DEVELOPMENT OF REGRESSIONAL MODELS FOR PREDICTING SOME MECHANICAL PROPERTIES OF SAND-QUARRY DUST CONCRETE

By

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Certification

I certify that this work, "**Development of Regressional Models for Predicting some Mechanical Properties of Sand-Quarry Dust Concrete**" was carried out by Virgilus Chukwudi Ezugu in partial fulfillment of the requirements, for the award of Master of Engineering(M.Eng) Degree in Civil Engineering(Structures) in the School of Engineering and Engineering Technology, Federal University of Technology, Owerri, Nigeria.

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Dedication

This work is dedicated to my wife Dr. Patience Ezugu and children for their support and encouragement.

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$2CaOSiO_2(C_2S)$	Dicalcuim Silicate
$3CaOSiO_2\ (C_3S)$	Tricalcuim Silcate
BS	British Standard
BS EN	British/European Standard
F_{ce}	Compressive Strength of Concrete
F	Force(load) acting on specimen
A	Area of Specimen
L	Length of Cylinder Specimen
D	Diameter of Cylinder Specimen
F_{cr}	Flexural Strength of Concrete
L	Length between supports
B	Beam breadth
F_{cr}	Characteristics strength of Concrete
K_1	Empirical constant
K_2	Empirical Constant
W/C	Water/Cement ratio
C	Degree celsuis
DOE	Design of experiment
$MgSO_4$	MagnesuimSulphate
NaCl	Sodium Chloride
HCl	Hydrochloric Acid
N/mm^2	Newton per millimeter squared
Y	Response
X	Pseudo Component
Z	Actual component
b_0	Free Term
b_1, b_2,--b_n	Linear term
N	Point within lattice
β	Coefficient
S_y^2	Replicate variance
ni,nj	Replicate observation

$\overline{y\imath}, \overline{y\imath\jmath}$	Average values responses
$\sum$	Summation
λ	Lander
t	T-Test value
kg	Kilogramme
g	Gramme
mm	Millimeter
μm	Micrometer
W_w	Surface dry weight
W_d	Oven dry weight
$\propto$	Alpha
S_i	Variance
Aggt	Aggregate

Abstract

This research presents regressional models for predicting the compressive strength, density and slump of sand-quarry dust concrete. The research was prompted by the need to utilize quarry dust, which is a by-product of the quarry industry and presently constitutes environmental menace. The tests conducted included sieve analysis, specific gravity, water absorption, slump, compressive strength and density of the quarry dust concrete. Five component mathematical models based on Scheffe’s simplex method were developed to predict the compressive strength, slump and density of the sand quarry dust concrete. The five components are: Cement, water, sand, quarry dust and crushed rock (chippings). Twenty two different mix ratios were used and each mix ratio contained different percentage replacement of sand with quarry dust. Three samples of each mix proportion were made, giving a total of sixty-six samples. The average of the compressive test results of the three samples of each mix ratio represented the compressive strength of the mix ratio. The average compressive strengths obtained ranged from 30.8N/mm^2(corresponding to mix ratio of 1:0.6:2.7:0:3.5) to 44.7N/mm^2(corresponding to mix ratio 1:0.5:2:0.4:3.2). The mix ratio refers to the ratio of cement: water:sand: quarry dust:granite chippings by weight. The average density ranged from 2,390.1Kg/m^3 to 2,696.3Kg/m^3 while the average slump ranged from 9.8mm to 20.8mm.The results from the modal equations using responses from the experimental control points were subjected to statistical analysis including T and F tests and found reliable. The mix with 9.1% quarry dust replacement of sand gave the highest compressive strength of 44.7N/mm^2 while the mix with 0% quarry dust gave the minimum strength of 30.8N/mm^2.

Keywords: Mathematical Models, Scheffe’s Simplex Method, Sieve Analysis, Specific Gravity, Water Absorption, Compressive Strength, Slump, Density, Percentage Replacement.

