-0.88589	0.009989	0.7848
C6	3.4947	4.0166	-0.14883338	0.671653	0.022151	0.451118
C7	4.3809	4.4323	0.737388625	1.087304	0.543742	1.18223
C8	3.4209	3.0898	-0.22261138	-0.25522	0.049556	0.065136
Total	29.14800	26.7598			2.219652	4.298755
Mean	3.643500	3.34498				

$$S_P^2 = \frac{\sum(Y_P - \ddot{Y}_P)^2}{N-1} = 0.3170932$$

$$S_M^2 = \frac{\sum(Y_M - \ddot{Y}_M)^2}{N-1} = \frac{2.980841943}{7} = 0.61410779$$

S_1^2 is the greater of S_P^2 and S_M^2, and S_2^2 is the smaller of the two values. So $S_1^2 = 0.61410779$and $S_2^2 = 0.3170932$. The $F_{calculated} = S_1^2/S_2^2 = 0.61410779/0.3170932 = 1.93667918$

From statistical tables $(V_1, V_2) = t_\alpha(7{,}7)$, from Appendix G, $F_{0.05(7,7)} = 3.79$. $1/F_{table} = 1/3.79 = 0.264$. The Null Hypothesis will be accepted if $1/F_{table} < F_{calculated} < F_{table}$;

$0.264 < 1.93667918 < 3.79$. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.42 Student-Statistical T-Test for Osadebe's Regression Model for River Sand concrete (Flexural Strength) Two-Tailed T-Test.

$Response$	Y_M	Y_E	$D_i = Y_M - Y_E$	$D_A - D_i$	$(D_A - D_i)^2$
C1	4.290285	4.4324	-0.142159	-0.15636125	0.0244
C2	3.046463	3.3338	-0.287315	0.287315	0.0825
C3	2.841314	3.8178	-0.976466	0.976466	0.9535
C4	2.584008	2.724	-0.139992	0.139992	0.0196
C5	2.459091	3.5436	-1.084465	1.084465	1.1761
C6	4.016633	3.4947	0.521966	-0.521966	0.2724
C7	4.432284	4.3809	0.051395	-0.051395	0.0026
C8	3.089763	3.4209	-0.331126	0.331126	0.1096
		$\sum D_i$	-2.388162	$\sum(D_A - D_i)^2$	2.6409
		$D_A = \sum D_i/N$	-0.29852025	$S^2 = \sum(D_A - D_i)^2/(N -$	0.3773
				$S = \sqrt{S^2}$	0.6142
				$T = D_A \times N^{0.5}/S$	1.375

t from the table (Appendix F) is given as $t_\alpha(V) = t_{0.05(7)} = 1.893$, and calculated $t = 1.375$

. Therefore, t from the table is higher than t calculated; so the difference between the lab result and the model result is insignificant. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.43 Residual for Flexural Strength(Osadebe Model for River Sand Concrete)

Obs	lab	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI
1	4.290	4.161	0.360	(3.280; 5.043)	0.129	0.30	0.27	0.405389
2	3.046	3.024	0.232	(2.457; 3.592)	0.022	0.04	0.04	0.168216
3	2.841	3.525	0.211	(3.010; 4.041)	-0.684	-1.30	-1.40	0.138686
4	2.584	2.393	0.402	(1.408; 3.378)	0.191	0.48	0.45	0.505931
5	2.459	3.242	0.204	(2.743; 3.740)	-0.782	-1.48	-1.70	0.129497
6	4.017	3.191	0.208	(2.682; 3.700)	0.826	1.57	1.86	0.134977
7	4.432	4.108	0.344	(3.266; 4.950)	0.324	0.72	0.69	0.369976
8	3.090	3.115	0.217	(2.583; 3.646)	-0.025	-0.05	-0.04	0.147327

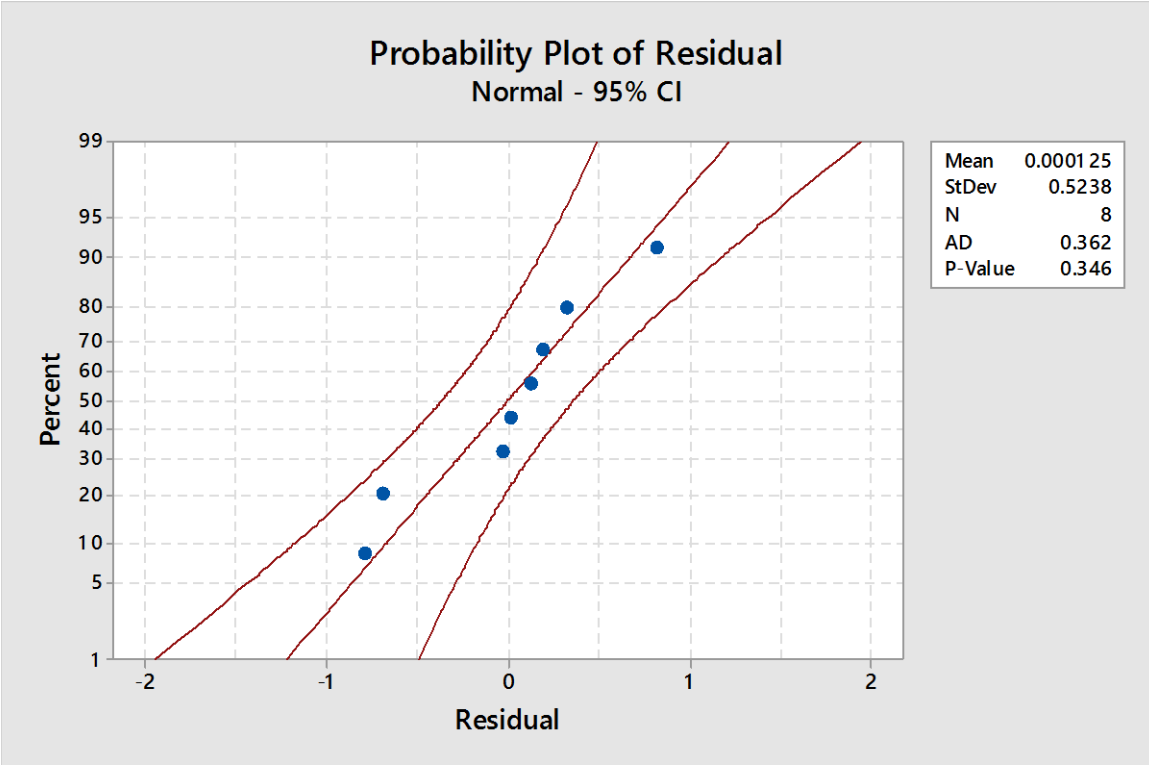

Fig 4.9 Normal Distribution plot for 28 days Flexural Strength

(Osadebe Model for River sand Concrete)

From the normal distribution plot (Fig. 4.9) it can be seen that p-value is greater than 0.05 (p-value = 0.346 > 0.05). There is no significant difference between the laboratory results and the model results, so the Null Hypothesis is accepted. The Osadebe's regression equation can be used to predict 28th day flexural strength of concrete made with river sand as fine aggregate.

4.6.7 Ibearugbulems Model for Quarry Dust Concrete

$$F(z) = \propto_1 z_1 + \propto_2 z_2 + \propto_3 z_3 + \propto_4 z_4 + \propto_{12} z_1z_2 + \propto_{13} z_1z_3 + \propto_{14} z_1z_4 + \propto_{23} z_2z_3 + \propto_{24} z_2z_4 + \propto_{34} z_3z_4 + \propto_{123} z_1z_2z_3 + \propto_{124} z_1z_2z_4 + \propto_{234} z_2z_3z_4 + \propto_{1234} z_1z_2z_3z_4$$

To write the Ibearugbulem model for Quarry Dust Concrete the values of the coefficients of the Regression $\propto_1, \propto_2, \dots\dots\dots\dots\dots\dots\dots\dots, \propto_{1234}$ is generated by substituting the values of the compressive strengths in table 4.13 into equation 3.127. After the computation the values are as given below;

$$\propto_1 = 4.751284, \propto_2 = -0.18501, \quad \propto_3 = 4.352881, \quad \propto_4 = 1.406582,$$

$$\propto_{12} = -0.94862 \; \propto_{13} = 8.831311 \; \propto_{14} = -4.17811 \; \propto_{23} = -4.06365 \; \propto_{24} = 4.352805$$

$$\propto_{34} = 1.842098 \; \propto_{123} = -5.79784, \propto_{124} = -11.9638: \; \propto_{234} = -7.35504: \; \propto_{1234} = -3.43595$$

$$F(z) = 4.751284z_1 - 0.18501z_2 + 4.352881z_3 + 1.406582z_4 - 0.94862z_1z_2 + 8.831311z_1z_3 - 4.17811z_1z_4 - 4.06365z_2z_3 + 4.352805z_2z_4 + 1.842098z_3z_4 - 5.79784z_1z_2z_3 - -11.9638z_1z_2z_4 - 7.35504z_2z_3z_4 - 3.43595z_1z_2z_3 \quad (4.7)$$

Table 4.44 F-Statistical Test for Ibearugbulems Model for Quarry Dust Concrete (Flexural Strength)

$LEGEND$: $\ddot{Y}_P = \sum Y_P/N$, $\ddot{Y}_M = \sum Y_M/N$, where $N = 8$

$Response$	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	2.3944	2.38031	-0.06376137	0.001799	0.004066	3.24E-06
C2	2.3878	2.38498	-0.07036138	0.006466	0.004951	4.18E-05
C3	2.511378	2.33991	0.053216625	-0.0386	0.002832	0.00149
C4	2.49074	2.4821	0.032578625	0.103585	0.001061	0.01073
C5	2.483556	2.3434	0.025394625	-0.03511	0.000645	0.001233
C6	2.414007	2.37774	-0.04415438	-0.00077	0.00195	5.99E-07
C7	2.58119	2.33421	0.123028625	-0.0443	0.015136	0.001963
C8	2.40222	2.38545	-0.05594138	0.006937	0.003129	4.81E-05
Total	19.665291	19.028098			0.03377	0.015509
Mean	2.45816138	2.37851225				

$$S_P^2 = \frac{\sum(Y_P - \ddot{Y}_P)^2}{N-1} = \frac{0.0289131}{7} = 0.00482423$$

$$S_M^2 = \frac{\sum(Y_M - \ddot{Y}_M)^2}{N-1} = \frac{0.284675}{7} = 0.00221556$$

S_1^2 is the greater of S_P^2 and S_M^2, and S_2^2 is the smaller of the two values. So $S_1^2 = 0.00482423$ and $S_2^2 = 0.00221556$. The $F_{calculated} = S_1^2/S_2^2 = 0.00482423/0.00221556$ =2.17743389.

From statistical tables $(V_1, V_2) = t_\alpha(7,7)$, from Appendix G, $F_{0.05(7,7)} = 3.79$. $1/F_{table} = 1/3.79 = 0.264$. The Null Hypothesis will be accepted if $1/F_{table} < F_{calculated} < F_{table}$;

$0.264 < 2.17743389 < 3.79$. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.45 Student-Statistical T-Test for Ibearugbulems Model for Quarry Dust Concrete (Flexural Strength) Two-Tailed T-Test.

$Response$	Y_E	Y_M	$D_i = Y_M - Y_E$	$D_A - D_i$	$(D_A - D_i)^2$
C1	2.3944	2.380311	-0.014089	-0.065560125	0.0043
C2	2.3878	2.384978	-0.002822	0.002822	8E-06
C3	2.511378	2.339914	-0.171464	0.171464	0.0294
C4	2.49074	2.482097	-0.008643	0.008643	7E-05
C5	2.483556	2.343402	-0.140154	0.140154	0.0196
C6	2.414007	2.377738	-0.036269	0.036269	0.0013
C7	2.58119	2.334209	-0.246981	0.246981	0.061
C8	2.40222	2.385449	-0.016771	0.016771	0.0003
		$\sum D_i$	-0.637193	$\sum(D_A - D_i)^2$	0.116
		$D_A = \sum D_i/N$	-0.079649125	$S^2 = \sum(D_A - D_i)^2/(N -$	0.0166
				$S = \sqrt{S^2}$	0.1287
				$T = D_A \times N^{0.5}/S$	1.75

t from the table (Appendix F) is given as $t_\alpha(V) = t_{0.05(7)} = 1.893$, and calculated $t = 1.75$.

Therefore, t from the table is higher than t calculated; so the difference between the lab result and the model result is insignificant. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.46 Residual for Flexural Strength(Ibearugbulem Model for Quary Dust Concrete)

Obs	lab	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI
1	2.3944	2.4575	0.0256	(2.3947; 2.5202)	-0.0631	-0.93	-0.92	0.125208
2	2.3878	2.4557	0.0259	(2.3923; 2.5190)	-0.0679	-1.00	-1.00	0.127697
3	2.5114	2.4730	0.0341	(2.3896; 2.5563)	0.0384	0.60	0.57	0.221077
4	2.4907	2.4185	0.0655	(2.2582; 2.5787)	0.0723	2.33	6.94	0.816840
5	2.4836	2.4716	0.0328	(2.3915; 2.5518)	0.0119	0.18	0.17	0.204490
6	2.4140	2.4585	0.0256	(2.3958; 2.5211)	-0.0444	-0.66	-0.62	0.125038
7	2.5812	2.4751	0.0363	(2.3862; 2.5641)	0.1060	1.69	2.14	0.251546
8	2.4022	2.4555	0.0259	(2.3921; 2.5190)	-0.0533	-0.79	-0.76	0.128103

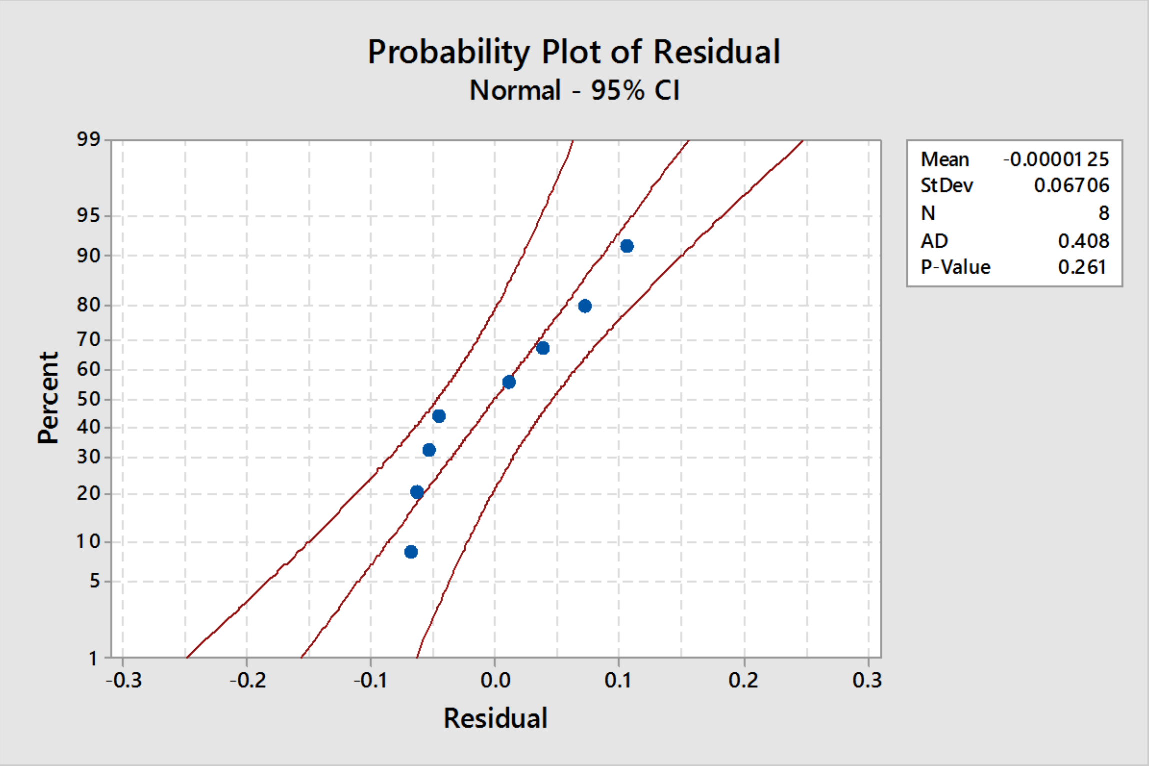

Fig 4.10 Normal Distribution plot for 28 days Flexural Strength

(Ibearugbulem Model for Quarry Dust Concrete)

From the normal distribution plot (Fig. 4.10) it can be seen that p-value is greater than 0.05 (p-value = 0.261 > 0.05). There is no significant difference between the laboratory results and the model results, so the Null Hypothesis is accepted. The Ibearugbulem's regression equation can be used to predict 28th day flexural strength of concrete made with quarry dust as fine aggregate.

4.6.8 Ibearugbulems Model for River Sand Concrete

$$F(z) = \propto_1 z_1 + \propto_2 z_2 + \propto_3 z_3 + \propto_4 z_4 + \propto_{12} z_1z_2 + \propto_{13} z_1z_3 + \propto_{14} z_1z_4 + \propto_{23} z_2z_3 + \propto_{24} z_2z_4 + \propto_{34} z_3z_4 + \propto_{123} z_1z_2z_3 + \propto_{124} z_1z_2z_4 + \propto_{234} z_2z_3z_4 + \propto_{1234} z_1z_2z_3z_4$$

To write the Ibearugbulem model for Quarry Dust Concrete the values of the coefficients of the Regression $\propto_1, \propto_2, \dots\dots\dots\dots\dots\dots\dots\dots, \propto_{1234}$ is generated by substituting the values of the compressive strengths in Table 4.15 into equation 3.127. After the computation the values are as given below;

$\propto_1 = -34.6155$, $\propto_2 = 25.7696, \propto_3 = -12.8686$, $\propto_4 = -10.8263$,
$\propto_{12} = 19.47503$ $\propto_{13} = -62.6107, \propto_{14} = 78.48002$, $\propto_{23} = 29.56732$,
$\propto_{24} = -22.7971$, $\propto_{34} = 60.30403$ $\propto_{123} = 61.52335$,
$\propto_{124} = 54.58375$, $\propto_{234} = 89.92496$, $\propto_{1234} = 89.43309$

$$F(z) = -34.6155z_1 + 25.7696z_2 - 12.8686z_3 - 10.8263z_4 + 19.47503z_1z_2 - 62.6107z_1z_3 + 78.48002z_1z_4 + 29.56732z_2z_3 - 22.7971z_2z_4 + 60.30403z_3z_4 + 61.52335z_1z_2z_3 + 54.58375z_1z_2z_4 + 89.92496z_2z_3z_4 + 89.43309z_1z_2z_3z_4 \quad (4.8)$$

Table 4.47 F-Statistical Test for Ibearugbulems Model for River Sand Concrete (Flexural Strength)

$LEGEND$: $\ddot{Y}_P = \sum Y_P/N$, $\ddot{Y}_M = \sum Y_M/N$, where $N = 8$

$Response$	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	4.4324	4.243532	-0.458	-0.057	0.209764	0.003249
C2	3.3338	4.023856	0.872	1.662	0.760384	2.762244
C3	3.8178	3.736453	-0.16	0.203	0.0256	0.041209
C4	2.724	3.914009	-0.959	-0.139	0.919681	0.019321
C5	3.5436	3.421095	-0.253	-0.783	0.064009	0.613089
C6	3.4947	4.129371	-0.354	-0.056	0.125316	0.003136
C7	4.3809	4.086894	-0.454	0.049	0.206116	0.002401
C8	3.4209	3.423168	1.766	-0.879	3.118756	0.772641
Total	23.144	23.984			5.429626	4.21729
Mean	2.893	2.998				

$$S_P^2 = \frac{\sum(Y_P - \ddot{Y}_P)^2}{N-1} = \frac{5.429626}{7} = 0.31708129$$

$$S_M^2 = \frac{\sum(Y_M - \ddot{Y}_M)^2}{N-1} = \frac{4.21729}{7} = 0.09977401$$

S_1^2 is the greater of S_P^2 and S_M^2, and S_2^2 is the smaller of the two values. So $S_1^2 = 0.31708129 S_2^2 = 0.09977401$. The $F_{calculated} = S_1^2/S_2^2 = 0.31708129/0.09977401 = 3.17799488$

From statistical tables $(V_1, V_2) = t_\alpha(7,7)$, from Appendix G, $F_{0.05(7,7)} = 3.79$. $1/F_{table} = 1/3.79 = 0.264$. The Null Hypothesis will be accepted if $1/F_{table} < F_{calculated} < F_{table}$;

$0.264 < 3.177995 < 3.79$. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.48 Student-Statistical T-Test for Ibearugbulems Model for River Sand Concrete (Flexural Strength) Two-Tailed T-Test

$Response$	Y_M	Y_E	$D_i = Y_M - Y_E$	$D_A - D_i$	$(D_A - D_i)^2$
C1	4.243532	4.4324	-0.188868	0.41765275	0.1744
C2	4.023856	3.3338	0.690056	-0.690056	0.4762
C3	3.736453	3.8178	-0.081347	0.081347	0.0066
C4	3.914009	2.724	1.190009	-1.190009	1.4161
C5	3.421095	3.5436	-0.122505	0.122505	0.015
C6	4.129371	3.4947	0.634671	-0.634671	0.4028
C7	4.086894	4.3809	-0.294006	0.294006	0.0864
C8	3.423168	3.4209	0.002268	-0.002268	5E-06
		$\sum D_i$	1.830278	$\sum(D_A - D_i)^2$	2.5776
		$D_A = \sum D_i/N$	0.22878475	$S^2 = \sum(D_A - D_i)^2/(N -$	0.3682
				$S = \sqrt{S^2}$	0.6068
				$T = D_A \times N^{0.5}/S$	1.0664

t from the table (Appendix F) is given as $t_{\alpha}(V) = t_{0.05(7)} = 1.893$, and calculated $t = 1.0664$.

Therefore, t from the table is higher than t calculated; so the difference between the lab result and the model result is insignificant. The Null Hypothesis is accepted and the model is adequate for use.