CHAPTER ONE
INTRODUCTION

1.1 Background of Study

In developing countries of the world such as Nigeria, the growing concerns of high cost of construction materials and the consequential problems of shelter have challenged many engineers to seek and develop new material relying on locally available ingredients for building construction. These include the use of by-products from industries and waste materials as aggregate for the production of concrete which has affected virtually all facets of construction industry in these countries and therefore requires urgent attention.

The most commonly used material in construction industries is concrete. According to Neville(1996),concrete is made up of cement, aggregate and water mixed in an appropriate proportion to give the required properties both in fresh and hardened state. The most frequentlyused fine aggregate for this purpose is riversand which is sourced from river bed and pits. The natural sand is limited in supply and continuous dredging of river and mining pits for this material leads to its eventual depletion. There are several environmental problems associated with this practice which ranges from erosion, flooding and danger to human life. Also the costs of dredging and transportation of river sand to construction sites haveaffected the cost of materials and the overall cost of construction.

This trend has led many researchers into the search for alternative and affordable materials for use in concrete. Quarry dust which is a waste product generated during the crushing process of rocks is the most available potential alternative to river sand in concrete production. This waste material is available in large quantity in quarry sites around Nigeria and constitute eyesore on environment. The successful utilization of quarry dust as fine aggregate in concrete production would turn this waste material that constitute environmental load due to disposal problem into valuable resources, reduction in the strain on the supply of river sand and economy in the production of concrete. In addition, since the cost of this locally available material (quarry dust) is several times less than that of natural sand, replacement of sand with this material as fine aggregate will significantly reduce the cost of the concrete.

However, it is not just enough to partially or wholly replace fine aggregate with quarry dust in concrete, finding the best combination of these ingredients to achieve the best result should be of paramount importance to the engineer. To achieve this, optimization principles which is a process of minimizing or maximizing value for a function of several variables while at the same time satisfying a number of other imposed requirements are needed. This process involves using statistical techniques which includes fitting empirical models to the data for each performance criterion. In these models, each response which may represent the resultant concrete property such as strength is expressed as an algebraic function of all the component proportions such as w/c ratio, cement content, percentage quarry dust replacement e.t.c. In the search for the best formulation, the main objective is to determine the optimum levels of the components or key ingredients. The ingredients are the independent variables and the dependent variable or response is the factor to be optimized. When various responses are involved, the term combined response optimization is preferable. Hence, as regards the replacement of fine sand with quarry dust, the optimum combination of the aggregates would be that corresponding to the target properties of concrete at reduced cost and this forms the basis for the research work.

1.2 Statement of Problem

Natural sand is a major constituent of concrete production in Nigeria. The increasing wave of construction projects by government and individuals alike has put a lot of strain on the supply of this material.Thishas led to high cost of concrete production and consequently made availability of cheap and affordable houses for the Nigeria people difficult. In some parts of the country, quarry dust is available in large quantity. This waste product constitute obstacle to the environment, health hazard and occupy spaces that would have been used for other purposes. It can also generate economic loss or gain to the operators of the quarries through expenses for proper disposal of the dust.

To obtain concrete that will meet the desired properties, an appropriate mix design has to be done and applied during the production of concrete. Therefore, the need to provide the appropriate mix proportion that will yield the desired properties at low cost is imperative. The dredging of river makes them deeper and wider, sometimes the river banks are cut off, thereby exposing communities around the river to the danger of flooding. This may lead to loss of lives and property, and consequently huge economic loss to the nation.

1.3 Objectives of Study

The main objective of this study is to develop regressional models for predicting the compressive strength, density and slump of sand - quarry dust concrete. The specific objectives are:

i. To determine the effect of partial replacement of sand with quarry dust on the mechanical properties of sand-quarry dust concrete.
ii. To determine the percentage replacement of sand with quarry dust that will optimize compressive strength and workability of normal weight concrete.