Table 4.49 Residual for Flexural Strength(Ibearugbulem Model for River Sand Concrete)

Obs	lab	Fit	SE Fit	95% CI	Resid	Std Resid	Del Resid	HI
1	4.432	3.882	0.322	(3.094; 4.670)	0.550	1.18	1.23	0.322325
2	3.334	3.741	0.225	(3.189; 4.293)	-0.407	-0.78	-0.75	0.157891
3	3.818	3.556	0.221	(3.016; 4.096)	0.262	0.50	0.47	0.151424
4	2.724	3.670	0.203	(3.175; 4.166)	-0.946	-1.79	-2.38	0.127491
5	3.544	3.353	0.366	(2.458; 4.249)	0.190	0.44	0.41	0.416489
6	3.495	3.809	0.266	(3.158; 4.459)	-0.314	-0.63	-0.59	0.219624
7	4.381	3.781	0.248	(3.175; 4.388)	0.599	1.17	1.22	0.190935
8	3.421	3.355	0.365	(2.462; 4.248)	0.066	0.15	0.14	0.413821

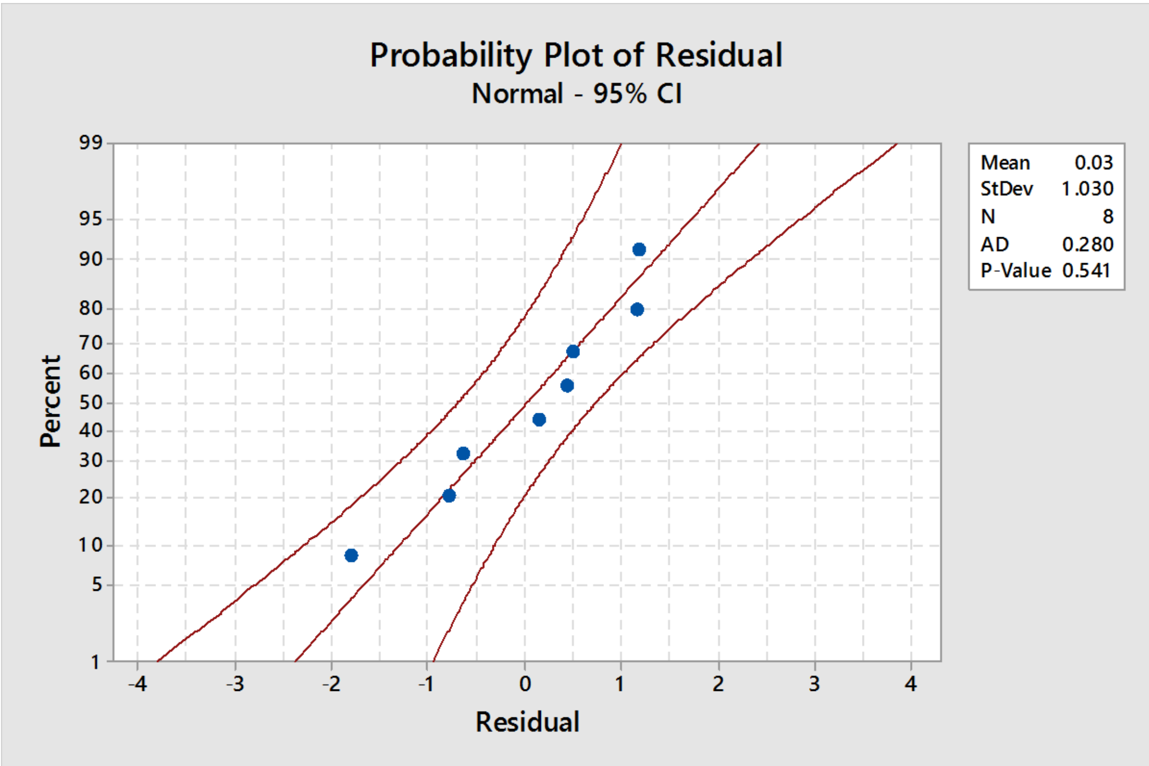

Fig 4.11 Normal Distribution plot for 28 days Flexural Strength

(Ibearugbule Model for River sand Concrete)

From the normal distribution plot (Fig. 4.11) it can be seen that p-value is greater than 0.05 (p-value = 0.541 > 0.05). There is no significant difference between the laboratory results and the model results, so the Null Hypothesis is accepted. The Ibearugbulem's regression equation can be used to predict 28th day flexural strength of concrete made with river sand as fine aggregate.

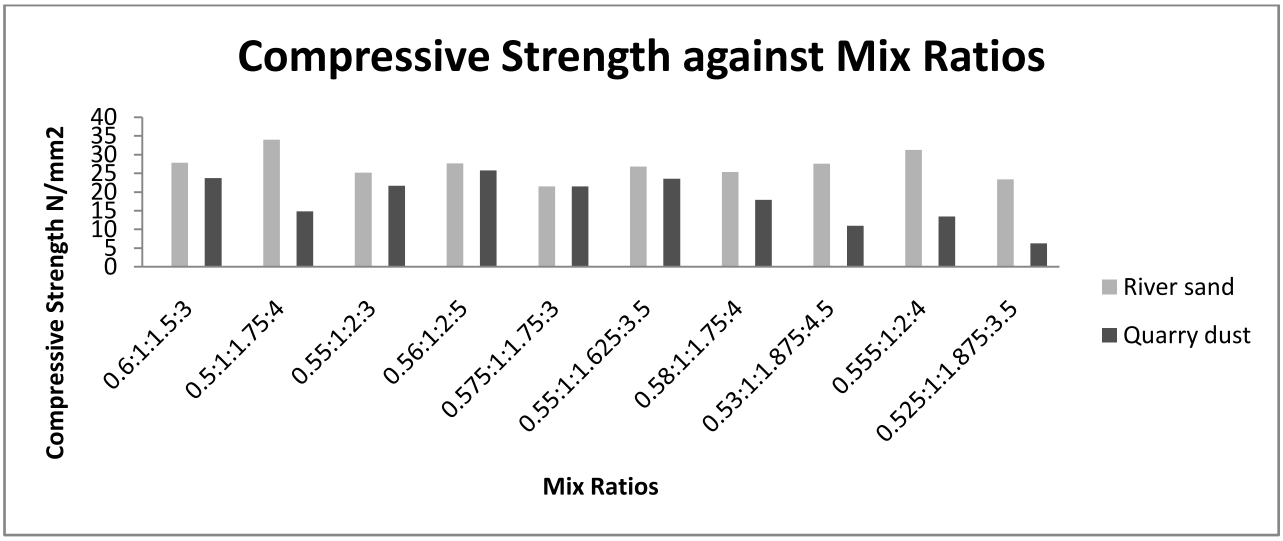

Fig 4.12 Bar chart of compressive strength versus mix proportion for concrete made with river sand and that made with quarry dust.

Fig. 4.12 shows that the bar chart shows that concrete made with quarry dust as fine aggregate has a compressive strength of 25.76N/mm^2 at a mix ratio of 1:1:2.5 and w/c of 0.56. The concrete made with river sand as fine aggregate has the highest compressive strength of 34.0N/mm^2 at mix ratio of 1:1.75:4 and w/c 0.5. The quarry dust concrete and river sand concrete has the same compressive strength of 21.48N/mm^2 at mix ratio of 1:1.75:3 at w/c ratio of 0.575

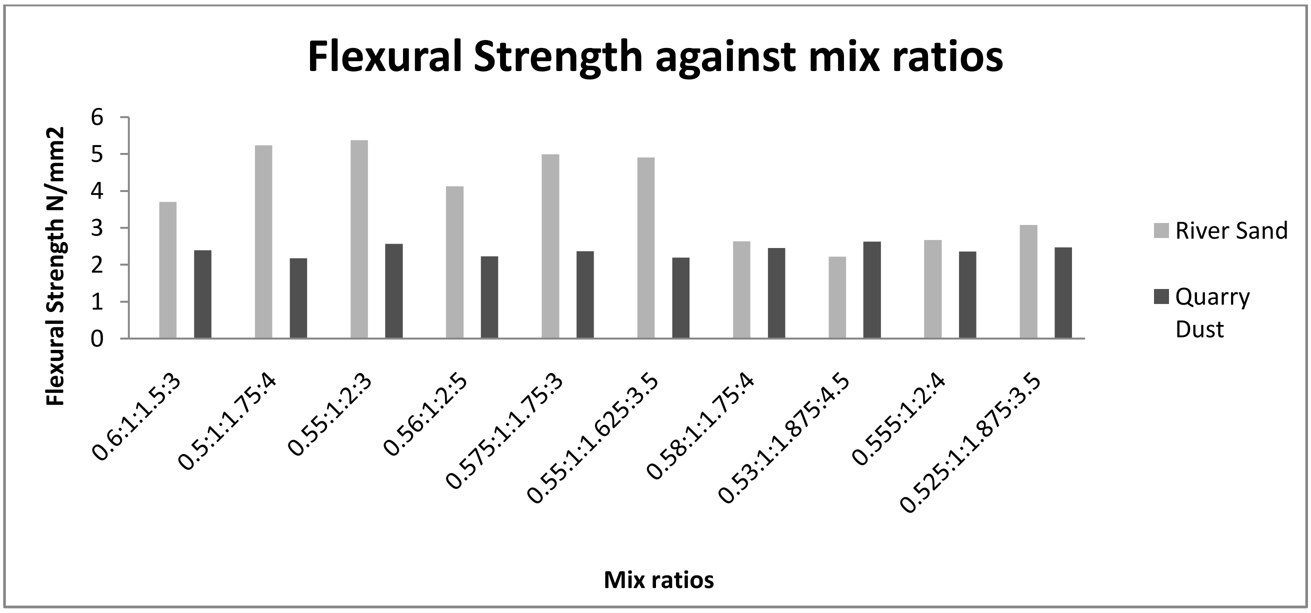

Fig 4.13 Bar chart of flexural strength versus mix proportion for concrete made with river sand and that made with quarry dust.

Fig. 4.13 shows that the bar chart shows that concrete made with quarry dust as fine aggregate has the highest compressive strength of 2.63111N/mm^2 at a mix ratio of 1:1.875:4.5 and w/c of 0.53. The concrete made with river sand as fine aggregate has the highest compressive strength of 5.375111N/mm^2 at a mix ratio of 1:2:3 and w/c of 0.55.

Table 4.50 Comparing the compressive strength results between Ibearugbulem and Osadebe models for Concrete made with Quarry dust as fine aggregate.

S/N	Points of observation points	Ibearugbulem Model compressive strength (N/mm^2)	Osadebe's Model compressive strength (N/mm^2)	Difference between Ibearugbulem Model and Osadebe's model	Percentage error (%)
1	Qc_1	19.6	19.254	-0.346	-1.76531
2	Qc_2	20.13	16.178	-3.952	-19.6324
3	Qc_3	19.87	17.201	-2.669	-13.4323
4	Qc_4	17.87	14.851	-3.019	-16.8942
5	Qc_{12}	17.87	15.147	-2.723	-15.2378
6	Qc_{13}	17.33	11.352	-5.978	-34.4951
7	Qc_{14}	21.68	25.015	3.335	15.38284
8	Qc_{23}	16.47	18.208	1.738	10.55252

From the table 4.50 above it can be observe that the highest percentage error is 34.4951%, this means that the 65.5049% of that results is in agreement with each other. Hence it can be seen that the difference between Ibearugbulem and Osadebe's models is insignificant since up to 65.5049% of the results are in agreement with each other.

Table 4.51 Comparing the compressive strength results between Ibearugbulem and Osadebe models for Concrete made with River sand as fine aggregate

S/N	Points of observation points	Ibearugbulem Model compressive results (N/mm^2)	Osadebe's model compressive strength (N/mm^2)	Difference between Ibearugbulem Model and Osadebe's model	Percentage error (%)
1	Sc_1	26.14	22.439	-3.701	-14.1584
2	Sc_2	26.4	25.102	-1.298	-4.91667
3	Sc_3	27.51	25.061	-2.449	-8.90222
4	Sc_4	27.27	25.047	-2.223	-8.15182
5	Sc_{12}	28.49	25.633	-2.857	-10.0281
6	Sc_{13}	27.05	23.956	-3.094	-11.4381
7	Sc_{14}	26.44	26.016	-0.424	-1.60363
8	Sc_{23}	28.45	30.284	1.834	6.446397

From the table in fig. 4.52 above it can be observe that the highest percentage error is 14.1584 %, this means that the 85.8416% of the results is in agreement with each other. Hence it can be seen that the difference between Ibearugbulem and Osadebe's models is insignificant since up to 85.8416% of the results are in agreement with each other.

Table 4.52 Comparing the flexural strength results between Ibearugbulem and Osadebe models for Concrete made with Quarry dust as fine aggregate

S/N	Points of observation points	Ibearugbulem's Model compressive results (N/mm^2)	Osadebe's model compressive strength (N/mm^2)	Difference between Ibearugbulem's Model and Osadebe's model	Percentage error (%)
1	Qc_1	2.3803	2.3095	-0.07081	-3.06603
2	Qc_2	2.385	2.4153	0.03032	1.255331
3	Qc_3	2.3399	2.4746	0.13469	5.4429
4	Qc_4	2.4821	2.4794	-0.0027	-0.1089
5	Qc_{12}	2.3434	2.5342	0.1908	7.529003
6	Qc_{13}	2.3777	2.3122	-0.06554	-2.83453
7	Qc_{14}	2.3342	2.2631	-0.07111	-3.14215
8	Qc_{23}	2.3855	2.279	-0.10645	-4.67091

From the table in fig. 4.52 it can be observe that the highest percentage error is 7.529003%, this means that the 92.471% of the results is in agreement with each other. Hence it can be seen that the difference between Ibearugbulem and Osadebe models is insignificant since up to 92.471% of the results are in agreement with each other.

Table 4.53 Comparing the flexural strength results between Ibearugbulem and Osadebe models for Concrete made with River sand as fine aggregate.

S/N	Points of observation points	Ibearugbulem's Model compressive results (N/mm^2)	Osadebe's model compressive strength (N/mm^2)	Difference between Ibearugbulem's Model Osadebe's model	Percentage error (%)
1	Sc_1	4.2435	4.2903	0.046768	1.090087
2	Sc_2	4.0239	3.0465	0.046768	1.535139
3	Sc_3	3.7365	2.8413	0.046768	1.646007
4	Sc_4	3.914	2.584	0.046768	1.809907
5	Sc_{12}	3.4211	2.4591	0.046768	1.901834
6	Sc_{13}	4.1294	4.0166	0.046768	1.164368

7	Sc_{14}	4.0869	4.4323	0.046768	1.055163
8	Sc_{23}	3.4232	3.0898	0.046768	1.513625

From the table in fig. 4.54 above it can be observe that the highest percentage error is 1.901834 %, this means that the 98.098% of those results is in agreement with each other. Hence it can be seen that the difference between Ibearugbulem and Osadebe model is insignificant since up to 98.098% of the results are in agreement with each other.

4.7 Computer Programs

Computer programmes each were written based on Osadebe's regression model and Ibearugbulem's regression model in Visual-Basic 6, for concrete made with river sand as fine aggregate and that made with quarry dust as fine aggregate. Osadebe's regression model and Ibearugbulem's regression model were tested (the lab results against the model results), using the Students T-test, F-distribution test, Error of replica and Normal Probability plot as shown in Table 4.26 to Table 4.53 and figure 4.4 to 4.11. It was proved that the null hypothesis is acceptable, for the normal probability plot it was seen that all the p-values were greater than 0.05. Hence all the models were adequate for use to predict the 28 days compressive strength/flexural strength of concrete. The computer programmes written were to execute the models so generated. This will prompt in a user friendly manner for an input of the desired strength and will then proceed to print all possible combination of the pseudo and true component that will match the strength configuration within a tolerance of $\pm 0.001\, N/mm^2$. The computer will inform the user whenever there is no any match combination. The computer program for Osadebe's optimization model and Ibearugbulem's model are as shown in Appendix A10 to A17 respectively.

The Normal Probability plots were done with MINITAB 17 to generate the residual values which were used to plot the **Normal Probability Plot of Response** of the laboratory results and the model results. This is done to verify if the relationship between the two (laboratory and model results) were within the acceptable limit of $p \geq 0.05$.

4.8 MIXES GENERATED USING MINITAB 17

4.8.1 Development of the CCD Matrix using Minitab 17

The CCD Matrix is developed by the software (Minitab 17) using the initial mix ratios, the CCD Matrix is based on 4 components of the mixture(concrete) namely; water, cement, fine aggregate and coarse aggregate, and this give rise to 30 mix ratios.

Table 4.54 CCD Matrix

StdOrder	RunOrder	PtType	Blocks	X_1	X_2	X_3	X_4
1	1	1	1	0.550	1.0000	2.00	4.00
2	2	1	1	0.600	0.9990	1.50	3.00
3	3	1	1	0.500	1.0000	2.00	5.00
4	4	1	1	0.600	1.0000	1.50	3.00
5	5	1	1	0.500	0.9990	2.00	3.00
6	6	1	1	0.550	0.9990	1.75	4.00
7	7	1	1	0.500	1.0000	2.00	3.00
8	8	1	1	0.600	1.0000	1.60	3.00
9	9	1	1	0.555	0.9990	1.75	4.75
10	10	1	1	0.550	0.9990	2.00	3.50
11	11	1	1	0.600	1.0000	1.50	4.00
12	12	1	1	0.600	1.0000	1.50	4.00
13	13	1	1	0.500	0.9990	2.00	5.00
14	14	1	1	0.600	0.9990	2.00	5.00
15	15	1	1	0.500	1.0000	2.00	5.00
16	16	1	1	0.600	1.0000	1.50	3.50
17	17	0	1	0.550	0.9995	1.75	4.00
18	18	0	1	0.550	0.9995	1.75	4.00
19	19	0	1	0.550	0.9995	1.75	4.00
20	20	0	1	0.550	0.9995	1.75	4.00
21	21	-1	2	0.550	0.9995	1.75	4.00
22	22	-1	2	0.600	0.9995	1.75	4.00
23	23	-1	2	0.550	0.9985	1.75	4.00
24	24	-1	2	0.550	1.0000	1.75	4.00
25	25	-1	2	0.550	0.9995	2.00	4.00
26	26	-1	2	0.550	0.9995	2.00	4.00
27	27	-1	2	0.550	0.9995	1.75	5.00
28	28	-1	2	0.550	0.9995	1.75	5.00
29	29	0	2	0.550	0.9995	1.75	4.00
30	30	0	2	0.550	0.9995	1.75	4.00

Where X_1, X_2, X_3, and X_4 represent the ratios of water, cement, fine aggregate and coarse aggregate in the mix respectively.

Cubes were cast based on the mix ratios generated by the software (Minitab 17). A total of 180 cubes (150mm by 150mm by 150mm) were cast for cubes to be used to determine the compressive strength of concrete made with river sand and that made with quarry dust as fine aggregate (90 cubes for each fine aggregate). Also a total of 180 cubes (150mm by 150mm by 500mm) were cast for concrete made with river sand and that made with quarry dust for the determination of flexural strength (90 cubes for each fine aggregate).

Table 4.55 Compressive Strength of concrete made with River sand based on CCD Matrix

S/NO	TAG NO (SAND)	MIX RATIO	MASS(kg)	VOLUME OF MOULD (m^3)	DENSITY (kg/m^3)	CRUSHING LOAD (kN)	COMPRESSIVE STRENGTH (N/mm^2)	MEAN COMPRESSIVE STRENGTH (N/mm^2)
1	S1	0.55:1:2:4	8.50	0.003375	2519	688.98	30.62	
2	S1	0.55:1:2:5	8.82	0.003375	2613	680.86	30.26	
3	S1	0.55:1:2:6	8.65	0.003375	2563	700.94	31.15	30.68
4	S2	0.60:1:1.5:3	8.30	0.003375	2459	620.44	27.58	
5	S2	0.60:1:1.5:3	8.45	0.003375	2504	628.22	27.92	
6	S2	0.60:1:1.5:3	8.54	0.003375	2530	630.22	28.01	27.84
7	S3	0.5:1:2:5	8.55	0.003375	2533	710.46	31.58	
8	S3	0.5:1:2:5	8.85	0.003375	2622	704.22	31.30	
9	S3	0.5:1:2:5	8.7	0.003375	2578	712.44	31.66	31.51
10	S4	0.6:1:1.5:3	8.90	0.003375	2637	620.44	27.58	
11	S4	0.6:1:1.5:3	8.65	0.003375	2563	628.22	27.92	
12	S4	0.6:1:1.5:3	8.79	0.003375	2604	630.22	28.01	27.84
13	S5	0.5:1:2:3	8.50	0.003375	2519	357.43	15.89	
14	S5	0.5:1:2:3	8.70	0.003375	2578	342.68	15.23	
15	S5	0.5:1:2:3	8.61	0.003375	2551	350.13	15.56	15.56
16	S6	0.55:1:1.75:4	8.50	0.003375	2519	586.89	26.08	
17	S6	0.55:1:1.75:4	8.55	0.003375	2533	578.22	25.70	
18	S6	0.55:1:1.75:4	8.65	0.003375	2563	570.05	25.34	25.71
19	S7	0.5:1:2:3	8.50	0.003375	2519	357.43	15.89	
20	S7	0.5:1:2:3	8.70	0.003375	2578	342.68	15.23	
21	S7	0.5:1:2:3	8.61	0.003375	2551	350.13	15.56	15.56
22	S8	0.6:1:1.6:3	8.25	0.003375	2444	572.88	25.46	
23	S8	0.6:1:1.6:3	8.35	0.003375	2474	576.11	25.60	
24	S8	0.6:1:1.6:3	8.4	0.003375	2489	574.89	25.55	25.54
25	S9	0.56:1:1.75:4.75	8.30	0.003375	2459	541.12	24.05	
26	S9	0.56:1:1.75:4.75	8.45	0.003375	2504	546.27	24.28	
27	S9	0.56:1:1.75:4.75	8.55	0.003375	2533	540.22	24.01	24.11
28	S10	0.56:1:2:3	8.65	0.003375	2563	658.43	29.26	
29	S10	0.56:1:2:3	8.60	0.003375	2548	679.68	30.21	
30	S10	0.56:1:2:3	8.75	0.003375	2593	665.13	29.56	29.68
31	S11	0.6:1:1.5:4	9.35	0.003375	2770	605.96	26.93	
32	S11	0.6:1:1.5:4	9.10	0.003375	2696	601.86	26.75	
33	S11	0.6:1:1.5:4	9.22	0.003375	2732	601.96	26.75	26.81
34	S12	0.6:1:1.5:4	9.35	0.003375	2770	605.96	26.93	
35	S12	0.6:1:1.5:4	9.10	0.003375	2696	601.86	26.75	
36	S12	0.6:1:1.5:4	9.22	0.003375	2732	601.96	26.75	26.81
37	S13	0.5:1:2:5	8.55	0.003375	2533	710.46	31.58	
38	S13	0.5:1:2:5	8.85	0.003375	2622	704.22	31.30	
39	S13	0.5:1:2:5	8.7	0.003375	2578	712.44	31.66	31.51
40	S14	0.6:1:2:5	9.00	0.003375	2667	675.98	30.04	
41	S14	0.6:1:2:5	8.98	0.003375	2661	686.86	30.53	
42	S14	0.6:1:2:5	8.8	0.003375	2607	710.94	31.60	30.72
43	S15	0.5:1:2:5	8.55	0.003375	2533	710.46	31.58	