1.4 Significance of study

If this research work becomes successful, it will benefit society in many ways.First, the environmental and health issues associated with this waste product will be reduced.Consequently, the research would be a major contribution to sustainability in engineering and construction, which presently is the focus of governments, researches and industry operators world over. The emphasis is on the protection of the environment for future generations. Secondly, itwill provide cheap alternative material source for the Nigerian people, and the provision of affordable housing for the low income earners will be possible especially those close to the quarry industry. It will also be an additional source of income for the quarry industry operators. Lastly, it will provide a data bank of useful information for engineers and scientists, and form the basis for further research on other possible uses of quarry dust in engineering and other fields.

1.5 Scope of Study

In this study,regressional models for the prediction of the compressive strength, density and slump of concrete containing quarry dust as replacement for granular sand were developed. Scheffe`s simplex lattice design was used to develop a five component model in which experimental data formed the coefficients. The models were used to predict the corresponding mechanical properties of the concrete and these were compared with data obtained from laboratory experiments for the compressive strength, density and slump of the concrete respectively.

CHAPTER TWO
LITERATURE REVIEW

2.1 Concrete

Concrete is a hard composite material formed from the mixture of four major constituent materials, namely cement, fine aggregate (sand), coarse aggregate (stone) and water. Sometimes, chemical substances called admixtures can be added to produce concrete of specific characteristics. These major constituents must be mixed in a right proportion so as to produce concrete that will meet the desired properties; such as strength, workability, durability and of course economy.

According to Jackson and Dhir(1978), concrete can be described as a man-made composite, the major constituents of which are natural aggregate and the binding medium (cement-water paste). The binding medium is a product of chemical reaction between cement and water in a process called hydration. Shetty (2005) described concrete as a freshly mixed material which can be molded into any shape. He also went further to explain that the relative quantity of water, cement, and aggregate in aconcrete control its properties in wet and hardened states. For example, the strength of concrete produced using a particular aggregate is a function of the characteristic properties of that aggregate. Therefore, strong aggregate will produce strong concrete and weak aggregate will produce weak concrete. The cement paste glues the aggregate together, fills voids within it and allows the mix to flow with ease. Less water in the paste will produce a stronger concrete, while more water will yield flowing mix with high slump. The strength of correctly designed concrete mix comes primarily from the coarse aggregate and the richness of the mix.

2.1.1 Constituents of Concrete

The major constituents of concrete are Cement, Aggregate and Water with Admixtures being included sometimes.

2.1.1.1 Cement

This is a finely ground powder that hydrates when mixed with water to form a hard and strong binding medium for the aggregate particles. This hydration of cement produces a gel that gives a cohesive property to concrete, even in its early stages (Jackson and Dhir1978). The most commonly used cement is the Ordinary Portland Cement which was developed in 1824 and derives its name from Portland limestone in Dorset, United Kingdom. There are other types of Portland Cement which are used when concrete with special properties are required.

2.1.1.1.1 Types of cement

i. Portland Cement:- This can be further divided into Ordinary Portland Cement; Rapid Hardening Portland Cement; Sulfate Resisting Portland Cement; and Low Heat Portland Cement.
ii. Slag Cement:- Under this type of cement are Portland Blast Furnace Cement; Low Heat Portland Blast Furnace Cement, and Super Sulfated Cement.
iii. High-Alumina Cement
iv. Pozzolanic Cement

2.1.1.1.2 Cement Production Processes.

Cement is produced by first grinding the constituent raw materials in certain proportions, burning this mixture at a very high temperature to produce clinker which is then ground into powder. The resulting material is mixed thoroughly to obtain uniform cement. This mixing may be in a dry or wet state depending on the hardness of the rock from which the basic materials are taken.

In a typical cement manufacturing process, slurry formed from chalk is fed into a kiln. The kiln is cylindrical steel which is slightly inclined to the horizontal and rotates continuously about its own axis. The firing is usually done by coal although gas or oil may be used. The slurry is feed in at the upper end of the kiln and the clinker is discharged at the lower end where fuel is injected. With its temperature increasing progressively the slurry undergoes a number of changes as it travels down the kiln. At a temperature of $100^{o}C$ the water is driven off, at about $850^{o}C$, Carbon(4)oxide is given off and at about $1400^{o}C$ fusion takes place in the firing zone where calcium silicates and calcium aluminates are formed. The clinker formed is allowed to cool and then ground with 1 to 5% gypsum to the required fineness.

Different types of Portland Cement can be produced by variation of the proportion of the constituent materials, temperature of burning, addition of some additives (e.g.$CaCl_2$) and changing the fineness. The addition of gypsum helps to reduce the rate of setting of cement (Jackson and Dhir, 1978).

2.1.1.1.3 Chemical Composition of Cement.

Cement is composed of four major compounds;CaO, SiO_2, Al_2O_3 and Fe_2O_3.These are usually denoted as C, S, A, and F respectively. Tricalcium silicate (C_3S) with the full chemical formula being $3CaO.SiO_2$;Dicalcium silicate C_2S or $2CaO.SiO_2$;Tricalcium aluminate C_3Aor $3CaO.Al_2O_3$ and Tetracalcium aluminoferrite C_4AF or $4CaO.Al_2O_3.Fe_2O_3$. Table 2.1 summarizes the composition of cement.

Table 2.1: SUMMARY OF COMPOSITION OF CEMENT

Material	Chemical Formula	Oxide Composition	Abbreviation
Tricalcium silicate	Ca_3SiO_5	$3CaO.SiO_2$	C_3S
Dicacium silicate	Ca_2SiO_4	$2Cao.SiO_2$	C_2S
Tricalcium aluminate	$Ca_3Al_2SiO_4$	$3CaO.Al_2O_3$	C_3A
Tetra-calcium aluminoferrate	$CaAl_2Fe_2.O_7$	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

Source: Shetty (2005)

Among these four compounds, the two silicates are the most stable. They form 70% to 80% of the constituent of the cement and contribute most of the physical properties of the resulting concrete. When cement is mixed with water C_3S hydrates rapidly generating a considerable amount of heat. This is responsible for strength development especially within the first 14 days. The C_2S on the other hand hydrates much slowly and it is responsible for strength development after 7 days and may remain active for a considerable period of time. Hydration of C_3A takes place rapidly and produces little increase in strength within 24 hours. This component is the least stable of all the components and any cement containing up to 10% of it will yield concrete that is susceptible to sulfate attack. Tetracalcium-alumino-ferrite(C_4AF) is less important than the other three components when considering the properties of hardened cement, mortar or concrete. Apart from these four major constituents, there are other minor compounds present in cement. These are mainly oxides of Magnesium(MgO), Sodium (Na_2O), and Potassium (K_2O); also oxides of Manganese and Tin are present. These constitute a few percentage of the entire composition of cement. Two of the minor component Sodium and Potassium Oxides called alkali can react with aggregate causing disintegration of concrete (Neville1996).

2.1.1.1.4 Hydration of Cement.

This is the chemical combination of water and cement to produce a binding medium for aggregate in the making of concrete. It is usually accompanied by liberation of heat (measured in calories per gram). The rate of hydration is usually dependent on the following:

i. The properties of the silicate and aluminate compounds in the cement.
ii. The degree of fineness of the cement.
iii. The ambient conditions, usually temperature and moisture, of the concrete.

The rate of hydration has a direct link to the rate of liberation of heat. This heat generated may have an adverse effect on strength and durability of concrete due to the micro cracking generated on the cement binder.