44	S15	0.5:1:2:5	8.85	0.003375	2622	704.22	31.30	
45	S15	0.5:1:2:5	8.7	0.003375	2578	712.44	31.66	31.51
46	S16	0.6:1:1.5:3.5	8.55	0.003375	2533	635.95	28.26	
47	S16	0.6:1:1.5:3.5	8.60	0.003375	2548	648.06	28.80	
48	S16	0.6:1:1.5:3.5	8.65	0.003375	2563	642.76	28.57	28.54
49	S17	0.55:1:1.75:4	8.50	0.003375	2519	588.89	26.17	
50	S17	0.55:1:1.75:4	8.55	0.003375	2533	579.62	25.76	
51	S17	0.55:1:1.75:4	8.65	0.003375	2563	568.85	25.28	25.74
52	S18	0.55:1:1.75:4	8.50	0.003375	2519	588.89	26.17	
53	S18	0.55:1:1.75:4	8.55	0.003375	2533	579.62	25.76	
54	S18	0.55:1:1.75:4	8.65	0.003375	2563	568.85	25.28	25.74
55	S19	0.55:1:1.75:4	8.50	0.003375	2519	588.89	26.17	
56	S19	0.55:1:1.75:4	8.55	0.003375	2533	579.62	25.76	
57	S19	0.55:1:1.75:4	8.65	0.003375	2563	568.85	25.28	25.74
58	S20	0.55:1:1.75:4	8.50	0.003375	2519	588.89	26.17	
59	S20	0.55:1:1.75:4	8.55	0.003375	2533	579.62	25.76	
60	S20	0.55:1:1.75:4	8.65	0.003375	2563	568.85	25.28	25.74
61	S21	0.55:1:1.75:4	8.50	0.003375	2519	588.89	26.17	
62	S21	0.55:1:1.75:4	8.55	0.003375	2533	579.62	25.76	
63	S21	0.55:1:1.75:4	8.65	0.003375	2563	568.85	25.28	25.74
64	S22	0.55:1:1.75:4	9.20	0.003375	2726	611.22	27.17	
65	S22	0.55:1:1.75:4	8.80	0.003375	2607	606.06	26.94	
66	S22	0.55:1:1.75:4	9.05	0.003375	2681	601.32	26.73	26.94
67	S23	0.55:1:1.75:4	8.50	0.003375	2519	578.89	25.73	
68	S23	0.55:1:1.75:4	8.55	0.003375	2533	574.22	25.52	
69	S23	0.55:1:1.75:4	8.65	0.003375	2563	580.05	25.78	25.68
70	S24	0.55:1:1.75:4	8.50	0.003375	2519	583.89	25.95	
71	S24	0.55:1:1.75:4	8.55	0.003375	2533	571.22	25.39	
72	S24	0.55:1:1.75:4	8.65	0.003375	2563	583.05	25.91	25.75
73	S25	0.55:1:2:4	8.75	0.003375	2593	679.33	30.19	
74	S25	0.55:1:2:4	8.99	0.003375	2664	697.29	30.99	
75	S25	0.55:1:2:4	9.08	0.003375	2690	701.12	31.16	30.78
76	S26	0.55:1:2:4	8.75	0.003375	2593	679.33	30.19	
77	S26	0.55:1:2:4	8.99	0.003375	2664	697.29	30.99	
78	S26	0.55:1:2:4	9.08	0.003375	2690	701.12	31.16	30.78
79	S27	0.55:1:1.75:5	8.75	0.003375	2593	548.23	24.37	
80	S27	0.55:1:1.75:5	8.62	0.003375	2554	529.78	23.55	
81	S27	0.55:1:1.75:5	8.55	0.003375	2533	525.67	23.36	23.76
82	S28	0.55:1:1.75:5	8.75	0.003375	2593	548.23	24.37	
83	S28	0.55:1:1.75:5	8.62	0.003375	2554	529.78	23.55	
84	S28	0.55:1:1.75:5	8.55	0.003375	2533	525.67	23.36	23.76
85	S29	0.55:1:1.75:4	8.50	0.003375	2519	569.69	25.32	
86	S29	0.55:1:1.75:4	8.55	0.003375	2533	579.99	25.78	
87	S29	0.55:1:1.75:4	8.65	0.003375	2563	590.35	26.24	25.78
88	S30	0.55:1:1.75:4	8.50	0.003375	2519	569.69	25.32	
89	S30	0.55:1:1.75:4	8.55	0.003375	2533	579.99	25.78	
90	S30	0.55:1:1.75:4	8.65	0.003375	2563	590.35	26.24	25.78

Table 4.56 Flexural Strength of concrete made with River sand based on CCD Matrix

S/NO	TAG NO (SAND)	MIX RATIO	MASS (kg)	VOLUME OF MOULD (m3)	DENSITY (kg/m3)	CRUSHING LOAD (kN)	FLEXURAL STRENGTH (N/mm^2)	MEAN FLEXURAL STRENGTH (N/mm^2)
1	S1	0.55:1:2:4	28.93	0.01125	2571.85	25.49	3.78	
2	S1	0.55:1:2:5	30.00	0.01125	2666.66	26.23	3.89	
3	S1	0.55:1:2:6	29.43	0.01125	2616.29	24.03	3.56	3.74
4	S2	0.60:1:1.5:3	28.27	0.01125	2512.59	25.52	3.78	
5	S2	0.60:1:1.5:3	28.77	0.01125	2557.03	23.81	3.53	
6	S2	0.60:1:1.5:3	29.07	0.01125	2583.70	24.06	3.56	3.62
7	S3	0.5:1:2:5	29.10	0.01125	2586.66	36.79	5.45	
8	S3	0.5:1:2:5	30.10	0.01125	2675.55	38.88	5.76	
9	S3	0.5:1:2:5	29.60	0.01125	2631.11	39.42	5.84	5.68
10	S4	0.6:1:1.5:3	30.27	0.01125	2690.37	25.79	3.82	
11	S4	0.6:1:1.5:3	29.43	0.01125	2616.29	23.93	3.54	
12	S4	0.6:1:1.5:3	29.90	0.01125	2657.78	25.31	3.75	3.70
13	S5	0.5:1:2:3	28.93	0.01125	2571.85	29.77	4.41	
14	S5	0.5:1:2:3	29.60	0.01125	2631.11	28.55	4.23	
15	S5	0.5:1:2:3	29.30	0.01125	2604.44	30.44	4.51	4.65
16	S6	0.55:1:1.75:4	28.93	0.01125	2571.85	17.82	2.64	
17	S6	0.55:1:1.75:4	29.10	0.01125	2586.66	18.77	2.78	
18	S6	0.55:1:1.75:4	29.43	0.01125	2616.29	18.09	2.68	2.69
19	S7	0.5:1:2:3	28.93	0.01125	2571.85	30.44	4.51	
20	S7	0.5:1:2:3	29.60	0.01125	2631.11	32.33	4.79	
21	S7	0.5:1:2:3	29.30	0.01125	2604.44	31.93	4.73	4.71
22	S8	0.6:1:1.6:3	28.10	0.01125	2497.78	26.73	3.96	
23	S8	0.6:1:1.6:3	28.43	0.01125	2527.40	25.31	3.75	
24	S8	0.6:1:1.6:3	28.60	0.01125	2542.22	25.72	3.81	3.84
25	S9	0.56:1:1.75:4.75	28.27	0.01125	2512.59	23.15	3.43	
26	S9	0.56:1:1.75:4.75	28.77	0.01125	2557.03	23.87	3.54	
27	S9	0.56:1:1.75:4.75	29.10	0.01125	2586.66	21.80	3.23	3.40
28	S10	0.56:1:2:3	29.43	0.01125	2616.29	22.48	3.33	
29	S10	0.56:1:2:3	29.27	0.01125	2601.48	20.45	3.03	
30	S10	0.56:1:2:3	29.77	0.01125	2645.92	21.06	3.12	3.16
31	S11	0.6:1:1.5:4	31.77	0.01125	2823.70	18.02	2.67	
32	S11	0.6:1:1.5:4	30.93	0.01125	2749.63	18.43	2.73	
33	S11	0.6:1:1.5:4	31.33	0.01125	2785.18	19.44	2.88	2.76
34	S12	0.6:1:1.5:4	31.77	0.01125	2823.70	18.02	2.67	
35	S12	0.6:1:1.5:4	30.93	0.01125	2749.63	18.43	2.73	
36	S12	0.6:1:1.5:4	31.33	0.01125	2785.18	19.44	2.88	2.76
37	S13	0.5:1:2:5	29.10	0.01125	2586.66	36.79	5.45	
38	S13	0.5:1:2:5	30.10	0.01125	2675.55	38.88	5.76	
39	S13	0.5:1:2:5	29.60	0.01125	2631.11	39.42	5.84	5.68
40	S14	0.6:1:2:5	30.60	0.01125	2720.00	36.99	5.48	
41	S14	0.6:1:2:5	30.53	0.01125	2714.07	37.60	5.57	
42	S14	0.6:1:2:5	29.93	0.01125	2660.74	36.38	5.39	5.48
43	S15	0.5:1:2:5	29.10	0.01125	2586.66	36.79	5.45	
44	S15	0.5:1:2:5	30.10	0.01125	2675.55	38.88	5.76	

45	S15	0.5:1:2:5	29.60	0.01125	2631.11	39.42	5.84	5.68
46	S16	0.6:1:1.5:3.5	29.10	0.01125	2586.66	19.37	2.87	
47	S16	0.6:1:1.5:3.5	29.27	0.01125	2601.48	19.17	2.84	
48	S16	0.6:1:1.5:3.5	29.43	0.01125	2616.29	20.39	3.02	2.91
49	S17	0.55:1:1.75:4	28.93	0.01125	2571.85	18.97	2.81	
50	S17	0.55:1:1.75:4	29.10	0.01125	2586.66	17.75	2.63	
51	S17	0.55:1:1.75:4	29.43	0.01125	2616.29	18.16	2.69	2.71
52	S18	0.55:1:1.75:4	28.93	0.01125	2571.85	18.97	2.81	
53	S18	0.55:1:1.75:4	29.10	0.01125	2586.66	17.75	2.63	
54	S18	0.55:1:1.75:4	29.43	0.01125	2616.29	18.16	2.69	2.71
55	S19	0.55:1:1.75:4	28.93	0.01125	2571.85	18.97	2.81	
56	S19	0.55:1:1.75:4	29.10	0.01125	2586.66	17.75	2.63	
57	S19	0.55:1:1.75:4	29.43	0.01125	2616.29	18.16	2.69	2.71
58	S20	0.55:1:1.75:4	28.93	0.01125	2571.85	18.97	2.81	
59	S20	0.55:1:1.75:4	29.10	0.01125	2586.66	17.75	2.63	
60	S20	0.55:1:1.75:4	29.43	0.01125	2616.29	18.16	2.69	2.71
61	S21	0.55:1:1.75:4	28.93	0.01125	2571.85	18.97	2.81	
62	S21	0.55:1:1.75:4	29.10	0.01125	2586.66	17.75	2.63	
63	S21	0.55:1:1.75:4	29.43	0.01125	2616.29	18.16	2.69	2.71
64	S22	0.55:1:1.75:4	31.27	0.01125	2779.26	21.40	3.17	
65	S22	0.55:1:1.75:4	29.93	0.01125	2660.74	21.87	3.24	
66	S22	0.55:1:1.75:4	30.77	0.01125	2734.81	20.72	3.07	3.16
67	S23	0.55:1:1.75:4	28.93	0.01125	2571.85	18.29	2.71	
68	S23	0.55:1:1.75:4	29.10	0.01125	2586.66	18.90	2.80	
69	S23	0.55:1:1.75:4	29.43	0.01125	2616.29	17.28	2.56	2.68
70	S24	0.55:1:1.75:4	28.93	0.01125	2571.85	18.16	2.69	
71	S24	0.55:1:1.75:4	29.10	0.01125	2586.66	18.43	2.73	
72	S24	0.55:1:1.75:4	29.43	0.01125	2616.29	18.50	2.74	2.72
73	S25	0.55:1:2:4	29.77	0.01125	2645.92	19.44	2.88	
74	S25	0.55:1:2:4	30.57	0.01125	2717.03	19.37	2.87	
75	S25	0.55:1:2:4	30.87	0.01125	2743.70	19.71	2.92	2.89
76	S26	0.55:1:2:4	29.77	0.01125	2645.92	19.44	2.88	
77	S26	0.55:1:2:4	30.57	0.01125	2717.03	19.37	2.87	
78	S26	0.55:1:2:4	30.87	0.01125	2743.70	19.71	2.92	2.89
79	S27	0.55:1:1.75:5	29.77	0.01125	2645.92	23.61	3.50	
80	S27	0.55:1:1.75:5	29.33	0.01125	2607.40	23.31	3.45	
81	S27	0.55:1:1.75:5	29.10	0.01125	2586.66	23.05	3.41	3.98
82	S28	0.55:1:1.75:5	29.77	0.01125	2645.92	23.61	3.50	
83	S28	0.55:1:1.75:5	29.33	0.01125	2607.40	23.31	3.45	
84	S28	0.55:1:1.75:5	29.10	0.01125	2586.66	23.05	3.41	3.98
85	S29	0.55:1:1.75:4	28.93	0.01125	2571.85	18.97	2.81	
86	S29	0.55:1:1.75:4	29.10	0.01125	2586.66	17.75	2.63	
87	S29	0.55:1:1.75:4	29.43	0.01125	2616.29	18.16	2.69	2.71
88	S30	0.55:1:1.75:4	28.93	0.01125	2571.85	18.97	2.81	
89	S30	0.55:1:1.75:4	29.10	0.01125	2586.66	17.75	2.63	
90	S30	0.55:1:1.75:4	29.43	0.01125	2616.29	18.16	2.69	2.71

Table 4.57 Compressive Strength of concrete made with Quarry dust based on CCD Matrix

S/NO	TAG NO (SAND)	MIX RATIO	MASS (kg)	VOLUME OF MOULD (m^3)	DENSITY(kg/m^3)	CRUSHING LOAD (kN)	COMPRESSIVE STRENGTH (N/mm^2)	MEAN COMPRESSIVE STRENGTH (N/mm^2)
1	Q1	0.55:1:2:4	8.30	0.003375	2459	264.872	11.7721	
2	Q1	0.55:1:2:5	8.65	0.003375	2563	256.336	11.3927	
3	Q1	0.55:1:2:6	8.42	0.003375	2495	299.592	13.3152	12.16
4	Q2	0.60:1:1.5:3	8.30	0.003375	2459	491.381	21.83914	
5	Q2	0.60:1:1.5:3	8.20	0.003375	2430	574.3	25.52445	
6	Q2	0.60:1:1.5:3	8.40	0.003375	2489	507.744	22.56641	23.31
7	Q3	0.5:1:2:5	8.40	0.003375	2489	608.3	27.03555	
8	Q3	0.5:1:2:5	8.40	0.003375	2489	520.471	23.13206	
9	Q3	0.5:1:2:5	8.50	0.003375	2519	537.804	23.90239	24.69
10	Q4	0.6:1:1.5:3	8.30	0.003375	2459	574.3	25.52445	
11	Q4	0.6:1:1.5:3	8.45	0.003375	2504	491.381	21.83914	
12	Q4	0.6:1:1.5:3	8.00	0.003375	2370	507.744	22.56641	23.31
13	Q5	0.5:1:2:3	8.35	0.003375	2474	528.721	23.4987	
14	Q5	0.5:1:2:3	8.10	0.003375	2400	452.382	20.10587	
15	Q5	0.5:1:2:3	8.20	0.003375	2430	467.447	20.77543	21.46
16	Q6	0.55:1:1.75:4	8.30	0.003375	2459	336.056	14.9358	
17	Q6	0.55:1:1.75:4	8.60	0.003375	2548	287.535	12.77932	
18	Q6	0.55:1:1.75:4	8.80	0.003375	2607	297.11	13.20488	13.64
19	Q7	0.5:1:2:3	8.35	0.003375	2474	467.447	20.77543	
20	Q7	0.5:1:2:3	8.10	0.003375	2400	452.382	20.10587	
21	Q7	0.5:1:2:3	8.20	0.003375	2430	528.721	23.4987	21.46
22	Q8	0.6:1:1.6:3	8.55	0.003375	2533	347.613	15.44948	
23	Q8	0.6:1:1.6:3	8.48	0.003375	2513	406.272	18.05655	
24	Q8	0.6:1:1.6:3	8.62	0.003375	2554	359.189	15.96397	16.49
25	Q9	0.56:1:1.75:4.75	8.55	0.003375	2533	380.157	16.89585	
26	Q9	0.56:1:1.75:4.75	8.70	0.003375	2578	325.268	14.45637	
27	Q9	0.56:1:1.75:4.75	8.15	0.003375	2415	336.1	14.93778	15.43
28	Q10	0.56:1:2:3	8.30	0.003375	2459	281.853	12.5268	
29	Q10	0.56:1:2:3	8.20	0.003375	2430	241.158	10.71814	
30	Q10	0.56:1:2:3	8.40	0.003375	2489	249.189	11.07506	11.44
31	Q11	0.6:1:1.5:4	8.50	0.003375	2519	343.94	15.2862	
32	Q11	0.6:1:1.5:4	8.40	0.003375	2489	294.28	13.07912	
33	Q11	0.6:1:1.5:4	8.60	0.003375	2548	304.08	13.51468	13.96
34	Q12	0.6:1:1.5:4	8.50	0.003375	2519	343.94	15.2862	
35	Q12	0.6:1:1.5:4	8.40	0.003375	2489	294.28	13.07912	
36	Q12	0.6:1:1.5:4	8.60	0.003375	2548	304.08	13.51468	13.96
37	Q13	0.5:1:2:5	8.40	0.003375	2489	608.3	27.03555	
38	Q13	0.5:1:2:5	8.40	0.003375	2489	520.471	23.13206	
39	Q13	0.5:1:2:5	8.50	0.003375	2519	537.804	23.90239	24.69
40	Q14	0.6:1:2:5	8.60	0.003375	2548	339.505	15.0891	
41	Q14	0.6:1:2:5	8.40	0.003375	2489	290.486	12.91048	
42	Q14	0.6:1:2:5	8.56	0.003375	2536	300.159	13.34042	13.78
43	Q15	0.5:1:2:5	8.40	0.003375	2489	626.532	27.84585	

44	Q15	0.5:1:2:5	8.40	0.003375	2489	536.071	23.82537	
45	Q15	0.5:1:2:5	8.50	0.003375	2519	553.923	24.61878	25.43
46	Q16	0.6:1:1.5:3.5	8.35	0.003375	2474	416.62	18.51645	
47	Q16	0.6:1:1.5:3.5	8.10	0.003375	2400	356.467	15.84298	
48	Q16	0.6:1:1.5:3.5	8.20	0.003375	2430	368.338	16.37057	16.91
49	Q17	0.55:1:1.75:4	8.30	0.003375	2459	358.722	15.9432	
50	Q17	0.55:1:1.75:4	8.60	0.003375	2548	317.15	14.09554	
51	Q17	0.55:1:1.75:4	8.80	0.003375	2607	306.928	13.64126	14.56
52	Q18	0.55:1:1.75:4	8.30	0.003375	2459	358.722	15.9432	
53	Q18	0.55:1:1.75:4	8.60	0.003375	2548	306.928	13.64126	
54	Q18	0.55:1:1.75:4	8.80	0.003375	2607	317.15	14.09554	14.56
55	Q19	0.55:1:1.75:4	8.30	0.003375	2459	358.722	15.9432	
56	Q19	0.55:1:1.75:4	8.60	0.003375	2548	306.928	13.64126	
57	Q19	0.55:1:1.75:4	8.80	0.003375	2607	317.15	14.09554	14.56
58	Q20	0.55:1:1.75:4	8.30	0.003375	2459	317.15	14.09554	
59	Q20	0.55:1:1.75:4	8.60	0.003375	2548	306.928	13.64126	
60	Q20	0.55:1:1.75:4	8.80	0.003375	2607	358.722	15.9432	14.56
61	Q21	0.55:1:1.75:4	8.30	0.003375	2459	358.722	15.9432	
62	Q21	0.55:1:1.75:4	8.60	0.003375	2548	306.928	13.64126	
63	Q21	0.55:1:1.75:4	8.80	0.003375	2607	317.15	14.09554	14.56
64	Q22	0.55:1:1.75:4	8.30	0.003375	2459	158.912	7.06275	
65	Q22	0.55:1:1.75:4	8.15	0.003375	2415	135.968	6.043005	
66	Q22	0.55:1:1.75:4	7.95	0.003375	2356	140.496	6.244245	6.45
67	Q23	0.55:1:1.75:4	8.60	0.003375	2548	321.942	14.30852	
68	Q23	0.55:1:1.75:4	8.48	0.003375	2513	311.566	13.84738	
69	Q23	0.55:1:1.75:4	8.50	0.003375	2519	364.142	16.1841	14.78
70	Q24	0.55:1:1.75:4	8.60	0.003375	2548	364.142	16.1841	
71	Q24	0.55:1:1.75:4	8.48	0.003375	2513	311.566	13.84738	
72	Q24	0.55:1:1.75:4	8.50	0.003375	2519	321.942	14.30852	14.78
73	Q25	0.55:1:2:4	8.40	0.003375	2489	320.534	14.24595	
74	Q25	0.55:1:2:4	8.10	0.003375	2400	274.254	12.18907	
75	Q25	0.55:1:2:4	8.55	0.003375	2533	283.387	12.59498	13.01
76	Q26	0.55:1:2:4	8.40	0.003375	2489	320.534	14.24595	
77	Q26	0.55:1:2:4	8.10	0.003375	2400	274.254	12.18907	
78	Q26	0.55:1:2:4	8.55	0.003375	2533	376.915	16.75177	13.01
79	Q27	0.55:1:1.75:5	8.40	0.003375	2489	440.519	19.5786	
80	Q27	0.55:1:1.75:5	8.30	0.003375	2459	283.387	12.59498	
81	Q27	0.55:1:1.75:5	8.20	0.003375	2430	389.467	17.30963	17.88
82	Q28	0.55:1:1.75:5	8.40	0.003375	2489	440.519	19.5786	
83	Q28	0.55:1:1.75:5	8.30	0.003375	2459	376.915	16.75177	
84	Q28	0.55:1:1.75:5	8.20	0.003375	2430	389.467	17.30963	17.88
85	Q29	0.55:1:1.75:4	8.60	0.003375	2548	321.942	14.30852	
86	Q29	0.55:1:1.75:4	8.48	0.003375	2513	311.566	13.84738	
87	Q29	0.55:1:1.75:4	8.50	0.003375	2519	364.142	16.1841	14.78
88	Q30	0.55:1:1.75:4	8.60	0.003375	2548	321.942	14.30852	
89	Q30	0.55:1:1.75:4	8.48	0.003375	2513	311.566	13.84738	
90	Q30	0.55:1:1.75:4	8.50	0.003375	2518.52	364.142	16.1841	14.78

Table 4.58 Flexural Strength of concrete made with Quarry dust based on CCD Matrix

S/NO	TAG NO (SAND)	MIX RATIO	MASS (kg)	VOLUME OF MOULD (m^3)	DENSITY (kg/m^3)	CRUSHING LOAD (kN)	FLEXURAL STRENGTH (N/mm^2)	MEAN FLEXURAL STRENGTH (N/mm^2)
1	Q1	0.55:1:2:4	28.17	0.01125	2503.68	15.28058	2.263789	
2	Q1	0.55:1:2:5	29.33	0.01125	2607.38	17.85915	2.645799	
3	Q1	0.55:1:2:6	28.57	0.01125	2539.23	15.78944	2.339177	2.416255
4	Q2	0.60:1:1.5:3	28.17	0.01125	2503.68	17.76407	2.631715	
5	Q2	0.60:1:1.5:3	27.83	0.01125	2474.05	15.70539	2.326724	
6	Q2	0.60:1:1.5:3	28.50	0.01125	2533.31	15.19923	2.251738	2.403392
7	Q3	0.5:1:2:5	28.50	0.01125	2533.31	19.17073	2.840108	
8	Q3	0.5:1:2:5	28.50	0.01125	2533.31	16.40279	2.430043	
9	Q3	0.5:1:2:5	28.83	0.01125	2562.94	16.94902	2.510966	2.593706
10	Q4	0.6:1:1.5:3	28.17	0.01125	2503.68	17.69402	2.621336	
11	Q4	0.6:1:1.5:3	28.67	0.01125	2548.12	15.1393	2.242859	
12	Q4	0.6:1:1.5:3	27.17	0.01125	2414.79	15.64345	2.317549	2.393915
13	Q5	0.5:1:2:3	28.33	0.01125	2518.49	19.35445	2.867325	
14	Q5	0.5:1:2:3	27.50	0.01125	2444.42	16.55998	2.453331	
15	Q5	0.5:1:2:3	27.83	0.01125	2474.05	17.11145	2.53503	2.618562
16	Q6	0.55:1:1.75:4	28.17	0.01125	2503.68	18.50244	2.741103	
17	Q6	0.55:1:1.75:4	29.17	0.01125	2592.57	15.83099	2.345332	
18	Q6	0.55:1:1.75:4	29.83	0.01125	2651.83	16.35819	2.423435	2.50329
19	Q7	0.5:1:2:3	28.33	0.01125	2518.49	16.50002	2.444447	
20	Q7	0.5:1:2:3	27.50	0.01125	2444.42	19.28436	2.856943	
21	Q7	0.5:1:2:3	27.83	0.01125	2474.05	17.04949	2.52585	2.60908
22	Q8	0.6:1:1.6:3	29.00	0.01125	2577.75	14.94309	2.213792	
23	Q8	0.6:1:1.6:3	28.77	0.01125	2557.01	17.46471	2.587365	
24	Q8	0.6:1:1.6:3	29.23	0.01125	2598.49	15.44072	2.287514	2.36289
25	Q9	0.56:1:1.75:4.75	29.00	0.01125	2577.75	18.32298	2.714516	
26	Q9	0.56:1:1.75:4.75	29.50	0.01125	2622.20	15.67745	2.322584	
27	Q9	0.56:1:1.75:4.75	27.67	0.01125	2459.24	16.19952	2.39993	2.47901
28	Q10	0.56:1:2:3	28.17	0.01125	2503.68	17.95763	2.66039	
29	Q10	0.56:1:2:3	27.83	0.01125	2474.05	15.36485	2.276274	
30	Q10	0.56:1:2:3	28.50	0.01125	2533.31	15.87652	2.352076	2.42958
31	Q11	0.6:1:1.5:4	28.83	0.01125	2562.94	17.63722	2.612922	
32	Q11	0.6:1:1.5:4	28.50	0.01125	2533.31	15.0907	2.235659	
33	Q11	0.6:1:1.5:4	29.17	0.01125	2592.57	15.59324	2.310109	2.38623
34	Q12	0.6:1:1.5:4	28.83	0.01125	2562.94	17.56331	2.601972	
35	Q12	0.6:1:1.5:4	28.50	0.01125	2533.31	15.02746	2.22629	
36	Q12	0.6:1:1.5:4	29.17	0.01125	2592.57	15.52789	2.300428	2.37623
37	Q13	0.5:1:2:5	28.50	0.01125	2533.31	16.35747	2.423329	
38	Q13	0.5:1:2:5	28.50	0.01125	2533.31	15.8303	2.345229	
39	Q13	0.5:1:2:5	28.83	0.01125	2562.94	18.50163	2.740982	2.50318
40	Q14	0.6:1:2:5	29.17	0.01125	2592.57	16.43289	2.434503	
41	Q14	0.6:1:2:5	28.50	0.01125	2533.31	14.06025	2.083	
42	Q14	0.6:1:2:5	29.03	0.01125	2580.72	14.52848	2.152367	2.22329
43	Q15	0.5:1:2:5	28.50	0.01125	2533.31	19.17076	2.840112	
44	Q15	0.5:1:2:5	28.50	0.01125	2533.31	16.40282	2.430047	

45	Q15	0.5:1:2:5	28.83	0.01125	2562.94	16.94905	2.510971	2.59371
46	Q16	0.6:1:1.5:3.5	28.33	0.01125	2518.49	17.6656	2.617127	
47	Q16	0.6:1:1.5:3.5	27.50	0.01125	2444.42	15.11498	2.239257	
48	Q16	0.6:1:1.5:3.5	27.83	0.01125	2474.05	15.61833	2.313827	2.39007
49	Q17	0.55:1:1.75:4	28.17	0.01125	2503.68	15.80102	2.340891	
50	Q17	0.55:1:1.75:4	29.17	0.01125	2592.57	18.46741	2.735912	
51	Q17	0.55:1:1.75:4	29.83	0.01125	2651.83	16.32721	2.418846	2.49855
52	Q18	0.55:1:1.75:4	28.17	0.01125	2503.68	16.32721	2.418846	
53	Q18	0.55:1:1.75:4	29.17	0.01125	2592.57	15.80102	2.340891	
54	Q18	0.55:1:1.75:4	29.83	0.01125	2651.83	18.46741	2.735912	2.49855
55	Q19	0.55:1:1.75:4	28.17	0.01125	2503.68	18.46741	2.735912	
56	Q19	0.55:1:1.75:4	29.17	0.01125	2592.57	15.80102	2.340891	
57	Q19	0.55:1:1.75:4	29.83	0.01125	2651.83	16.32721	2.418846	2.49855
58	Q20	0.55:1:1.75:4	28.17	0.01125	2503.68	18.46741	2.735912	
59	Q20	0.55:1:1.75:4	29.17	0.01125	2592.57	15.80102	2.340891	
60	Q20	0.55:1:1.75:4	29.83	0.01125	2651.83	16.32721	2.418846	2.49855
61	Q21	0.55:1:1.75:4	28.17	0.01125	2503.68	18.46741	2.735912	
62	Q21	0.55:1:1.75:4	29.17	0.01125	2592.57	15.80102	2.340891	
63	Q21	0.55:1:1.75:4	29.83	0.01125	2651.83	16.32721	2.418846	2.49855
64	Q22	0.55:1:1.75:4	28.17	0.01125	2503.68	17.09899	2.533184	
65	Q22	0.55:1:1.75:4	27.67	0.01125	2459.24	14.63018	2.167434	
66	Q22	0.55:1:1.75:4	27.00	0.01125	2399.98	15.11738	2.239612	2.31341
67	Q23	0.55:1:1.75:4	29.17	0.01125	2592.57	18.53748	2.746293	
68	Q23	0.55:1:1.75:4	28.77	0.01125	2557.01	15.86097	2.349773	
69	Q23	0.55:1:1.75:4	28.83	0.01125	2562.94	16.38916	2.428024	2.50803
70	Q24	0.55:1:1.75:4	29.17	0.01125	2592.57	18.43237	2.730722	
71	Q24	0.55:1:1.75:4	28.77	0.01125	2557.01	15.77104	2.336451	
72	Q24	0.55:1:1.75:4	28.83	0.01125	2562.94	16.29624	2.414257	2.49381
73	Q25	0.55:1:2:4	28.50	0.01125	2533.31	17.89414	2.650984	
74	Q25	0.55:1:2:4	27.50	0.01125	2444.42	15.31052	2.268226	
75	Q25	0.55:1:2:4	29.00	0.01125	2577.75	15.82038	2.34376	2.42099
76	Q26	0.55:1:2:4	28.50	0.01125	2533.31	17.89414	2.650984	
77	Q26	0.55:1:2:4	27.50	0.01125	2444.42	15.31052	2.268226	
78	Q26	0.55:1:2:4	29.00	0.01125	2577.75	15.82038	2.34376	2.42099
79	Q27	0.55:1:1.75:5	28.50	0.01125	2533.31	18.41057	2.727492	
80	Q27	0.55:1:1.75:5	28.17	0.01125	2503.68	15.75239	2.333687	
81	Q27	0.55:1:1.75:5	27.83	0.01125	2474.05	16.27696	2.411402	2.49086
82	Q28	0.55:1:1.75:5	28.50	0.01125	2533.31	18.41057	2.727492	
83	Q28	0.55:1:1.75:5	28.17	0.01125	2503.68	15.75239	2.333687	
84	Q28	0.55:1:1.75:5	27.83	0.01125	2474.05	16.27696	2.411402	2.49086
85	Q29	0.55:1:1.75:4	29.17	0.01125	2592.57	15.80102	2.340891	
86	Q29	0.55:1:1.75:4	28.77	0.01125	2557.01	18.46741	2.735912	
87	Q29	0.55:1:1.75:4	28.83	0.01125	2562.94	16.32721	2.418846	2.49855
88	Q30	0.55:1:1.75:4	29.17	0.01125	2592.57	18.46741	2.735912	
89	Q30	0.55:1:1.75:4	28.77	0.01125	2557.01	16.32721	2.418846	
90	Q30	0.55:1:1.75:4	28.83	0.01125	2562.94	15.80102	2.340891	2.49855

4.9 Model Equations developed using Minitab 17

4.9.1 Compressive Strength Model equation for concrete made with river sand as fine aggregate

Response Surface Regression: y versus Blocks, A, B, C, D

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	434.114	28.9409	782.06	0.000
Blocks	1	0.015	0.0152	0.41	0.532
Linear	4	22.022	5.5056	148.77	0.000
A	1	0.139	0.1386	3.74	0.073
B	1	0.012	0.0117	0.32	0.583
C	1	0.116	0.1158	3.13	0.099
D	1	13.247	13.2468	357.96	0.000
Square	4	70.043	17.5108	473.18	0.000
A*A	1	0.327	0.3273	8.84	0.010
B*B	1	0.020	0.0196	0.53	0.479
C*C	1	1.976	1.9765	53.41	0.000
D*D	1	38.140	38.1397	1030.63	0.000
2-Way Interaction	6	186.455	31.0758	839.74	0.000
A*B	1	0.056	0.0556	1.50	0.241
A*C	1	0.778	0.7779	21.02	0.000
A*D	1	3.831	3.8308	103.52	0.000
B*C	1	0.037	0.0371	1.00	0.334
B*D	1	0.025	0.0246	0.66	0.429
C*D	1	0.029	0.0292	0.79	0.390
Error	14	0.518	0.0370		
Lack-of-Fit	5	0.518	0.1036	*	*
Pure Error	9	0.000	0.0000		
Total	29	434.632			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.192370	99.88%	99.75%	80.16%

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		25.7597	0.0678	380.04	0.000	
Blocks						
1		-0.0309	0.0482	-0.64	0.532	1.68
A	-3.88	-1.94	1.00	-1.94	0.073	345.13
B	-0.0800	-0.0400	0.0712	-0.56	0.583	2.87
C	-3.62	-1.81	1.02	-1.77	0.099	415.37
D	3.4525	1.7262	0.0912	18.92	0.000	2.71
A*A	5.686	2.843	0.956	2.97	0.010	181.73
B*B	-0.0861	-0.0431	0.0592	-0.73	0.479	1.73
C*C	13.808	6.904	0.945	7.31	0.000	175.22
D*D	-7.679	-3.839	0.120	-32.10	0.000	2.55
A*B	-0.526	-0.263	0.215	-1.23	0.241	14.79
A*C	16.51	8.25	1.80	4.58	0.000	725.74
A*D	-13.798	-6.899	0.678	-10.17	0.000	110.14
B*C	-0.461	-0.231	0.230	-1.00	0.334	18.55
B*D	0.1411	0.0706	0.0866	0.81	0.429	2.02

```
C*D          -1.256   -0.628    0.707    -0.89    0.390  110.25

Regression Equation in Uncoded Units
```

$$Y = -179470 + 8619Z_1 + 352728Z_2 + 1097Z_3 - 28Z_4 + 1137zZ_1^2 - 172266Z_2^2 + 110.5Z_3^2 - 3.839Z_4^2 - 10518Z_1Z_2 + 660Z_1Z_3 - 138Z_1Z_4 - 1845\,Z_2Z_3 + 141Z_2Z_4 - 2.51Z_3Z_4 \quad (4.24)$$

Table 4.59 the differences between observed values and model values for the compressive strength of concrete made with river sand as fine aggregate.
$LEGEND$: Y_p = laboratory value, Y_m = model vaues

Yp	Ym	Yp - Ym
30.68	30.3885	0.2915
27.84	27.58603	0.253966
31.51	31.675	-0.165
27.84	27.299	0.541
15.56	15.29673	0.263266
25.71	25.63613	0.073866
15.56	15.139	0.421
25.54	25.601	-0.061
24.11	24.20459	-0.09459
29.68	29.35788	0.322116
26.81	26.861	-0.051
26.81	26.861	-0.051
31.51	31.55073	-0.04073
30.72	30.77253	-0.05253
31.51	31.675	-0.165
28.54	28.03975	0.50025
25.74	25.63851	0.101491
25.74	25.63851	0.101491
25.74	25.63851	0.101491
25.74	25.63851	0.101491
25.74	25.63851	0.101491
26.94	26.47896	0.461042
25.68	25.54763	0.132374
25.75	25.55475	0.19525
30.78	30.70288	0.077116
30.78	30.70288	0.077116
23.76	23.72451	0.035491
23.76	23.72451	0.035491
25.78	25.63851	0.141491
25.78	25.63851	0.141491

The final model equation can be used to predict at 28th days the compressive strength of concrete made with river sand as fine aggregate.

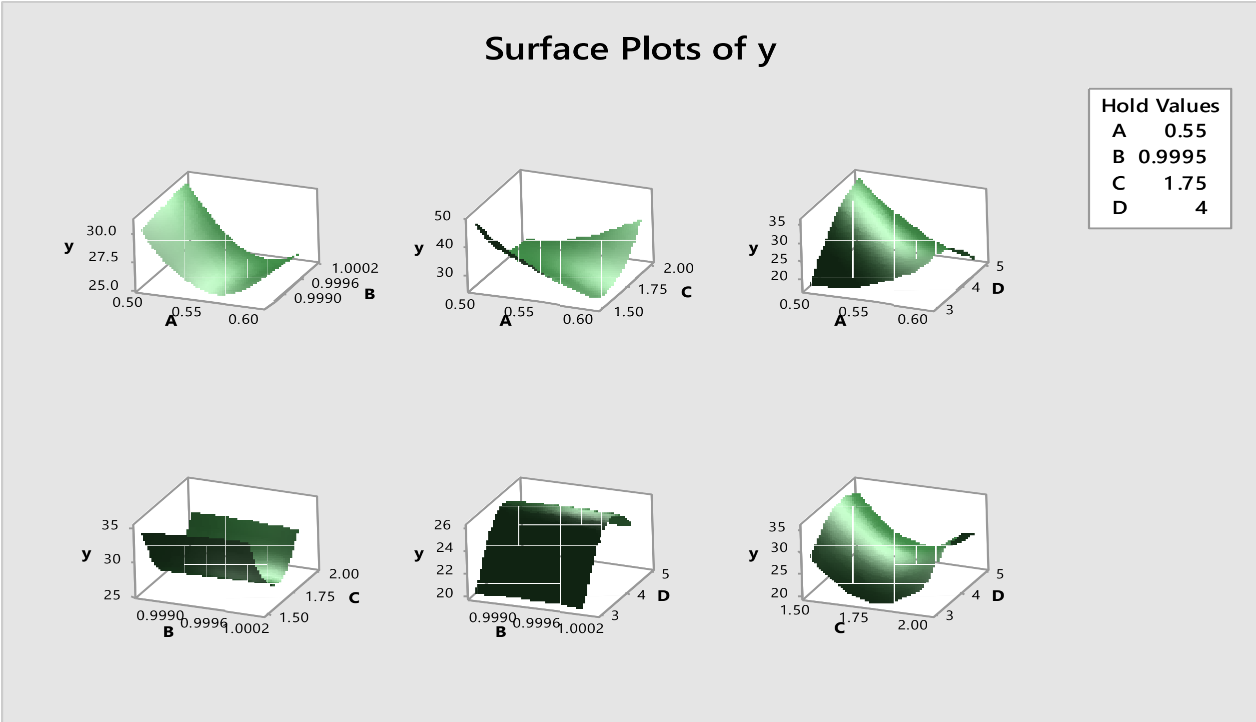

Fig. 4.14 Relationship between compressive strength and the various components in the mix for concrete made with river sand as fine aggregate.

4.9.2 Flexural Strength Model equation for concrete made with river sand as fine aggregate

Response Surface Regression: y versus Blocks, A, B, C, D

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	30.2284	2.01523	298.49	0.000
Blocks	1	0.0404	0.04040	5.98	0.028
Linear	4	5.5126	1.37816	204.13	0.000
A	1	0.1582	0.15817	23.43	0.000
B	1	0.0002	0.00019	0.03	0.868
C	1	0.0683	0.06830	10.12	0.007
D	1	0.5376	0.53757	79.62	0.000
Square	4	5.0804	1.27011	188.12	0.000
A*A	1	0.2605	0.26046	38.58	0.000
B*B	1	0.0065	0.00649	0.96	0.344
C*C	1	0.1235	0.12354	18.30	0.001
D*D	1	2.6267	2.62667	389.05	0.000
2-Way Interaction	6	0.4064	0.06774	10.03	0.000
A*B	1	0.2022	0.20220	29.95	0.000
A*C	1	0.1438	0.14376	21.29	0.000
A*D	1	0.0905	0.09047	13.40	0.003
B*C	1	0.1956	0.19556	28.96	0.000
B*D	1	0.0016	0.00159	0.24	0.635
C*D	1	0.0615	0.06154	9.12	0.009

```
Error                14   0.0945  0.00675
  Lack-of-Fit         5   0.0945  0.01890        *        *
  Pure Error          9   0.0000  0.00000
Total                29  30.3229
```

```
Model Summary

        S    R-sq  R-sq(adj)  R-sq(pred)
0.0821674  99.69%     99.35%      54.86%
```

```
Coded Coefficients

Term       Effect     Coef  SE Coef  T-Value  P-Value      VIF
Constant            2.6948   0.0290    93.08    0.000
Blocks
  1                 0.0504   0.0206     2.45    0.028     1.68
A          -4.148   -2.074    0.429    -4.84    0.000   345.13
B          0.0103   0.0051   0.0304     0.17    0.868     2.87
C          -2.777   -1.389    0.437    -3.18    0.007   415.37
D          0.6955   0.3477   0.0390     8.92    0.000     2.71
A*A         5.073    2.536    0.408     6.21    0.000   181.73
B*B        0.0496   0.0248   0.0253     0.98    0.344     1.73
C*C         3.452    1.726    0.404     4.28    0.001   175.22
D*D        2.0151   1.0075   0.0511    19.72    0.000     2.55
A*B        1.0029   0.5015   0.0916     5.47    0.000    14.79
A*C         7.096    3.548    0.769     4.61    0.000   725.74
A*D        -2.120   -1.060    0.290    -3.66    0.003   110.14
B*C        1.0593   0.5297   0.0984     5.38    0.000    18.55
B*D       -0.0359  -0.0180   0.0370    -0.49    0.635     2.02
C*D        -1.824   -0.912    0.302    -3.02    0.009   110.25
Regression Equation in Uncoded Units
```

$$Y = 96.93556 - 126.742X_1 - 242.215X_2 - 75.7851X_3 - 24.3074X_4 + 165.6849X_1^2 + 197.0795X_2^2 - 3.58658X_3^2 + 1.128737X_4^2 - 26.8742X_1X_2 - 28.9352X_1X_3 + 5.715447X_1X_4 + 99.41571X_2X_3 + 8.907229X_2X_4 + 1.987082X_3X_4 \quad (4.25)$$

Table 4.60 the differences between observed values and model values for the flexural strength of concrete made with river sand as fine aggregate.

LEGEND: Y_p = **laboratory value**, Y_m = **model vaues**

Yp	Ym	Yp - Ym
3.74	3.446421	0.293579
3.62	3.487376	0.132624
5.68	5.769516	-0.08952
3.7	3.798844	-0.09884
4.65	4.482517	0.167483
2.69	2.546131	0.143869
4.71	4.84638	-0.13638
3.84	3.910074	-0.07007
3.4	3.392313	0.007687

3.16	2.987962	0.172038
2.76	2.709678	0.050322
2.76	2.709678	0.050322
5.68	5.387839	0.292161
5.48	5.324917	0.155083
5.68	5.769516	-0.08952
2.91	2.972077	-0.06208
2.71	2.719368	-0.00937
2.71	2.719368	-0.00937
2.71	2.719368	-0.00937
2.71	2.719368	-0.00937
2.71	2.719368	-0.00937
3.16	3.177365	-0.01737
2.68	2.372993	0.307007
2.72	2.892703	-0.1727
2.89	3.260659	-0.37066
2.89	3.260659	-0.37066
3.98	4.094221	-0.11422
3.98	4.094221	-0.11422
2.71	2.719368	-0.00937
2.71	2.719368	-0.00937

The final model equation can be used to predict at 28th days the flex strength of concrete made with river sand as fine aggregate.

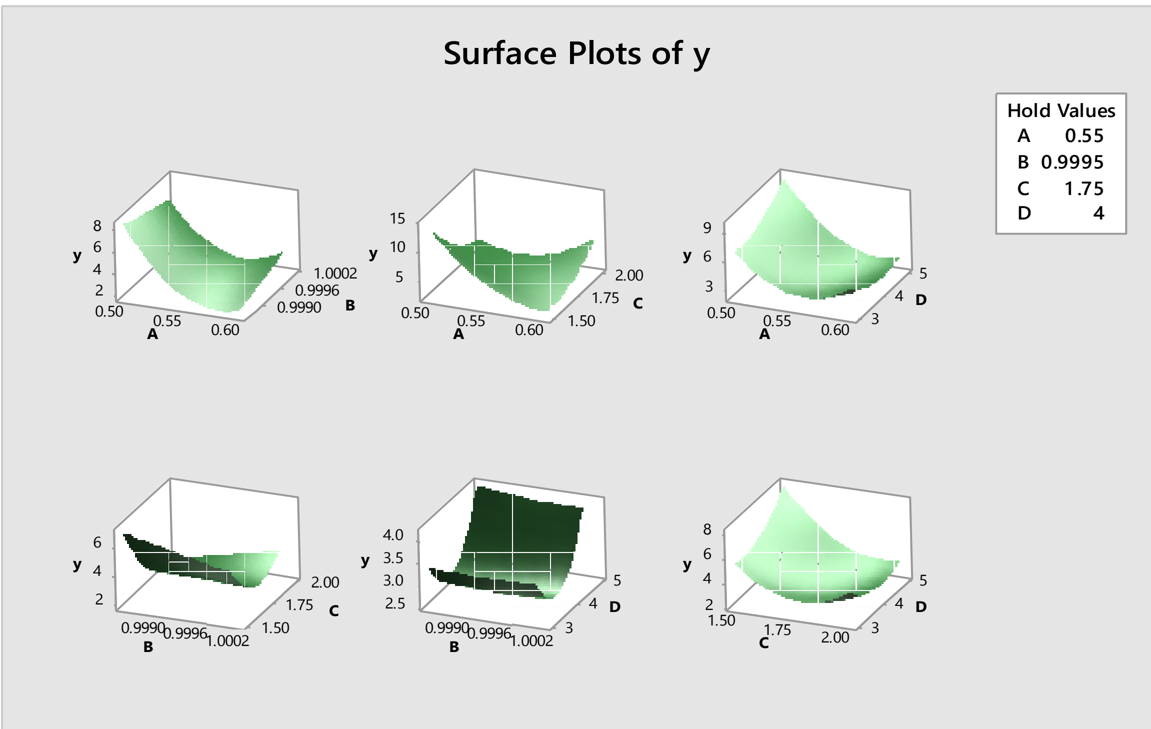

Fig.4.15Relationship between flexural strength and the various components in the mix for concrete made with river sand as fine aggregate

4.9.3 Compressive Strength Model equation for concrete made with quarry dust as fine aggregate

Response Surface Regression: y versus Blocks, A, B, C, D

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	588.413	39.2275	440.15	0.000
Blocks	1	0.700	0.7000	7.85	0.014
Linear	4	29.093	7.2732	81.61	0.000
A	1	0.701	0.7011	7.87	0.014
B	1	0.032	0.0325	0.36	0.556
C	1	0.143	0.1434	1.61	0.225
D	1	10.092	10.0919	113.24	0.000
Square	4	64.641	16.1601	181.32	0.000
A*A	1	0.676	0.6759	7.58	0.016
B*B	1	0.004	0.0041	0.05	0.832
C*C	1	0.003	0.0029	0.03	0.859
D*D	1	54.503	54.5034	611.55	0.000
2-Way Interaction	6	49.769	8.2948	93.07	0.000
A*B	1	0.281	0.2811	3.15	0.097
A*C	1	0.370	0.3695	4.15	0.061
A*D	1	1.332	1.3319	14.94	0.002
B*C	1	0.206	0.2060	2.31	0.151
B*D	1	0.095	0.0953	1.07	0.319
C*D	1	3.905	3.9048	43.81	0.000
Error	14	1.248	0.0891		
Lack-of-Fit	5	0.942	0.1883	5.54	0.013
Pure Error	9	0.306	0.0340		
Total	29	589.661			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.298535	99.79%	99.56%	92.76%

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		14.576	0.105	138.57	0.000	
Blocks						
1		-0.2097	0.0748	-2.80	0.014	1.68
A	-8.73	-4.37	1.56	-2.80	0.014	345.13
B	0.133	0.067	0.110	0.60	0.556	2.87
C	-4.02	-2.01	1.59	-1.27	0.225	415.37
D	-3.013	-1.507	0.142	-10.64	0.000	2.71
A*A	-8.17	-4.09	1.48	-2.75	0.016	181.73
B*B	-0.0396	-0.0198	0.0919	-0.22	0.832	1.73
C*C	0.53	0.26	1.47	0.18	0.859	175.22
D*D	9.179	4.590	0.186	24.73	0.000	2.55
A*B	-1.183	-0.591	0.333	-1.78	0.097	14.79
A*C	-11.38	-5.69	2.79	-2.04	0.061	725.74
A*D	8.14	4.07	1.05	3.87	0.002	110.14
B*C	-1.087	-0.544	0.358	-1.52	0.151	18.55
B*D	0.278	0.139	0.134	1.03	0.319	2.02
C*D	14.53	7.27	1.10	6.62	0.000	110.25

Regression Equation in Uncoded Units

$$y = -248.451 - 1165.29X_1 + 944.1143X_2 + 389.962X_3 - 18.9403X_4 - 965.899X_1^2 - 559.583X_2^2 + 30.71971X_2^3 + 4.357962X_4^2 + 2169.72X_1X_2 - 189.505X_1X_3 + 65.81441X_1X_4 - 514.371X_2X_3 - 99.7219X_2X_4 + 26.32535X_3X_4 \quad (4.26)$$

Table 4.61the differences between observed values and model values for the compressive strength of concrete made with quarry dust as fine aggregate.

***LEGEND*: Y_p = laboratory value, Y_m = model vaues**

Yp	Ym	yp - Ym
12.16	12.4121	-0.2521
23.31	23.07555	0.23445
24.69	24.80534	-0.11534
23.31	23.13217	0.177832
21.46	21.7039	-0.2439
13.64	14.72632	-1.08632
21.46	21.28636	0.173644
16.49	16.74172	-0.25172
15.43	15.68375	-0.25375
11.44	11.3354	0.104599
13.96	13.95246	0.007538
13.96	13.95246	0.007538
24.69	25.42232	-0.73232
13.78	14.40573	-0.62573
25.43	24.80534	0.624661
16.91	17.45282	-0.54282
14.56	14.58637	-0.02637
14.56	14.58637	-0.02637
14.56	14.58637	-0.02637
14.56	14.58637	-0.02637
14.56	14.58637	-0.02637
6.45	5.795648	0.654352
14.78	14.86599	-0.08599
14.78	14.44613	0.333866
13.01	12.61663	0.39337
13.01	12.61663	0.39337
17.88	17.46306	0.416937
17.88	17.46306	0.416937
14.78	14.58637	0.193634
14.78	14.58637	0.193634

The final model equation can be used to predict at 28th days the compressive strength of concrete made with quarry dust as fine aggregate.

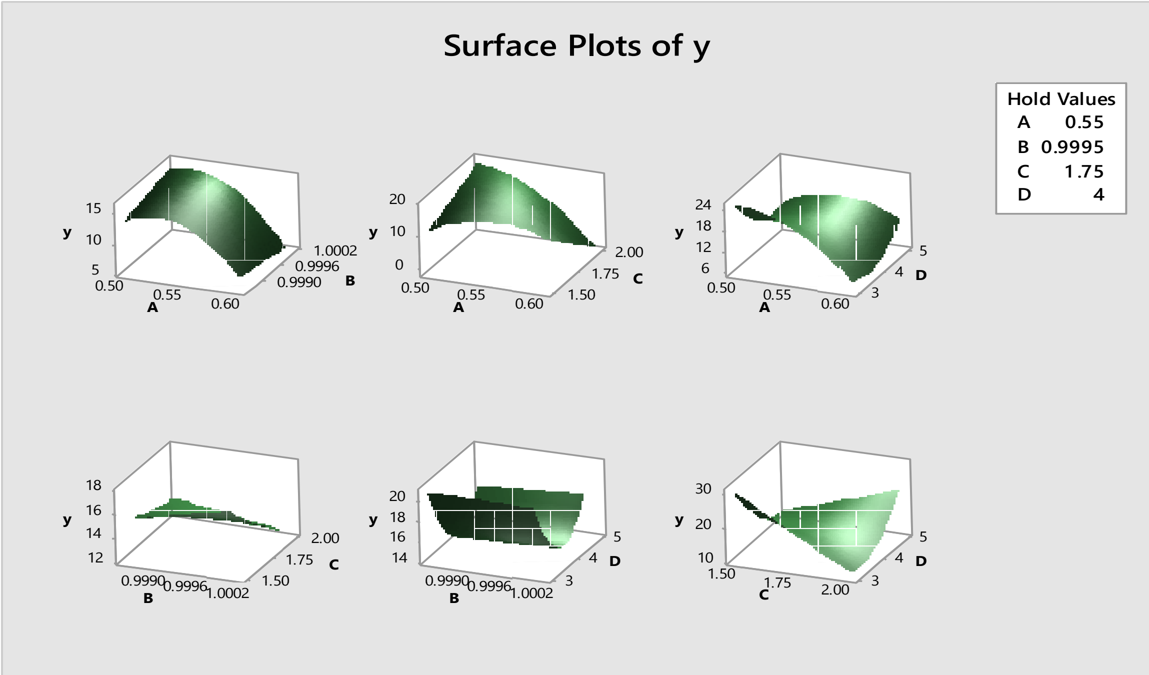

Fig: 4.16Relationship between compressive strength and the various components in the mix for concrete made with quarry dust as fine aggregate.

4.9.4 Flexural Strength Model equation for concrete made with quarry dust as fine aggregate

Response Surface Regression: y versus Blocks, A, B, C, D

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	0.219271	0.014618	194.77	0.000
Blocks	1	0.000155	0.000155	2.07	0.172
Linear	4	0.047821	0.011955	159.30	0.000
A	1	0.000029	0.000029	0.38	0.546
B	1	0.001351	0.001351	18.01	0.001
C	1	0.000165	0.000165	2.19	0.161
D	1	0.002039	0.002039	27.17	0.000
Square	4	0.001593	0.000398	5.31	0.008
A*A	1	0.000915	0.000915	12.19	0.004
B*B	1	0.000916	0.000916	12.20	0.004
C*C	1	0.000843	0.000843	11.23	0.005
D*D	1	0.000829	0.000829	11.05	0.005
2-Way Interaction	6	0.004894	0.000816	10.87	0.000
A*B	1	0.000874	0.000874	11.64	0.004
A*C	1	0.000726	0.000726	9.67	0.008
A*D	1	0.000837	0.000837	11.15	0.005
B*C	1	0.000627	0.000627	8.35	0.012
B*D	1	0.002254	0.002254	30.03	0.000
C*D	1	0.000627	0.000627	8.36	0.012
Error	14	0.001051	0.000075		

```
  Lack-of-Fit         5  0.001001  0.000200    36.03    0.000
  Pure Error          9  0.000050  0.000006
Total                29  0.220322


Model Summary

        S    R-sq  R-sq(adj)  R-sq(pred)
0.0086632  99.52%     99.01%      87.31%


Coded Coefficients

Term        Effect      Coef  SE Coef  T-Value  P-Value     VIF
Constant             2.49669  0.00305   817.92    0.000
Blocks
  1                  0.00312  0.00217     1.44    0.172    1.68
A          -0.0558   -0.0279   0.0452    -0.62    0.546  345.13
B          0.02719   0.01360  0.00320     4.24    0.001    2.87
C           0.1364    0.0682   0.0460     1.48    0.161  415.37
D         -0.04284  -0.02142  0.00411    -5.21    0.000    2.71
A*A        -0.3006   -0.1503   0.0431    -3.49    0.004  181.73
B*B        0.01863   0.00931  0.00267     3.49    0.004    1.73
C*C        -0.2851   -0.1426   0.0425    -3.35    0.005  175.22
D*D        0.03581   0.01790  0.00539     3.32    0.005    2.55
A*B       -0.06593  -0.03296  0.00966    -3.41    0.004   14.79
A*C        -0.5041   -0.2521   0.0811    -3.11    0.008  725.74
A*D         0.2040    0.1020   0.0305     3.34    0.005  110.14
B*C        -0.0600   -0.0300   0.0104    -2.89    0.012   18.55
B*D        0.04276   0.02138  0.00390     5.48    0.000    2.02
C*D         0.1842    0.0921   0.0319     2.89    0.012  110.25


Regression Equation in Uncoded Units
```

$$y = - 9.28516 – 4.4193X_1 + 11.99515X_2 + 5.128137X_3 + 1.569137X_4 - 19.2847X_1^2 – 7.38366X_2^2 – 0.48965X_3^2 + 0.007262X_4^2 + 27.9741X_1X_2 – 4.85914X_1X_3 + 0.80766X_1X_4 – 1.4575X_2X_3 – 2.32229 X_2X_4 + 0.132123X_3X_4 \quad (4.27)$$

Table 4.62the differences between observed values and model values for the flexural strength of concrete made with quarry dust as fine aggregate.
***LEGEND*: Y_p = laboratory value, Y_m = model vaues**

Yp	Ym	Yp - Ym
2.416255	2.422826	-0.00657
2.403392	2.397039	0.006353
2.593706	2.562207	0.031499
2.393915	2.401905	-0.00799
2.618562	2.614827	0.003735
2.50329	2.499441	0.003849
2.60908	2.616168	-0.00709
2.36289	2.365266	-0.00238
2.47901	2.478296	0.000714
2.42958	2.416362	0.013218
2.38623	2.382367	0.003863
2.37623	2.382367	-0.00614
2.50318	2.565511	-0.06233
2.22329	2.228857	-0.00557
2.59371	2.562207	0.031503

2.39007	2.390321	-0.00025
2.49855	2.499834	-0.00128
2.49855	2.499834	-0.00128
2.49855	2.499834	-0.00128
2.49855	2.499834	-0.00128
2.49855	2.499834	-0.00128
2.31341	2.30435	0.00906
2.50803	2.499045	0.008985
2.49381	2.500222	-0.00641
2.42099	2.422619	-0.00163
2.42099	2.422619	-0.00163
2.49086	2.488629	0.002231
2.49086	2.488629	0.002231
2.49855	2.499834	-0.00128
2.49855	2.499834	-0.00128

The final model equation can be used to predict at 28th days the flexural strength of concrete made with quarry dust as fine aggregate.

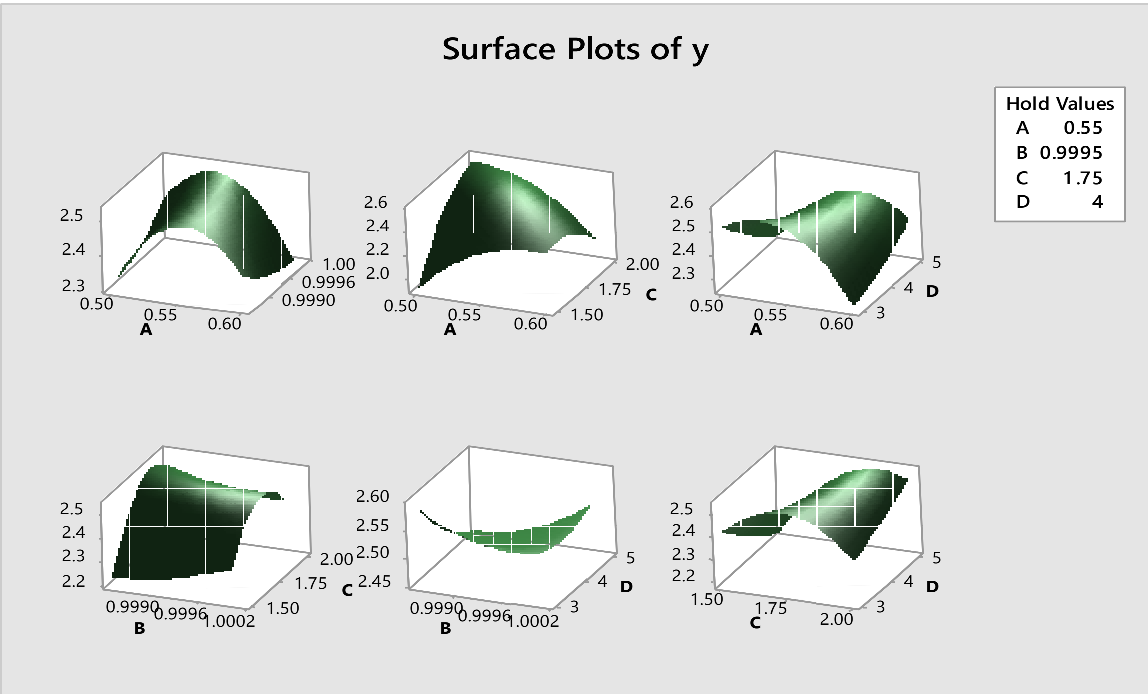

Fig. 4.17Relationship between flexural strength and the various components in the mix for concrete made with quarry dust as fine aggregate.

CHAPTER FIVE

CONCLUTION AND RECOMMENDATION

5.1 CONCLUSION

The following conclusions were drawn from this research:

i. The literatures reviewed on the effect of quarry dust on the properties of concrete have been carried out by researchers, and it has been proved that quarry dust can be used as an alternative to river sand in the production of concrete.

ii. The results obtained on the concrete made with quarry dust as fine aggregate shows a compressive strength of 25.76N/mm^2 at a mix ratio of 0.56:1:2:5. This result is very good and can be used in the construction of so many structures.

iii. Four new models were developed on experimental results.

iv. The compressive strength sand flexural strengths obtained from the models were function of the proportions of its ingredient namely: water, cement, river sand/quarry dust and coarse aggregate.

v. The optimum compressive strength of concrete made with river sand and that made with quarry dust were found to be 53.09N/mm^2 at a mix ratio of 1:1.5:5 at water cement ratio of 0.5, and 37.86N/mm^2 at mix ratio of 1:1.5:3at water cement ratio of 0.50respectively.

vi. The optimum flexural strength of concrete made with river sand and that made with quarry dust were found to be 5.53N/mm^2 at a mix ratio of 1:1.99:5 at water cement ratio of 0.5, and 2.67N/mm^2 at mix ratio of 1:1.67:3at water cement ratio of 0.5respectively.

vii. The written computer programs for Osadebe and Ibearugbulem regression models (Visual Basic 6.0) can predict accurately all possible combination of mix proportions of concrete made with river sand/quarry dust, if the desired compressive strength is given. With these programs, the errors developed and the efforts wasted while using the traditional methods will be eliminated. The computer programs is easy to operate and user friendly.

viii. The regression models developed by using MINITAB 17 can predict all possible combinations for any given mix ratios.

ix. Since quarry dust is an industrial waste from quarry industries, its use in the production of concrete will also serve the purpose of disposing this waste and also managing it. This will in turn bring down the price of river sand.

x. The use of quarry dust in the production of concrete will go a long way in stabilizing our eco-system which have been badly damaged due to the activities of miners in our local streams, sea and water ways.

5.2 RECOMMENDATIONS

The following recommendations are made:

a) Since from the test carried out and analysed quarry dust can effectively serve as a substitute to river sand in the production of concrete, it is recommend that it should be used in the production of concrete especially in areas that do not have rivers around them, like Abakaliki and its environs.
b) Since all the models developed were tested and found to be adequate for the prediction of concrete made with river sand/quarry dust, these models should be used to determine the compressive/flexural strength of concrete given mix proportions.
c) From the charts developed those in Abakaliki and its environs do not need to bother themselves on the mixes that can give a particular compressive/flexural strength, since it can be read off from the chart developed.
d) Minitab 17 can predict the compressive/flexural strength give mix ratios with easy and more precise.
e) Further works can be carried out on the effects of concrete made with quarry dust as fine aggregate from other sources apart from Abakaliki.

5.3 CONTRIBUTION TO KNOWLEDGE

I. This research developed four new models that can be used to predict the compressive/flexural strength of concrete made with river sand/quarry dust as fine aggregate.

II. This research demonstrated the possible use of Osadebe's regression model for modelling mix design of concrete made with quarry dust as fine aggregate.

III. This research showed that a compressive strength of up to 53.09N/mm^{2}and 37.86 N/mm^2 are achievable at a mix ratio of 1:1.5:5 at water-cement ratio of 0.5 and

1:1.5:3 at water cement ratio of 0.50 for concrete made with river sand and quarry dust as fine aggregate respectively.

IV. This research showed that a flexural strength of up to 5.53/$mm^2$and 2.67N/mm^2 are achievable at a mix ratio of 1:1.99:5 at water-cement ratio of 0.5 and 1:1.67:3 at water cement ratio of 0.5 for concrete made with river sand and quarry dust as fine aggregate respectively

V. This research developed design tables (Appendix 3 to 18) of various compressive/flexural strengths and mix ratios associated with them (based on computer program writing in Visual-Basic 6 for the four models) for concrete made with quarry dust as fine aggregate.

VI. From theses design tables developed the quantity of quarry dust that can be calculated for a particular project. Hence, it will be easy to determine the cost of quarry dust that can be used in a given project.

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APPENDIX 1

TABLES OF MECHANICAL PROPERTIES

Table 1 specific gravity of Quarry Dust

Soil Specimen No.		**1**	**2**	**3**
Bottle No		A	B	C
Mass of bottle + soil +water (m_3)	(g)	1323	1322	1321
Mass of bottle +soil (m_2)	(g)	611	610	610
Mass of bottle full of water (m_4)	(g)	1200	1200	1201
Mass of bottle (m_1)	(g)	411	410	410
Mass of water of water ($m_3 - m_2$)	(g)	712	712	711
Mass of soil used ($m_2 - m_1$)	(g)	200	200	200
Volume of soil ($m_4 - m_1$)$-$($m_3 - m_2$)	(ml)	77	78	80
Specific gravity of soil particles $= \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$		2.60	2.56	2.50
Average S.G		2.55		

Table 2 Specific gravity of River Sand

Soil Specimen No.		**1**	**2**	**3**
Bottle No		A	B	C
Mass of bottle + soil +water (m_3)	(g)	1327	1328	1335
Mass of bottle +soil (m_2)	(g)	610	609	611
Mass of bottle full of water (m_4)	(g)	1201	1201	1214
Mass of bottle (m_1)	(g)	410	409	411
Mass of water of water ($m_3 - m_2$)	(g)	717	719	724
Mass of soil used ($m_2 - m_1$)	(g)	200	200	200
Volume of soil ($m_4 - m_1$)$-$($m_3 - m_2$)	(ml)	74	73	79
Specific gravity of soil particles $= \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$		2.70	2.74	2.53
Average S.G		2.66		

Table 3 Specific gravity of coarse aggregate (chippings)

Soil Specimen No.	**1**	**2**	**3**
Bottle No	A	B	C
Mass of bottle + chippings +water (m_3) (g)	1325	1333	1324
Mass of bottle +chippings (m_2) (g)	609	608	609
Mass of bottle full of water (m_4) (g)	1200	1212	1201
Mass of bottle (m_1) (g)	409	408	409
Mass of water of water ($m_3 - m_2$) (g)	716	725	715
Mass of chippings used ($m_2 - m_1$) (g)	200	200	200
Volume of chippings ($m_4 - m_1$)−($m_3 - m_2$) (ml)	75	79	77
Specific gravity of chippings particles $= \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$	2.67	2.53	2.60
Average S.G	2.60		

Table 4 Specific gravity of Port land Cement

Soil Specimen No.	**1**	**2**	
Bottle No	A	B	
Mass of bottle + soil +water (m_3) (g)	1332	1336	
Mass of bottle +soil (m_2) (g)	608	611	
Mass of bottle full of water (m_4) (g)	1198	1200	
Mass of bottle (m_1) (g)	408	411	
Mass of water of water ($m_3 - m_2$) (g)	724	725	
Mass of soil used ($m_2 - m_1$) (g)	200	200	
Volume of soil ($m_4 - m_1$)−($m_3 - m_2$) (ml)	66	64	
Specific gravity of soil particles $= \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$	3.03	3.13	
Average S.G	3.08		

Table 5 Bulk Density of Quarry Dust

Soil specimen number	**1**	**2**
Weight of can m_1 (g)	1770.00	1770.00
Weight of can+sample m_2 (g)	3517.00	3525.00
Weight of sample $m_2 - m_1$ (g)	1747.00	1755.00
Volume of can V_c (cm^3)	1178.30	1178.3
Bulk density $\frac{m_2 - m_1}{V_c}$ (Mg/m^3)	1.48	1.49
Average bulk density (Mg/m^3)	1.48	

Table 6 Bulk Density of Sand

Soil specimen number	**1**	**2**
Weight of can m_1 (g)	1770.00	1770.00
Weight of can+sample m_2 (g)	3637.00	3657.00
Weight of sample $m_2 - m_1$ (g)	1867.00	1887.00
Volume of can V_c (cm^3)	1178.30	1178.3
Bulk density $\frac{m_2 - m_1}{V_c}$ (Mg/m^3)	1.585	1.60
Average bulk density (Mg/m^3)	1.593	

Table 7 Bulk Density of Coarse Aggregate (chippings)

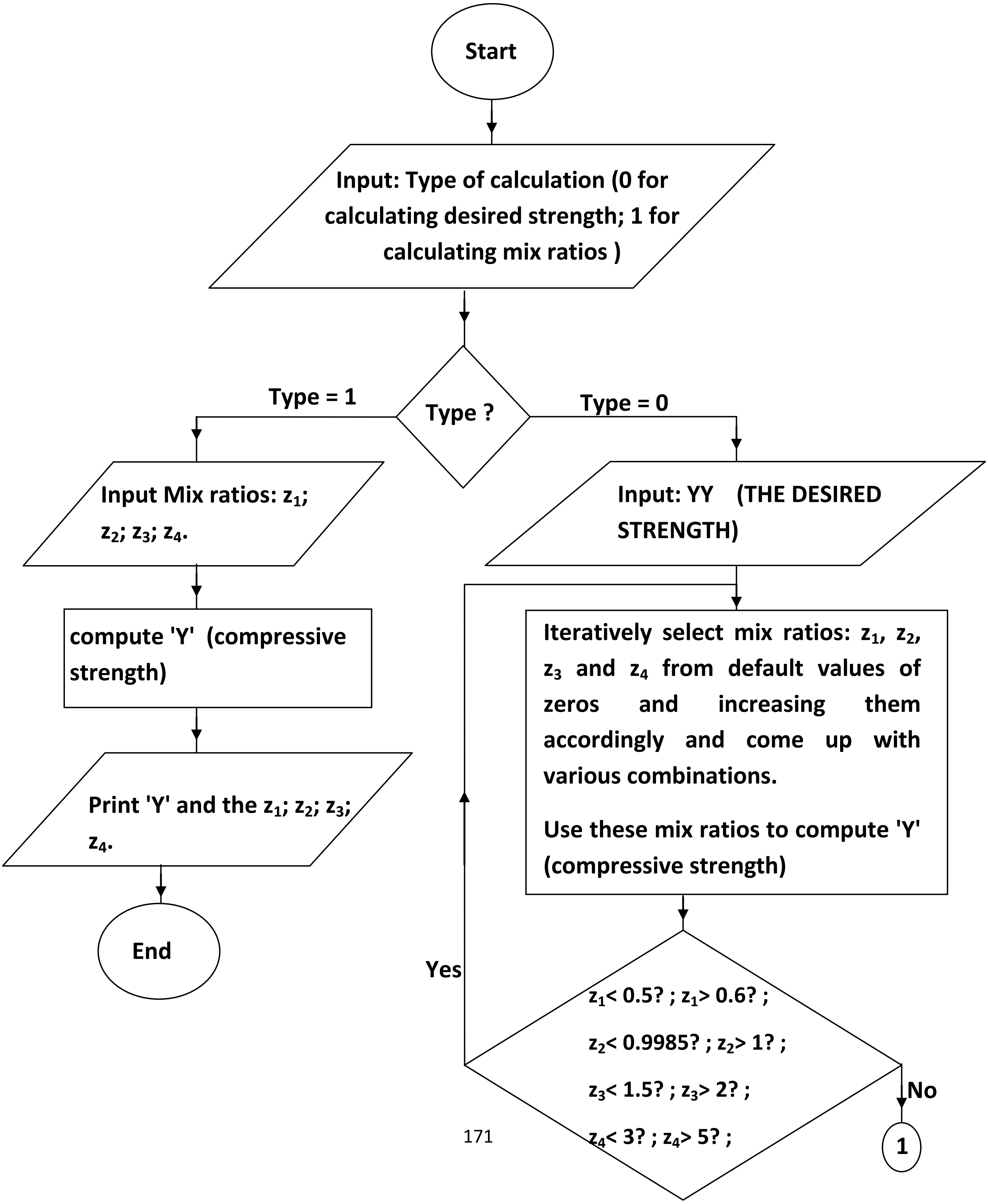
Soil specimen number	**1**	**2**
Weight of can m_1 (g)	1770.00	1770.00
Weight of can+sample m_2 (g)	3413.00	3442.00
Weight of sample $m_2 - m_1$ (g)	1643.00	1672.00
Volume of can V_c (cm^3)	1178.30	1178.3
Bulk density $\frac{m_2 - m_1}{V_c}$ (Mg/m^3)	1.39	1.42
Average bulk density (Mg/m^3)	1.41	

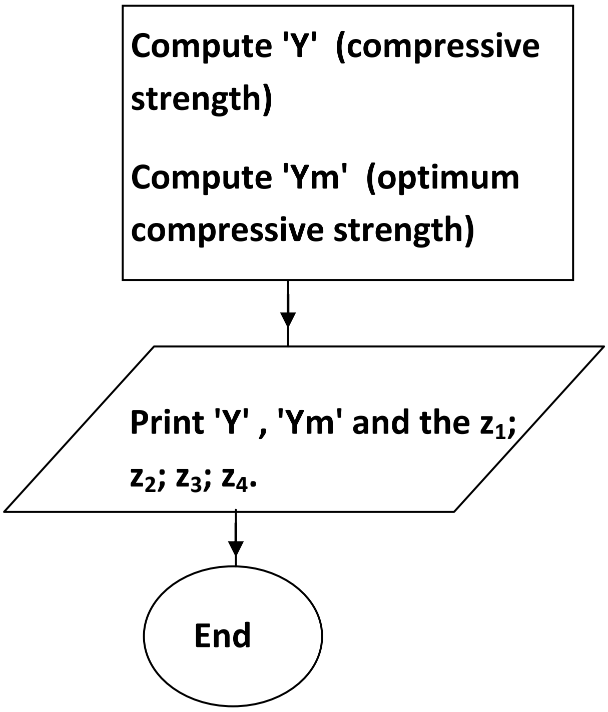
Table 8 Bulk Density of Cement

Soil specimen number	**1**	**2**
Weight of can m_1 (g)	1770.00	1770.00
Weight of can+sample m_2 (g)	3062.00	3022.00
Weight of sample $m_2 - m_1$ (g)	1292.00	1252.00
Volume of can V_c (cm^3)	1178.30	1178.3
Bulk modulus $\frac{m_2 - m_1}{V_c}$ (Mg/m^3)	1.11	1.10
Average bulk density (Mg/m^3)	1.105	

APPENDIX 2

THE FLOW CHART OF THE COMPUTER PROGRAM WRITTEN IN VISUAL BASIC 6




Compute 'Y' (compressive strength)
Compute 'Ym' (optimum compressive strength)
Print 'Y' , 'Ym' and the z_1; z_2; z_3; z_4.
End

APPENDIX 3

```
Private Sub ENDMNU_Click()

End

End Sub


Private Sub Form_Load()


End Sub


Private Sub STARTMNU_Click()

'    MODEL DEVELOPED FROM SURFACE RESPONSE USING MINITAB 17.0 TO DETERMINE COMPRESSIVE STRENGTH OF CONCRETE MADE WITH QUARRY DUST AS FINE AGGREGATE.

Print "     THE PROGRAM WAS WRITTEN BY"

Print: Print

Print "     CHIJIOKE CHIEMELA"

Print:

Print "  DEPARTMENT OF CIVIL ENGINEERING, NAU"


Text1.Text = " "


'ReDim A(50), ZZ(22), AA(6, 6), BB(6, 6), ZY(6)

Text1.Text = Text1.Text + (" ") & vbCrLf

5   QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED Compressive STRENGTH OR CALCULATING Compressive STRENGTH GIVEN MIX RATIO?", "IF THE Compressive STRENGTH IS KNOWN TYPE 1 ELSE TYPE 0", "TYPE 1 OR 0 and CLICK OK")

If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK and do so"): GoTo 5
```

```
If QQ = 0 Then GoTo 30

ym = 0

yy = InputBox("WHAT IS THE DESIRED STRENGTH?"): yy = yy * 1

Text1.Text = Text1.Text + CStr("Comp. Strength" & vbTab & " Water     " & vbTab & "Cement     " & " Sand     " & " Gravel") & vbCrLf

For z1 = 0.5 To 0.6 Step 0.01

For z2 = 0.9985 To 1 Step 0.001

For z3 = 1.5 To 2 Step 0.01

For z4 = 3 To 5 Step 0.01


y = -248.451 - 1165.29 * z1 + 944.1143 * z2 + 389.9625 * z3 - 18.9403 * z4 - 965.899 * z1 ^ 2

y = y - 559.583 * z2 ^ 2 + 30.71971 * z3 ^ 2 + 4.357962 * z4 ^ 2 + 2169.72 * z1 * z2 - 189.505 * z1 * z3

y = y + 65.81441 * z1 * z4 - 514.371 * z2 * z3 - 99.7219 * z2 * z4 + 26.32535 * z3 * z4


If z1 < 0.5 Then GoTo 20

If z1 > 0.6 Then GoTo 20

If z2 < 0.9985 Then GoTo 20

If z2 > 1 Then GoTo 20

If z3 < 1.5 Then GoTo 20

If z3 > 2 Then GoTo 20

If z4 < 3 Then GoTo 20

If z4 > 5 Then GoTo 20

If y > ym Then ym = y: w1 = z1: w2 = z2: w3 = z3: w4 = z4

10      If y > yy - 0.01 And y < yy + 0.01 Then GoTo 15 Else GoTo 20
```

```
15     ' s1 = z1: s2 = z2: s3 = z3: s4 = z4

Text1.Text = Text1.Text + CStr(Format(y, "0.00") & vbTab & "                    ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z1, "0.00") & "  ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z2, "0.00") & "          " & Format(z3, "0.00") & "       ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z4, "0.00")) & vbCrLf

20

Next z4

Next z3

Next z2

Next z1

Text1.Text = Text1.Text + CStr("OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS ") & vbCrLf

Text1.Text = Text1.Text + CStr(Format(ym, "0.00")) & vbCrLf

Text1.Text = Text1.Text + CStr(" THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:") & vbCrLf

Text1.Text = Text1.Text + CStr("     WATER =" & vbTab & vbTab & Format(w1, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("    CEMENT =" & vbTab & Format(w2, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("     SAND =" & vbTab & vbTab & Format(w3, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("    GRAVEL =" & vbTab & Format(w4, "0.00")) & vbCrLf

GoTo 40
```

```
30 ' Calculating Compressive strength when mix ratios are known
z1 = InputBox("ENTER THE VALUE OF Water"): z1 = z1 * 1
z2 = InputBox("ENTER THE VALUE OF Cement"): z2 = z2 * 1
z3 = InputBox("ENTER THE VALUE OF SAND"): z3 = z3 * 1
z4 = InputBox("ENTER THE VALUE OF GRAVEL"): z4 = z4 * 1

y = -248.451 - 1165.29 * z1 + 944.1143 * z2 + 389.9625 * z3 - 18.9403 * z4 - 965.899 * z1 ^ 2
y = y - 559.583 * z2 ^ 2 + 30.71971 * z3 ^ 2 + 4.357962 * z4 ^ 2 + 2169.72 * z1 * z2 - 189.505 * z1 * z3
y = y + 65.81441 * z1 * z4 - 514.371 * z2 * z3 - 99.7219 * z2 * z4 + 26.32535 * z3 * z4

Text1.Text = Text1.Text + CStr("COMPRESSIVE STRENGTH =" & vbTab & Format(y, "0.00") & ",") & vbTab

Text1.Text = Text1.Text + CStr("      WATER   =" & vbTab & Format(z1, "0.00") & ",") & vbTab
Text1.Text = Text1.Text + CStr("      CEMENT  =" & vbTab & Format(z2, "0.00") & ",") & vbTab
Text1.Text = Text1.Text + CStr("      SAND  =" & vbTab & Format(z3, "0.00") & ",") & vbTab
Text1.Text = Text1.Text + CStr("      GRAVEL  =" & vbTab & Format(z4, "0.00") & ",") & vbCrLf

40

End Sub
```

APPENDIX 4

```
Private Sub ENDMNU_Click()

End

End Sub


Private Sub STARTMNU_Click()

'   MODEL MODEL DEVELOPED FROM SURFACE RESPONSE USING MINITAB 17.0 TO DETERMINE COMPRESSIVE STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE.

Print "     THE PROGRAM WAS WRITTEN BY"

Print: Print

Print "     CHIJIOKE CHIEMELA"

Print:

Print "  DEPARTMENT OF CIVIL ENGINEERING, NAU"


Text1.Text = " "


'ReDim A(50), ZZ(22), AA(6, 6), BB(6, 6), ZY(6)

Text1.Text = Text1.Text + (" ") & vbCrLf

5   QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED Compressive STRENGTH OR CALCULATING Compressive STRENGTH GIVEN MIX RATIO?", "IF THE Compressive STRENGTH IS KNOWN TYPE 1 ELSE TYPE 0", "TYPE 1 OR 0 and CLICK OK")

If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK and do so"): GoTo 5

If QQ = 0 Then GoTo 30

ym = 0

yy = InputBox("WHAT IS THE DESIRED STRENGTH?"): yy = yy * 1

Text1.Text = Text1.Text + CStr("Comp. Strength" & vbTab & " Water     " & vbTab & "Cement     " & " Sand    " & " Gravel") & vbCrLf
```

```
For z1 = 0.5 To 0.6 Step 0.01
For z2 = 0.9985 To 1 Step 0.001
For z3 = 1.5 To 2 Step 0.01
For z4 = 3 To 5 Step 0.01

y = -179470 + 8619 * z1 + 352728 * z2 + 1097 * z3 - 28 * z4 + 1137 * z1 ^ 2 - 172266 * z2 ^ 2

y = y + 110.5 * z3 ^ 2 - 3.839 * z4 ^ 2 - 10518 * z1 * z2 + 660 * z1 * z3 - 138# * z1 * z4

y = y - 1845 * z2 * z3 + 141 * z2 * z4 - 2.51 * z3 * z4

If z1 < 0.5 Then GoTo 20
If z1 > 0.6 Then GoTo 20
If z2 < 0.9985 Then GoTo 20
If z2 > 1 Then GoTo 20
If z3 < 1.5 Then GoTo 20
If z3 > 2 Then GoTo 20
If z4 < 3 Then GoTo 20
If z4 > 5 Then GoTo 20
If y > ym Then ym = y: w1 = z1: w2 = z2: w3 = z3: w4 = z4
10      If y > yy - 0.01 And y < yy + 0.01 Then GoTo 15 Else GoTo 20
15     ' s1 = z1: s2 = z2: s3 = z3: s4 = z4

Text1.Text = Text1.Text + CStr(Format(y, "0.00") & vbTab & "                    ") & vbTab
Text1.Text = Text1.Text + CStr(Format(z1, "0.00") & "  ") & vbTab
```

```
Text1.Text = Text1.Text + CStr(Format(z2, "0.00") & "          " & Format(z3, "0.00") & "       ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z4, "0.00")) & vbCrLf


20

Next z4

Next z3

Next z2

Next z1


Text1.Text = Text1.Text + CStr("OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS ") & vbCrLf

Text1.Text = Text1.Text + CStr(Format(ym, "0.00")) & vbCrLf

Text1.Text = Text1.Text + CStr(" THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:") & vbCrLf

Text1.Text = Text1.Text + CStr("     WATER =" & vbTab & vbTab & Format(w1, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("    CEMENT =" & vbTab & Format(w2, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("     SAND =" & vbTab & vbTab & Format(w3, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("    GRAVEL =" & vbTab & Format(w4, "0.00")) & vbCrLf


GoTo 40


30 ' Calculating Compressive strength when mix ratios are known

z1 = InputBox("ENTER THE VALUE OF Water"): z1 = z1 * 1

z2 = InputBox("ENTER THE VALUE OF Cement"): z2 = z2 * 1

z3 = InputBox("ENTER THE VALUE OF SAND"): z3 = z3 * 1
```

```
z4 = InputBox("ENTER THE VALUE OF GRAVEL"): z4 = z4 * 1

y = -179470 + 8619 * z1 + 352728 * z2 + 1097 * z3 - 28 * z4 + 1137 * z1 ^ 2 - 172266 * z2 ^ 2

y = y + 110.5 * z3 ^ 2 - 3.839 * z4 ^ 2 - 10518 * z1 * z2 + 660 * z1 * z3 - 138# * z1 * z4

y = y - 1845 * z2 * z3 + 141 * z2 * z4 - 2.51 * z3 * z4

Text1.Text = Text1.Text + CStr("COMPRESSIVE STRENGTH =" & vbTab & Format(y, "0.00") & ",") & vbTab

Text1.Text = Text1.Text + CStr("      WATER   =" & vbTab & Format(z1, "0.00") & ",") & vbTab

Text1.Text = Text1.Text + CStr("      CEMENT  =" & vbTab & Format(z2, "0.00") & ",") & vbTab

Text1.Text = Text1.Text + CStr("      SAND  =" & vbTab & Format(z3, "0.00") & ",") & vbTab

Text1.Text = Text1.Text + CStr("      GRAVEL  =" & vbTab & Format(z4, "0.00") & ",") & vbCrLf

40

End
```

APPENDIX 5

```
Private Sub ENDMNU_Click()

End

End Sub


Private Sub Form_Load()


End Sub


Private Sub STARTMNU_Click()

'   MODEL DEVELOPED FROM SURFACE RESPONSE USING MINITAB 17.0 TO DETERMINE FLEXURAL STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE.

Print "     THE PROGRAM WAS WRITTEN BY"

Print: Print

Print "     CHIJIOKE CHIEMELA"

Print:

Print "  DEPARTMENT OF CIVIL ENGINEERING, NAU"


Text1.Text = " "


'ReDim A(50), ZZ(22), AA(6, 6), BB(6, 6), ZY(6)

Text1.Text = Text1.Text + (" ") & vbCrLf

5   QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED Compressive STRENGTH OR CALCULATING Compressive STRENGTH GIVEN MIX RATIO?", "IF THE Compressive STRENGTH IS KNOWN TYPE 1 ELSE TYPE 0", "TYPE 1 OR 0 and CLICK OK")

If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK and do so"): GoTo 5
```

```
If QQ = 0 Then GoTo 30

ym = 0

yy = InputBox("WHAT IS THE DESIRED STRENGTH?"): yy = yy * 1

Text1.Text = Text1.Text + CStr("Comp. Strength" & vbTab & " Water     " & vbTab & "Cement     " & " Sand    " & " Gravel") & vbCrLf

For z1 = 0.5 To 0.6 Step 0.01

For z2 = 0.9985 To 1 Step 0.001

For z3 = 1.5 To 2 Step 0.01

For z4 = 3 To 5 Step 0.01


y = 96.93556 - 126.742 * z1 - 242.215 * z2 - 75.7851 * z3 - 24.3074 * z4 + 165.6849 * z1 ^ 2

y = y + 197.0795 * z2 ^ 2 - 3.58658 * z3 ^ 2 + 1.128737 * z4 ^ 2 - 26.8742 * z1 * z2 - 28.9352 * z1 * z3

y = y + 5.715447 * z1 * z4 + 99.41571 * z2 * z3 + 8.907229 * z2 * z4 + 1.987082 * z3 * z4


If z1 < 0.5 Then GoTo 20

If z1 > 0.6 Then GoTo 20

If z2 < 0.9985 Then GoTo 20

If z2 > 1 Then GoTo 20

If z3 < 1.5 Then GoTo 20

If z3 > 2 Then GoTo 20

If z4 < 3 Then GoTo 20

If z4 > 5 Then GoTo 20

If y > ym Then ym = y: w1 = z1: w2 = z2: w3 = z3: w4 = z4

10      If y > yy - 0.01 And y < yy + 0.01 Then GoTo 15 Else GoTo 20
```

```
15    ' s1 = z1: s2 = z2: s3 = z3: s4 = z4

Text1.Text = Text1.Text + CStr(Format(y, "0.00") & vbTab & "                    ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z1, "0.00") & "  ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z2, "0.00") & "          " & Format(z3, "0.00") & "       ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z4, "0.00")) & vbCrLf

20

Next z4

Next z3

Next z2

Next z1

Text1.Text = Text1.Text + CStr("OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS ") & vbCrLf

Text1.Text = Text1.Text + CStr(Format(ym, "0.00")) & vbCrLf

Text1.Text = Text1.Text + CStr(" THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:") & vbCrLf

Text1.Text = Text1.Text + CStr("    WATER =" & vbTab & vbTab & Format(w1, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("    CEMENT =" & vbTab & Format(w2, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("    SAND =" & vbTab & vbTab & Format(w3, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("    GRAVEL =" & vbTab & Format(w4, "0.00")) & vbCrLf

GoTo 40
```

```
30 ' Calculating Compressive strength when mix ratios are known
z1 = InputBox("ENTER THE VALUE OF Water"): z1 = z1 * 1
z2 = InputBox("ENTER THE VALUE OF Cement"): z2 = z2 * 1
z3 = InputBox("ENTER THE VALUE OF SAND"): z3 = z3 * 1
z4 = InputBox("ENTER THE VALUE OF GRAVEL"): z4 = z4 * 1

y = 96.93556 - 126.742 * z1 - 242.215 * z2 - 75.7851 * z3 - 24.3074 * z4 + 165.6849 * z1 ^ 2
y = y + 197.0795 * z2 ^ 2 - 3.58658 * z3 ^ 2 + 1.128737 * z4 ^ 2 - 26.8742 * z1 * z2 - 28.9352 * z1 * z3
y = y + 5.715447 * z1 * z4 + 99.41571 * z2 * z3 + 8.907229 * z2 * z4 + 1.987082 * z3 * z4

Text1.Text = Text1.Text + CStr("COMPRESSIVE STRENGTH =" & vbTab & Format(y, "0.00") & ",") & vbTab

Text1.Text = Text1.Text + CStr("      WATER   =" & vbTab & Format(z1, "0.00") & ",") & vbTab
Text1.Text = Text1.Text + CStr("      CEMENT  =" & vbTab & Format(z2, "0.00") & ",") & vbTab
Text1.Text = Text1.Text + CStr("      SAND  =" & vbTab & Format(z3, "0.00") & ",") & vbTab
Text1.Text = Text1.Text + CStr("      GRAVEL  =" & vbTab & Format(z4, "0.00") & ",") & vbCrLf

40
```

End Sub

APPENDIX 6

```
Private Sub ENDMNU_Click()
End
End Sub

Private Sub Form_Load()

End Sub

Private Sub STARTMNU_Click()
'    MODEL DEVELOPED FROM SURFACE RESPONSE USING MINITAB 17.0 TO DETERMINE FLEXURAL STRENGTH OF CONCRETE MADE WITH QUARRY DUST AS FINE AGGREGATE.
Print "     THE PROGRAM WAS WRITTEN BY"
Print: Print
Print "     CHIJIOKE CHIEMELA"
Print:
Print "  DEPARTMENT OF CIVIL ENGINEERING, NAU"

Text1.Text = " "

'ReDim A(50), ZZ(22), AA(6, 6), BB(6, 6), ZY(6)
Text1.Text = Text1.Text + (" ") & vbCrLf
5   QQ = InputBox("WHAT DO YOU WANT TO DO? TO CALCULATE MIX RATIOS GIVEN DESIRED Compressive STRENGTH OR CALCULATING Compressive STRENGTH GIVEN MIX RATIO?", "IF THE Compressive STRENGTH IS KNOWN TYPE 1 ELSE TYPE 0", "TYPE 1 OR 0 and CLICK OK")
If QQ <> 1 And QQ <> 0 Then EE = InputBox("No Way! You must ENTER 1 or 0", , "CLICK OK and do so"): GoTo 5
```

```
If QQ = 0 Then GoTo 30
ym = 0
yy = InputBox("WHAT IS THE DESIRED STRENGTH?"): yy = yy * 1
Text1.Text = Text1.Text + CStr("Comp. Strength" & vbTab & " Water     " & vbTab & "Cement     " & " Sand    " & " Gravel") & vbCrLf
For z1 = 0.5 To 0.6 Step 0.01
For z2 = 0.9985 To 1 Step 0.001
For z3 = 1.5 To 2 Step 0.01
For z4 = 3 To 5 Step 0.01

y = -9.28516 - 4.4193 * z1 + 11.99515 * z2 + 5.128137 * z3 + 1.569137 * z4 - 19.2847 * z1 ^ 2
y = y - 7.38366 * z2 ^ 2 - 0.48965 * z3 ^ 2 + 0.007262 * z4 ^ 2 + 27.974 * z1 * z2 - 4.85914 * z1 * z3
y = y + 0.80766 * z1 * z4 - 1.4575 * z2 * z3 - 2.32229 * z2 * z4 + 0.132123 * z3 * z4

If z1 < 0.5 Then GoTo 20
If z1 > 0.6 Then GoTo 20
If z2 < 0.9985 Then GoTo 20
If z2 > 1 Then GoTo 20
If z3 < 1.5 Then GoTo 20
If z3 > 2 Then GoTo 20
If z4 < 3 Then GoTo 20
If z4 > 5 Then GoTo 20
If y > ym Then ym = y: w1 = z1: w2 = z2: w3 = z3: w4 = z4
10      If y > yy - 0.01 And y < yy + 0.01 Then GoTo 15 Else GoTo 20
15      ' s1 = z1: s2 = z2: s3 = z3: s4 = z4
```

```
Text1.Text = Text1.Text + CStr(Format(y, "0.00") & vbTab & "                    ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z1, "0.00") & "  ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z2, "0.00") & "          " & Format(z3, "0.00") & "       ") & vbTab

Text1.Text = Text1.Text + CStr(Format(z4, "0.00")) & vbCrLf


20

Next z4

Next z3

Next z2

Next z1


Text1.Text = Text1.Text + CStr("OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS ") & vbCrLf

Text1.Text = Text1.Text + CStr(Format(ym, "0.00")) & vbCrLf

Text1.Text = Text1.Text + CStr(" THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:") & vbCrLf

Text1.Text = Text1.Text + CStr("     WATER =" & vbTab & vbTab & Format(w1, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("    CEMENT =" & vbTab & Format(w2, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("     SAND =" & vbTab & vbTab & Format(w3, "0.00")) & vbTab

Text1.Text = Text1.Text + CStr("    GRAVEL =" & vbTab & Format(w4, "0.00")) & vbCrLf


GoTo 40
```

```
30 ' Calculating Compressive strength when mix ratios are known
z1 = InputBox("ENTER THE VALUE OF Water"): z1 = z1 * 1
z2 = InputBox("ENTER THE VALUE OF Cement"): z2 = z2 * 1
z3 = InputBox("ENTER THE VALUE OF SAND"): z3 = z3 * 1
z4 = InputBox("ENTER THE VALUE OF GRAVEL"): z4 = z4 * 1

y = -9.28516 - 4.4193 * z1 + 11.99515 * z2 + 5.128137 * z3 + 1.569137 * z4 - 19.2847 * z1 ^ 2
y = y - 7.38366 * z2 ^ 2 - 0.48965 * z3 ^ 2 + 0.007262 * z4 ^ 2 + 27.974 * z1 * z2 - 4.85914 * z1 * z3
y = y + 0.80766 * z1 * z4 - 1.4575 * z2 * z3 - 2.32229 * z2 * z4 + 0.132123 * z3 * z4

Text1.Text = Text1.Text + CStr("COMPRESSIVE STRENGTH =" & vbTab & Format(y, "0.00") & ",") & vbTab

Text1.Text = Text1.Text + CStr("      WATER   =" & vbTab & Format(z1, "0.00") & ",") & vbTab
Text1.Text = Text1.Text + CStr("      CEMENT  =" & vbTab & Format(z2, "0.00") & ",") & vbTab
Text1.Text = Text1.Text + CStr("      SAND  =" & vbTab & Format(z3, "0.00") & ",") & vbTab
Text1.Text = Text1.Text + CStr("      GRAVEL  =" & vbTab & Format(z4, "0.00") & ",") & vbCrLf

40

End Sub
```

APPENDIX 7

THE OUTPUT RESULTS FOR 20N/MM^2 FOR COMPRESSIVE STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE.

C/Strength	Water	Cement	Sand	Gravel
20.00	0.50	1.00	1.89	3.38
20.00	0.50	1.00	1.71	3.03
20.00	0.50	1.00	1.89	3.36
20.00	0.50	1.00	1.92	3.37
20.00	0.50	1.00	1.93	3.37
20.00	0.50	1.00	1.96	3.36
20.01	0.51	1.00	1.68	3.00
20.00	0.51	1.00	1.72	3.11
20.00	0.51	1.00	1.90	3.34
20.00	0.51	1.00	1.72	3.08
20.00	0.51	1.00	1.74	3.13
20.00	0.51	1.00	1.80	3.25
20.00	0.51	1.00	1.85	3.31
20.00	0.51	1.00	1.94	3.31
19.99	0.51	1.00	1.96	3.29
20.00	0.52	1.00	1.69	3.04
20.01	0.52	1.00	1.96	3.18
20.00	0.52	1.00	1.84	3.27
20.01	0.52	1.00	1.89	3.27
20.00	0.52	1.00	1.94	3.22
20.01	0.53	1.00	1.68	3.01
20.00	0.53	1.00	1.71	3.08
20.00	0.53	1.00	1.73	3.12

20.00	**0.53**	**1.00**	**1.77**	**3.18**
19.99	**0.53**	**1.00**	**1.78**	**3.19**
20.01	**0.53**	**1.00**	**1.79**	**3.20**
20.00	**0.53**	**1.00**	**1.81**	**3.21**
20.00	**0.53**	**1.00**	**1.84**	**3.21**
20.00	**0.53**	**1.00**	**1.86**	**3.20**
20.01	**0.53**	**1.00**	**1.92**	**3.12**
19.99	**0.53**	**1.00**	**1.97**	**3.00**
20.00	**0.53**	**1.00**	**1.71**	**3.06**
19.99	**0.53**	**1.00**	**1.74**	**3.12**
19.99	**0.53**	**1.00**	**1.95**	**3.07**
20.01	**0.54**	**1.00**	**1.74**	**3.09**
20.00	**0.54**	**1.00**	**1.75**	**3.10**
20.00	**0.54**	**1.00**	**1.78**	**3.12**
20.00	**0.54**	**1.00**	**1.81**	**3.12**
20.01	**0.54**	**1.00**	**1.84**	**3.10**
20.01	**0.54**	**1.00**	**1.87**	**3.06**
20.00	**0.54**	**1.00**	**1.90**	**3.00**
20.00	**0.54**	**1.00**	**1.72**	**3.05**
19.99	**0.54**	**1.00**	**1.74**	**3.08**
20.01	**0.54**	**1.00**	**1.84**	**3.11**
20.00	**0.54**	**1.00**	**1.85**	**3.10**
20.00	**0.54**	**1.00**	**1.91**	**3.00**
20.00	**0.55**	**1.00**	**1.76**	**3.01**
20.00	**0.55**	**1.00**	**1.77**	**3.01**
20.00	**0.55**	**1.00**	**1.80**	**3.01**
20.01	**0.58**	**1.00**	**1.61**	**5.00**

19.99	**0.58**	**1.00**	**1.65**	**4.94**
19.99	**0.58**	**1.00**	**1.66**	**4.93**
20.01	**0.58**	**1.00**	**1.72**	**4.92**
20.00	**0.58**	**1.00**	**1.63**	**4.98**
19.99	**0.58**	**1.00**	**1.65**	**4.95**
20.01	**0.58**	**1.00**	**1.68**	**4.92**
19.99	**0.58**	**1.00**	**1.74**	**4.93**
20.00	**0.58**	**1.00**	**1.76**	**4.95**
20.00	**0.58**	**1.00**	**1.78**	**4.98**
20.00	**0.59**	**1.00**	**1.55**	**4.94**
20.01	**0.59**	**1.00**	**1.60**	**4.84**
20.00	**0.59**	**1.00**	**1.64**	**4.80**
20.01	**0.59**	**1.00**	**1.69**	**4.80**
20.01	**0.59**	**1.00**	**1.73**	**4.84**
20.01	**0.59**	**1.00**	**1.56**	**4.93**
19.99	**0.59**	**1.00**	**1.69**	**4.79**
20.00	**0.59**	**1.00**	**1.76**	**4.87**
20.00	**0.59**	**1.00**	**1.77**	**4.89**
20.01	**0.59**	**1.00**	**1.78**	**4.91**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

53.09

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.50 GRAVEL = 5.00

APPENDIX 8

THE OUT PUT RESULTS FOR 25N/MM^2 FOR COMPRESSIVE STRENGTH OF CONCRETE MADE WITH RIVER SAND SA FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
24.99	0.50	1.00	1.70	3.37
25.00	0.50	1.00	1.87	3.80
25.00	0.50	1.00	1.88	3.81
25.00	0.50	1.00	1.92	3.83
25.00	0.50	1.00	1.93	3.83
25.01	0.50	1.00	1.66	3.18
24.99	0.50	1.00	1.69	3.29
25.00	0.50	1.00	1.74	3.46
24.99	0.50	1.00	1.77	3.55
25.00	0.50	1.00	1.80	3.63
25.00	0.50	1.00	1.86	3.75
25.01	0.51	1.00	1.69	3.40
25.00	0.51	1.00	1.71	3.47
25.01	0.51	1.00	1.80	3.73
25.00	0.51	1.00	1.81	3.75
25.00	0.51	1.00	1.84	3.80
25.01	0.51	1.00	1.87	3.83
25.01	0.51	1.00	1.68	3.32
24.99	0.51	1.00	1.72	3.46
25.00	0.51	1.00	1.78	3.64
25.01	0.51	1.00	1.80	3.69
24.99	0.51	1.00	1.81	3.71
24.99	0.51	1.00	1.82	3.73

25.01	0.59	1.00	1.62	3.08
25.00	0.59	1.00	1.62	4.07
25.00	0.59	1.00	1.64	4.03
24.99	0.59	1.00	1.65	3.11
25.00	0.59	1.00	1.66	3.11
25.00	0.59	1.00	1.66	4.01
25.01	0.59	1.00	1.67	4.01
25.00	0.59	1.00	1.68	3.09
25.00	0.59	1.00	1.68	4.02
24.99	0.59	1.00	1.69	3.07
25.01	0.59	1.00	1.69	4.03
25.00	0.59	1.00	1.70	4.05
25.01	0.59	1.00	1.71	3.02
25.01	0.59	1.00	1.71	4.07
24.99	0.59	1.00	1.72	4.10
24.99	0.59	1.00	1.73	4.13
25.01	0.59	1.00	1.74	4.16
25.00	0.59	1.00	1.81	4.44
25.00	0.59	1.00	1.83	4.53
25.00	0.59	1.00	1.85	4.62
25.00	0.59	1.00	1.88	4.76
25.00	0.59	1.00	1.92	4.95

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

53.09

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.50 GRAVEL = 5.00

APPENDIX 9

THE OUT PUT RESULTS FOR 30N/MM^2 FOR COMPRESSIVE STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
30.00	0.50	1.00	1.57	3.16
30.00	0.50	1.00	1.64	3.50
30.00	0.50	1.00	1.74	3.97
30.00	0.50	1.00	1.76	4.06
29.99	0.50	1.00	1.79	4.19
29.99	0.50	1.00	1.83	4.35
30.01	0.50	1.00	1.84	4.39
30.01	0.50	1.00	1.91	4.57
30.01	0.50	1.00	1.92	4.58
30.00	0.50	1.00	1.93	4.58
30.00	0.50	1.00	1.94	4.58
30.00	0.50	1.00	1.95	4.57
30.01	0.50	1.00	1.56	3.06
30.00	0.50	1.00	1.61	3.30
30.00	0.50	1.00	1.65	3.49
29.99	0.50	1.00	1.68	3.63
30.00	0.50	1.00	1.76	3.99
30.01	0.50	1.00	1.83	4.27
29.99	0.50	1.00	1.88	4.42
30.01	0.50	1.00	1.92	4.49
29.99	0.50	1.00	1.97	4.47
29.99	0.51	1.00	1.53	3.05
30.01	0.51	1.00	1.58	3.31

30.00	**0.58**	**1.00**	**1.94**	**4.42**
29.99	**0.58**	**1.00**	**1.96**	**4.59**
30.00	**0.58**	**1.00**	**1.98**	**4.74**
30.01	**0.58**	**1.00**	**1.99**	**4.81**
29.99	**0.59**	**1.00**	**1.85**	**3.15**
30.00	**0.59**	**1.00**	**1.85**	**3.81**
29.99	**0.59**	**1.00**	**1.86**	**3.00**
29.99	**0.59**	**1.00**	**1.86**	**3.23**
29.99	**0.59**	**1.00**	**1.86**	**3.76**
30.00	**0.59**	**1.00**	**1.87**	**3.06**
29.99	**0.59**	**1.00**	**1.88**	**4.05**
30.01	**0.59**	**1.00**	**1.89**	**4.15**
29.99	**0.59**	**1.00**	**1.91**	**4.33**
29.99	**0.59**	**1.00**	**1.92**	**4.41**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

53.09

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.50
GRAVEL = 5.00

APPENDIX 10

THE OUT PUT RESULTS FOR 40N/MM^2 FOR COMPRESSIVE STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
40.00	0.50	1.00	1.51	3.51
40.00	0.50	1.00	1.52	3.58
40.00	0.50	1.00	1.55	3.80
40.01	0.50	1.00	1.57	3.96
40.00	0.50	1.00	1.63	4.58
40.00	0.50	1.00	1.64	4.75
40.00	0.50	1.00	1.50	3.37
39.99	0.50	1.00	1.60	4.11
40.00	0.50	1.00	1.62	4.30
40.01	0.50	1.00	1.64	4.53
40.00	0.50	1.00	1.66	4.88
40.01	0.51	1.00	1.52	3.80
40.01	0.51	1.00	1.53	3.89
40.00	0.51	1.00	1.56	4.20
39.99	0.51	1.00	1.58	4.48
40.00	0.51	1.00	1.59	4.70
40.00	0.51	1.00	1.50	3.55
39.99	0.51	1.00	1.55	3.97
40.00	0.51	1.00	1.56	4.07
40.01	0.51	1.00	1.58	4.30
40.00	0.51	1.00	1.59	4.44
40.00	0.52	1.00	1.50	3.90
40.00	0.53	1.00	1.50	4.24

39.99	**0.53**	**1.00**	**1.51**	**4.61**
40.00	**0.53**	**1.00**	**1.51**	**4.62**
40.00	**0.53**	**1.00**	**1.51**	**4.63**
40.01	**0.53**	**1.00**	**1.51**	**4.64**
40.01	**0.53**	**1.00**	**1.51**	**4.65**
40.01	**0.53**	**1.00**	**1.51**	**4.73**
40.01	**0.53**	**1.00**	**1.51**	**4.74**
40.00	**0.53**	**1.00**	**1.51**	**4.75**
40.00	**0.53**	**1.00**	**1.51**	**4.76**
39.99	**0.53**	**1.00**	**1.51**	**4.77**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

53.09

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.50
GRAVEL = 5.00

APPENDIX 11

THE OUTPUT RESULTS FOR 50N/MM^2 FOR COMPRESSIVE STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
49.99	0.50	1.00	1.52	5.00
50.00	0.50	1.00	1.51	4.45
49.99	0.50	1.00	1.53	4.88

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

53.09

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.50 GRAVEL = 5.00

APPENDIX 12

THE OUT PUT RESULTS FOR 20N/MM^2 FOR COMPRESSIVE STRENGTH OF CONCRETE MADE WITH QUARY DUST AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
19.99	0.50	1.00	1.53	4.17
20.00	0.50	1.00	1.56	4.12
20.00	0.50	1.00	1.64	3.99
20.00	0.50	1.00	1.67	3.94
20.00	0.50	1.00	1.70	3.89
20.00	0.50	1.00	1.73	3.84
20.00	0.50	1.00	1.76	3.79
20.00	0.50	1.00	1.79	3.74
19.99	0.50	1.00	1.82	3.69
20.00	0.50	1.00	1.82	4.96
20.01	0.50	1.00	1.83	3.67
19.99	0.50	1.00	1.85	4.83
20.00	0.50	1.00	1.86	3.62
19.99	0.50	1.00	1.88	4.70
20.00	0.50	1.00	1.89	4.66
20.00	0.50	1.00	1.90	3.55
20.01	0.50	1.00	1.91	3.53
20.00	0.50	1.00	1.92	4.53
20.01	0.50	1.00	1.93	4.49
19.99	0.50	1.00	1.94	3.48
20.00	0.50	1.00	1.95	3.46
20.01	0.50	1.00	1.96	3.44
19.99	0.50	1.00	1.96	4.36

20.00	**0.56**	**1.00**	**1.68**	**3.15**
20.00	**0.56**	**1.00**	**1.98**	**4.97**
20.01	**0.57**	**1.00**	**1.56**	**3.52**
19.99	**0.57**	**1.00**	**1.64**	**3.15**
20.01	**0.57**	**1.00**	**1.67**	**3.01**
19.99	**0.57**	**1.00**	**1.61**	**3.28**
20.00	**0.57**	**1.00**	**1.64**	**3.14**
20.00	**0.58**	**1.00**	**1.59**	**3.19**
19.99	**0.58**	**1.00**	**1.54**	**3.43**
20.00	**0.58**	**1.00**	**1.55**	**3.38**
20.00	**0.58**	**1.00**	**1.62**	**3.04**
20.01	**0.59**	**1.00**	**1.54**	**3.24**
20.00	**0.59**	**1.00**	**1.55**	**3.19**
20.01	**0.59**	**1.00**	**1.53**	**3.29**
20.00	**0.59**	**1.00**	**1.54**	**3.24**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

37.86

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.50
GRAVEL = 3.00

APPENDIX 13

THE OUT PUT RESULTS FOR 25N/MM^2 FOR COMPRESSIVE STRENGTH OF CONCRETE MADE WITH QUARY DUST AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
25.00	0.50	1.00	1.58	3.61
25.00	0.50	1.00	1.66	3.44
25.00	0.50	1.00	1.71	3.33
25.00	0.50	1.00	1.75	3.24
25.01	0.50	1.00	1.57	3.61
24.99	0.50	1.00	1.58	3.59
25.00	0.50	1.00	1.64	3.46
24.99	0.50	1.00	1.69	3.35
25.00	0.50	1.00	1.76	3.19
25.00	0.50	1.00	1.79	3.12
25.01	0.50	1.00	1.84	3.00
25.00	0.51	1.00	1.58	3.58
24.99	0.51	1.00	1.63	3.46
25.00	0.51	1.00	1.65	3.41
25.00	0.51	1.00	1.67	3.36
25.00	0.51	1.00	1.69	3.31
24.99	0.51	1.00	1.71	3.26
25.00	0.51	1.00	1.76	3.13
25.00	0.51	1.00	1.79	3.05
25.00	0.51	1.00	1.50	3.75
25.00	0.51	1.00	1.53	3.68
25.01	0.51	1.00	1.58	3.56

25.00	**0.54**	**1.00**	**1.63**	**3.19**
25.00	**0.55**	**1.00**	**1.52**	**3.48**
24.99	**0.55**	**1.00**	**1.60**	**3.19**
25.01	**0.55**	**1.00**	**1.52**	**3.47**
24.99	**0.55**	**1.00**	**1.57**	**3.29**
24.99	**0.55**	**1.00**	**1.60**	**3.18**
24.99	**0.56**	**1.00**	**1.52**	**3.37**
25.01	**0.56**	**1.00**	**1.53**	**3.33**
24.99	**0.56**	**1.00**	**1.61**	**3.01**
24.99	**0.57**	**1.00**	**1.53**	**3.20**
25.01	**0.57**	**1.00**	**1.50**	**3.32**
25.01	**0.57**	**1.00**	**1.56**	**3.07**
25.00	**0.58**	**1.00**	**1.51**	**3.14**
24.99	**0.58**	**1.00**	**1.51**	**3.14**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

37.86

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.50 GRAVEL = 3.00

APPENDIX 14

THE OUT PUT RESULTS FOR 30N/MM^2 FOR COMPRESSIVE STRENGTH OF CONCRETE MADE WITH QUARY DUST AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
30.01	0.50	1.00	1.52	3.39
30.01	0.50	1.00	1.56	3.30
29.99	0.50	1.00	1.60	3.21
30.00	0.50	1.00	1.63	3.14
30.00	0.50	1.00	1.66	3.07
30.00	0.50	1.00	1.51	3.40
29.99	0.50	1.00	1.55	3.31
30.00	0.50	1.00	1.67	3.03
29.99	0.51	1.00	1.51	3.39
30.01	0.51	1.00	1.53	3.34
30.00	0.51	1.00	1.61	3.14
30.00	0.52	1.00	1.62	3.05
30.01	0.52	1.00	1.54	3.26
30.00	0.52	1.00	1.58	3.15
29.99	0.53	1.00	1.51	3.30
30.00	0.53	1.00	1.52	3.27
30.00	0.53	1.00	1.53	3.24
30.01	0.53	1.00	1.54	3.21
30.01	0.53	1.00	1.59	3.06
30.00	0.53	1.00	1.60	3.03
29.99	0.53	1.00	1.61	3.00
30.00	0.53	1.00	1.50	3.32
30.00	0.53	1.00	1.60	3.02

29.99	**0.54**	**1.00**	**1.56**	**3.07**
29.99	**0.54**	**1.00**	**1.53**	**3.16**
29.99	**0.54**	**1.00**	**1.57**	**3.03**
30.01	**0.55**	**1.00**	**1.50**	**3.18**
30.00	**0.56**	**1.00**	**1.50**	**3.08**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

37.86

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.50 GRAVEL = 3.00

APPENDIX 15

THE OUT PUT RESULTS FOR 35N/MM^2 FOR COMPRESSIVE STRENGTH OF CONCRETE MADE WITH QUARY DUST AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
34.99	0.51	1.00	1.50	3.12

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

37.86

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.50 GRAVEL = 3.00

APPENDIX 16

THE OUT PUT RESULTS FOR 2.0N/MM^2 FOR FLEXURAL STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
2.00	0.50	1.00	1.50	3.48
2.00	0.50	1.00	1.50	5.00
2.01	0.50	1.00	1.51	3.51
2.00	0.50	1.00	1.51	4.95
2.01	0.50	1.00	1.52	3.54
1.99	0.50	1.00	1.52	3.55
2.00	0.50	1.00	1.52	4.90
2.00	0.50	1.00	1.53	3.58
2.00	0.50	1.00	1.53	4.85
2.00	0.50	1.00	1.54	3.62
1.99	0.50	1.00	1.54	4.79
2.01	0.50	1.00	1.54	4.80
2.00	0.50	1.00	1.55	3.66
1.99	0.50	1.00	1.55	4.73
2.01	0.50	1.00	1.55	4.74
2.00	0.50	1.00	1.56	3.70
1.99	0.50	1.00	1.56	3.71
2.00	0.50	1.00	1.56	4.67
2.01	0.50	1.00	1.56	4.68
2.00	0.50	1.00	1.57	3.75
2.00	0.50	1.00	1.57	3.76
2.00	0.50	1.00	1.57	4.60
2.00	0.50	1.00	1.57	4.61

2.00	**0.59**	**1.00**	**1.50**	**4.03**
2.00	**0.59**	**1.00**	**1.50**	**4.04**
2.00	**0.59**	**1.00**	**1.50**	**4.05**
2.00	**0.59**	**1.00**	**1.50**	**4.06**
2.00	**0.59**	**1.00**	**1.50**	**4.07**
2.00	**0.59**	**1.00**	**1.50**	**4.08**
2.01	**0.59**	**1.00**	**1.50**	**4.09**
2.01	**0.59**	**1.00**	**1.50**	**4.10**
2.01	**0.59**	**1.00**	**1.50**	**4.11**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

5.53

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.99 GRAVEL = 5.00

APPENDIX 17

THE OUT PUT RESULTS FOR 2.5N/MM^2 FOR FLEXURAL STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
2.51	0.50	1.00	1.50	3.23
2.51	0.50	1.00	1.51	3.25
2.51	0.50	1.00	1.52	3.27
2.49	0.50	1.00	1.53	3.30
2.50	0.50	1.00	1.54	3.32
2.50	0.50	1.00	1.55	3.34
2.49	0.50	1.00	1.56	3.37
2.50	0.50	1.00	1.57	3.39
2.50	0.50	1.00	1.57	4.97
2.49	0.50	1.00	1.58	3.42
2.51	0.50	1.00	1.58	4.93
2.50	0.50	1.00	1.59	3.44
2.50	0.50	1.00	1.59	4.88
2.50	0.50	1.00	1.60	3.47
2.49	0.50	1.00	1.60	4.83
2.51	0.50	1.00	1.60	4.84
2.50	0.50	1.00	1.61	3.50
2.50	0.50	1.00	1.61	4.79
2.50	0.50	1.00	1.62	3.53
2.50	0.50	1.00	1.62	4.74
2.51	0.50	1.00	1.63	3.56
2.49	0.50	1.00	1.63	3.57
2.50	0.50	1.00	1.63	4.69

2.50	**0.53**	**1.00**	**1.76**	**4.14**
2.50	**0.53**	**1.00**	**1.76**	**4.15**
2.51	**0.53**	**1.00**	**1.76**	**4.16**
2.51	**0.53**	**1.00**	**1.77**	**3.78**
2.51	**0.53**	**1.00**	**1.77**	**3.79**
2.50	**0.53**	**1.00**	**1.77**	**3.80**
2.50	**0.53**	**1.00**	**1.77**	**3.81**
2.50	**0.53**	**1.00**	**1.77**	**3.82**
2.50	**0.53**	**1.00**	**1.77**	**3.83**
2.49	**0.53**	**1.00**	**1.77**	**3.84**
2.49	**0.53**	**1.00**	**1.77**	**3.85**
2.49	**0.53**	**1.00**	**1.77**	**3.86**
2.49	**0.53**	**1.00**	**1.77**	**4.00**
2.49	**0.53**	**1.00**	**1.77**	**4.01**
2.49	**0.53**	**1.00**	**1.77**	**4.02**
2.50	**0.53**	**1.00**	**1.77**	**4.03**
2.50	**0.53**	**1.00**	**1.77**	**4.04**
2.50	**0.53**	**1.00**	**1.77**	**4.05**
2.50	**0.53**	**1.00**	**1.77**	**4.06**
2.51	**0.53**	**1.00**	**1.77**	**4.07**
2.50	**0.53**	**1.00**	**1.50**	**3.27**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

5.53

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.99 GRAVEL = 5.00

APPENDIX 18

THE OUT PUT RESULTS FOR 3.0N/MM^2 FOR FLEXURAL STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
3.01	0.50	1.00	1.50	3.03
3.00	0.50	1.00	1.51	3.05
3.00	0.50	1.00	1.53	3.08
2.99	0.50	1.00	1.54	3.10
3.01	0.50	1.00	1.55	3.11
3.00	0.50	1.00	1.56	3.13
2.99	0.50	1.00	1.57	3.15
3.00	0.50	1.00	1.59	3.18
3.00	0.50	1.00	1.60	3.20
3.00	0.50	1.00	1.61	3.22
2.99	0.50	1.00	1.62	3.24
2.99	0.50	1.00	1.63	3.26
3.00	0.50	1.00	1.63	5.00
2.99	0.50	1.00	1.64	3.28
3.00	0.50	1.00	1.64	4.96
2.99	0.50	1.00	1.65	3.30
2.99	0.50	1.00	1.65	4.92
2.99	0.50	1.00	1.66	3.32
2.99	0.50	1.00	1.66	4.88
3.01	0.50	1.00	1.66	4.89
3.00	0.50	1.00	1.67	3.34
3.01	0.50	1.00	1.67	4.85
3.00	0.50	1.00	1.68	3.36

3.00	0.50	1.00	1.68	4.81
3.00	0.50	1.00	1.69	3.38
3.01	0.50	1.00	1.69	4.77
3.01	0.50	1.00	1.70	3.40
2.99	0.50	1.00	1.70	3.41
2.99	0.50	1.00	1.70	4.72
3.01	0.50	1.00	1.70	4.73
3.00	0.50	1.00	1.71	3.43
3.00	0.50	1.00	1.71	4.68
3.01	0.50	1.00	1.71	4.69
3.01	0.50	1.00	1.72	3.45
2.99	0.50	1.00	1.72	3.46
3.00	0.50	1.00	1.72	4.64
3.00	0.50	1.00	1.73	3.48
2.99	0.50	1.00	1.73	3.49
2.99	0.50	1.00	1.73	4.59
3.01	0.50	1.00	1.73	4.60
3.00	0.50	1.00	1.74	3.51
2.99	0.50	1.00	1.74	3.52
2.99	0.50	1.00	1.74	4.54
3.00	0.50	1.00	1.74	4.55
3.00	0.50	1.00	1.75	3.54

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS 5.53

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.99 GRAVEL = 5.00

APPENDIX 19

THE OUT PUT RESULTS FOR 4.0N/MM^2 FOR FLEXURAL STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
4.01	0.50	1.00	1.79	4.97
4.01	0.50	1.00	1.80	3.01
4.00	0.50	1.00	1.80	4.94
4.01	0.50	1.00	1.81	3.02
3.99	0.50	1.00	1.81	4.91
4.01	0.50	1.00	1.82	3.03
4.01	0.50	1.00	1.82	4.89
4.01	0.50	1.00	1.83	3.04
4.00	0.50	1.00	1.83	4.86
4.01	0.50	1.00	1.84	3.05
4.00	0.50	1.00	1.84	4.83
4.00	0.50	1.00	1.85	3.06
4.01	0.50	1.00	1.85	4.81
4.00	0.50	1.00	1.86	3.07
4.00	0.50	1.00	1.86	4.78
4.00	0.50	1.00	1.87	3.08
4.00	0.50	1.00	1.87	4.75
4.00	0.50	1.00	1.88	3.09
3.99	0.50	1.00	1.88	4.72
4.01	0.50	1.00	1.88	4.73
4.00	0.50	1.00	1.89	3.10
4.00	0.50	1.00	1.89	4.70

3.99	**0.50**	**1.00**	**1.82**	**4.69**
4.01	**0.50**	**1.00**	**1.83**	**3.23**
4.00	**0.51**	**1.00**	**1.93**	**4.68**
4.00	**0.51**	**1.00**	**1.94**	**3.00**
4.00	**0.51**	**1.00**	**1.94**	**4.66**
4.01	**0.51**	**1.00**	**1.95**	**3.00**
4.01	**0.51**	**1.00**	**1.95**	**4.64**
3.99	**0.51**	**1.00**	**1.96**	**3.01**
4.01	**0.51**	**1.00**	**1.96**	**4.62**
4.00	**0.51**	**1.00**	**1.97**	**3.01**
3.99	**0.51**	**1.00**	**1.97**	**4.59**
4.01	**0.51**	**1.00**	**1.97**	**4.60**
4.01	**0.51**	**1.00**	**1.98**	**3.01**
3.99	**0.51**	**1.00**	**1.98**	**4.57**
4.01	**0.51**	**1.00**	**1.98**	**4.58**
3.99	**0.51**	**1.00**	**1.99**	**3.02**
3.99	**0.51**	**1.00**	**1.99**	**4.55**
3.99	**0.51**	**1.00**	**1.72**	**3.00**
3.99	**0.51**	**1.00**	**1.73**	**3.01**
3.99	**0.51**	**1.00**	**1.74**	**3.02**
3.99	**0.51**	**1.00**	**1.75**	**3.03**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

5.53

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.99
GRAVEL = 5.00

APPENDIX 20

THE OUT PUT RESULTS FOR 5.0N/MM^2 FOR FLEXURAL STRENGTH OF CONCRETE MADE WITH RIVER SAND AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
5.01	0.50	1.00	1.96	5.00
5.00	0.50	1.00	1.97	4.98
5.00	0.50	1.00	1.98	4.96
4.99	0.50	1.00	1.99	4.94
4.99	0.50	1.00	1.89	4.99
5.00	0.50	1.00	1.90	4.97
5.00	0.50	1.00	1.91	4.95
5.01	0.50	1.00	1.92	4.93
5.01	0.50	1.00	1.93	4.91
4.99	0.50	1.00	1.95	4.86
4.99	0.50	1.00	1.96	4.84
4.99	0.50	1.00	1.97	4.82
4.99	0.50	1.00	1.98	4.80
4.99	0.50	1.00	1.99	4.78
5.00	0.51	1.00	1.99	5.00
5.00	0.51	1.00	1.91	5.00
5.00	0.51	1.00	1.92	4.98
4.99	0.51	1.00	1.93	4.96
4.99	0.51	1.00	1.94	4.94
5.01	0.51	1.00	1.96	4.91
5.00	0.51	1.00	1.97	4.89
5.00	0.51	1.00	1.98	4.87
4.99	0.51	1.00	1.99	4.85

5.01	**0.59**	**1.00**	**1.90**	**4.96**
5.00	**0.59**	**1.00**	**1.91**	**4.95**
5.00	**0.59**	**1.00**	**1.92**	**4.94**
5.00	**0.59**	**1.00**	**1.93**	**4.93**
4.99	**0.59**	**1.00**	**1.94**	**4.92**
5.01	**0.59**	**1.00**	**1.96**	**4.91**
5.00	**0.59**	**1.00**	**1.97**	**4.90**
4.99	**0.59**	**1.00**	**1.98**	**4.89**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS

5.53

THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.99
GRAVEL = 5.00

APPENDIX 21

THE OUT PUT RESULTS FOR 2.5N/MM^2 FOR FLEXURAL STRENGTH OF CONCRETE MADE WITH QUARRY DUST AS FINE AGGREGATE

C/Strength	Water	Cement	Sand	Gravel
2.51	0.50	1.00	1.50	4.52
2.51	0.50	1.00	1.50	4.53
2.51	0.50	1.00	1.50	4.54
2.51	0.50	1.00	1.50	4.55
2.51	0.50	1.00	1.50	4.56
2.51	0.50	1.00	1.50	4.57
2.50	0.50	1.00	1.50	4.58
2.50	0.50	1.00	1.50	4.59
2.50	0.50	1.00	1.50	4.60
2.50	0.50	1.00	1.50	4.61
2.50	0.50	1.00	1.50	4.62
2.50	0.50	1.00	1.50	4.63
2.50	0.50	1.00	1.50	4.64
2.50	0.50	1.00	1.50	4.65
2.50	0.50	1.00	1.50	4.66
2.50	0.50	1.00	1.50	4.67
2.50	0.50	1.00	1.50	4.68
2.50	0.50	1.00	1.50	4.69
2.50	0.50	1.00	1.50	4.70
2.49	0.50	1.00	1.50	4.71
2.49	0.50	1.00	1.50	4.72
2.49	0.50	1.00	1.50	4.73
2.49	0.50	1.00	1.50	4.74

2.49	**0.50**	**1.00**	**1.53**	**4.92**
2.51	**0.50**	**1.00**	**1.54**	**4.71**
2.51	**0.50**	**1.00**	**1.54**	**4.72**
2.51	**0.50**	**1.00**	**1.54**	**4.73**
2.51	**0.50**	**1.00**	**1.54**	**4.74**
2.51	**0.50**	**1.00**	**1.54**	**4.75**
2.51	**0.50**	**1.00**	**1.54**	**4.76**
2.51	**0.50**	**1.00**	**1.54**	**4.77**
2.50	**0.50**	**1.00**	**1.54**	**4.78**
2.50	**0.50**	**1.00**	**1.54**	**4.79**
2.50	**0.50**	**1.00**	**1.54**	**4.80**
2.50	**0.50**	**1.00**	**1.54**	**4.81**
2.50	**0.50**	**1.00**	**1.54**	**4.82**
2.50	**0.50**	**1.00**	**1.54**	**4.83**
2.50	**0.50**	**1.00**	**1.54**	**4.84**
2.50	**0.50**	**1.00**	**1.54**	**4.85**
2.50	**0.50**	**1.00**	**1.54**	**4.86**
2.50	**0.50**	**1.00**	**1.54**	**4.87**
2.50	**0.50**	**1.00**	**1.54**	**4.88**

OPTIMUM COMPRESSIVE STRENGTH PREDICTABLE BY THIS MODEL IS 5.53

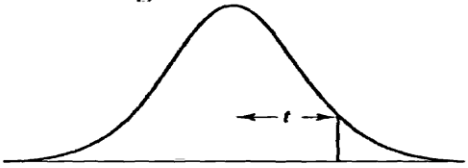
THE CORRESPONDING MIXTURE RATIO IS AS FOLLOWS:

WATER = 0.50 CEMENT = 1.00 SAND = 1.99 GRAVEL = 5.00

APPENDIX 22

Table of Percentage points of the t-distribution

Table B1. Probability Points of the *t* Distribution with *ν* Degrees of Freedom



ν	0.4	0.25	0.1	0.05	0.025	0.01	0.005	0.0025	0.001	0.0005
	Tail Area Probability									
1	0.325	1.000	3.078	6.314	12.706	31.821	63.657	127.32	318.31	636.62
2	0.289	0.816	1.886	2.920	4.303	6.965	9.925	14.089	22.326	31.598
3	0.277	0.765	1.638	2.353	3.182	4.541	5.841	7.453	10.213	12.924
4	0.271	0.741	1.533	2.132	2.776	3.747	4.604	5.598	7.173	8.610
5	0.267	0.727	1.476	2.015	2.571	3.365	4.032	4.773	5.893	6.869
6	0.265	0.718	1.440	1.943	2.447	3.143	3.707	4.317	5.208	5.959
7	0.263	0.711	1.415	1.895	2.365	2.998	3.499	4.029	4.785	5.408
8	0.262	0.706	1.397	1.860	2.306	2.896	3.355	3.833	4.501	5.041
9	0.261	0.703	1.383	1.833	2.262	2.821	3.250	3.690	4.297	4.781
10	0.260	0.700	1.372	1.812	2.228	2.764	3.169	3.581	4.144	4.587
11	0.260	0.697	1.363	1.796	2.201	2.718	3.106	3.497	4.025	4.437
12	0.259	0.695	1.356	1.782	2.179	2.681	3.055	3.428	3.930	4.318
13	0.259	0.694	1.350	1.771	2.160	2.650	3.012	3.372	3.852	4.221
14	0.258	0.692	1.345	1.761	2.145	2.624	2.977	3.326	3.787	4.140
15	0.258	0.691	1.341	1.753	2.131	2.602	2.947	3.286	3.733	4.073
16	0.258	0.690	1.337	1.746	2.120	2.583	2.921	3.252	3.686	4.015
17	0.257	0.689	1.333	1.740	2.110	2.567	2.898	3.222	3.646	3.965
18	0.257	0.688	1.330	1.734	2.101	2.552	2.878	3.197	3.610	3.922
19	0.257	0.688	1.328	1.729	2.093	2.539	2.861	3.174	3.579	3.883
20	0.257	0.687	1.325	1.725	2.086	2.528	2.845	3.153	3.552	3.850
21	0.257	0.686	1.323	1.721	2.080	2.518	2.831	3.135	3.527	3.819
22	0.256	0.686	1.321	1.717	2.074	2.508	2.819	3.119	3.505	3.792
23	0.256	0.685	1.319	1.714	2.069	2.500	2.807	3.104	3.485	3.767
24	0.256	0.685	1.318	1.711	2.064	2.492	2.797	3.091	3.467	3.745
25	0.256	0.684	1.316	1.708	2.060	2.485	2.787	3.078	3.450	3.725
26	0.256	0.684	1.315	1.706	2.056	2.479	2.779	3.067	3.435	3.707
27	0.256	0.684	1.314	1.703	2.052	2.473	2.771	3.057	3.421	3.690
28	0.256	0.683	1.313	1.701	2.048	2.467	2.763	3.047	3.408	3.674
29	0.256	0.683	1.311	1.699	2.045	2.462	2.756	3.038	3.396	3.659
30	0.256	0.683	1.310	1.697	2.042	2.457	2.750	3.030	3.385	3.646
40	0.255	0.681	1.303	1.684	2.021	2.423	2.704	2.971	3.307	3.551
60	0.254	0.679	1.296	1.671	2.000	2.390	2.660	2.915	3.232	3.460
120	0.254	0.677	1.289	1.658	1.980	2.358	2.617	2.860	3.160	3.373
∞	0.253	0.674	1.282	1.645	1.960	2.326	2.576	2.807	3.090	3.291

Source: Taken with permission from E. S. Pearson and H. O. Hartley (Eds.) (1958), *Biometrika Tables for Statisticians*, Vol. 1, Cambridge University Press.
Parts of the table are also taken from Table III of Fisher, R.A., and Yates, F. (1963): *Statistical Tables for Biological, Agricultural and Medical Research*, published by Longman Group Ltd., London (previously published by Oliver and Boyd, Edinburgh), by permission of the authors and publishers.

Appendix 23

Table of Percentage points of the F distribution upper 5%

Table D. (*continued*), Percentage Points of the F Distribution: Upper 5% Points

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3	254.3
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

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APPENDIX 20

Table of Percentage points of the *F* distribution upper 5%