2.1.1.1.5 Heat ofHydration.

This is the quantity of heat energy (measured in joules per gram) produced upon completion of hydration at a given temperature. The temperature at which hydration takes place greatly affects the rate of heat development during the early stages of concrete. On the other hand, there is little effect of temperature on the long time value of heat of hydration. The most common method of measuring the heat of hydration is by comparing the heat of hydration of unhydrated and hydrated cement in a mixture of nitric acid and hydrofluoric acid; the difference between the values represent the heat of hydration. The heat of hydration measured as described above consists of the chemical heat of hydration and heat of adsorption of water on the surface of the gel formed by the process of hydration. This means that heat of hydration is a composite quantity. It should be noted that it is the rate at which heat is generated and not the total liberated heat that affect the rise in temperature in practice. Therefore, the heat characteristic of a particular type of cement must be taken into consideration while considering its suitability for a specific project, especially in projects such as Dams.

2.1.1.1.6 Effect of Hydration on Strength of Hardened Concrete.

The rate of hydration at the early age of concrete determines the strength of concrete produced. Under normal conditions, once cement and water are mixed the hydration process will begin and the concrete or mortar will gain strength and increase in durability with the passage of time. If the rate of hydration is high, this helps in early striping of formwork especially for non-critical structural elements. Therefore, it is necessary that there should be enough water in the cement paste for complete hydration to take place.

2.1.1.1.7 Water Requirement for Hydration

It has long been established that the water content of the concrete at the time of hardening plays a large role in determining the ultimate strength and durability of the concrete. It has also been reported that as the water content is increased, the ultimate strength will decrease. This is correct because as the water content is increased, the particles of anhydrous cement are pushed further apart. This reduces the ability of the cement to bond to itself and to the aggregate.

During the hydration process, water is chemically combined with cement in the ratio of approximately 25 grams of water to 100 grams of cement which is about a water-cement ratio of 0.25 plus extra water (physically bonded) that is required to maintain contact with all the cement. The physically bonded water required is an additional 20 grams of water. Therefore, the total amount of water required for total hydration can be stated as 45 grams of water per 100 grams of cement, or a water/cement ratio of 0.45. In addition, there must be an accounting for the water lost from the system through evaporation. This would require the water-cement ratio to be something higher than 0.45 (Haque, 1980). The concept of the water/cement ratio and the need for more water than is required for hydration, teaches us two things about how to improve the strength of concrete.

a. Keep the water to cement ratio as low as possible in order to produce the densest possible hydrated cement paste.
b. After the concrete has hardened, keep the internal moisture content of the concrete as high as possible, for as long as possible, by using proper curing procedures.

2.1.1.1.8 Qualities of Good Cement

a) Fineness

The degree of fineness of cement has a direct relationship on the behavior of concrete. Increase in fineness leads to an increase in the rate of hydration, strength gaining and heat evolution. In a cement sample, maximum particle should have a size less than 100 microns and the smallest particle may have a size of about 1.5 microns. In general, the average size of cement particles is about 10 microns. Increase in fineness of cement leads to air-setting, early deterioration and increase in the drying shrinkage of concrete(Neville, 1996). Fineness of cement is tested in two ways: by sieving and by determination of specific surface.

b) Standard Consistency

The standard consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having 10mm diameter and 50mm length to penetrate a depth of 30-35mm from the top of the mould (Shetty, 2005). The basic aim is to find out the water content required to produce a cement paste of standard consistency. The apparatus is calledVicat Apparatus.

c) Setting Time

This is divided into two parts; the initial and final setting times. It is difficult to differentiate the two but for convenience, the initial setting time is regarded as the time elapsed between the moment water is added to the cement to the time the paste starts loosing plasticity while the final setting time is the time elapsed between the time water is added to the cement to the time the paste has completely lost its plasticity and has acquired sufficient strength to resist pressure (Neville, 1996).

d) 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, manner of mixing and molding specimens, curing conditions, size and shape of specimen, moisture content at time of test, loading conditions and age (Mindness, et al 2003). Since cement gains strength over time, the time at which strength test is to be conducted must be specified. Typical times are 1 day (for high early strength cement), 3 days, 7 days, 28 days and 90 days (for low heat of hydration cement). When considering cement paste strength tests, there are two items to consider:

- Cement mortar strength is not directly related to concrete strength. Cement paste strength is typically used as a quality control measure.
- Strength tests are done on cement mortars (cement + water + sand) and not on cement pastes (Neville 1996).

e) Heat of Hydration

The hydration of cement is exothermic, implying that heat is liberated during the reaction. This can be observed when cement is mixed with water and placed in a Thermos flask. It is estimated that about 120 calories of heat is generated by 1 gram of cement during hydration (Shetty 2005). From this, the total quantity of heat generated in the interior of a system such as mass concrete dam can be estimated. A temperature rise of about 50°C has been observed in the interior of a mass concrete dam (Shetty 2005). This high temperature cause serious expansion of the dam which leads to shrinkage after cooling, resulting in cracking and damage of concrete. Therefore, test for heat of hydration is essentially required for such mass concrete structures such as dams. This test is carried out over a few days by vacuum flask method or over a long period of time by the adiabatic calorimeter method. When tested in a standard manner, the heat of hydration of low heat Portland Cement should not exceed 65cal/gm at 7 days and 75cal/gm at 28 days (Shetty 2005).

2.1.1.2 Aggregates

BS 882: 1992 defines aggregate as a granular material obtained by processing or from natural materials. Aggregate is a collective term for the mineral materials such as sand, gravel and crushed stone that are used with a binding medium (such as bitumen, Portland Cement, lime, etc.) to form composite materials (such as asphalt concrete or Portland Cement concrete). By volume, aggregate generally accounts for about 70 to 75 percent of concrete (Troxel, et al1968). Aggregate is also used for base and sub base courses for both flexible and rigid pavements; the aggregate serves as reinforcement to add strength to the overall composite material. Aggregates are much cheaper than cement and maximum economy is obtained by using as much aggregate as possible in concrete making. Apart from economy, aggregate offers stability and durability to concrete. Before now it was common to think of aggregates as inert filler in concrete but the physical and sometimes chemical composition of aggregates and their characteristics affect to a varying degree the properties of concrete in both the plastic and hardened states (Jackson and Dhir, 1978).

2.1.1.2.1 Sources of Aggregates

Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often the byproduct of other manufacturing industries. In addition, there are some (minor) materials that are used as special lightweight aggregates: clay, pumice, perilite, and vermiculite. Aggregates can also be sourced from rivers e.g. river stone which have smooth and round surface (Shetty 2005).

2.1.1.2.2 Classification of Aggregates

Aggregate can be classified as fine or coarse. Aggregate mainly passing a 5.0 mm BS 410 test sieve and containing no more coarser material than is permitted for the various grading in this specification are known as fine aggregate (sand) while those larger than 5.0 mm are referred to as coarse aggregate (Neville 1996).

a) Classification of Aggregates according to Weight.

The variability in density can be used to produce concrete of widely different unit weights. The most common classification of aggregates on the basis of bulk specific gravity is lightweight, normal-weight, and heavyweight aggregates. (BS EN 206-1:2000)

i) Lightweight aggregates:

Lightweight aggregates are aggregates which may be natural or synthetic and weigh less than 1100 kg/m^3 (Mehta P.K. AND Monteiro P.J. 2006). The lightweight is due to the cellular or high internal porous microstructure, which gives this type of aggregate a low bulk specific gravity. The most important aspect of lightweight aggregate is the porosity. They have high absorption values, which require a modified approach to concrete proportioning. For instance, slump loss in lightweight concrete due to absorption can be an acute problem, which can be alleviated by pre-wetting (but not saturating) the aggregate before batching. Lightweight aggregates and their method of testing are covered in BS 3681-2-1973.

ii) Normal Weight Aggregate.

Normal weight aggregates can be natural or artificial. They are suitable for most purposes and produce concrete of density ranging from 2300 to 2500kg/m^3(Shetty, 2005). Normal weight aggregate can be obtained by crushing granite (Igneous) rock to the required size, it can also be provided by extraction of gravel from alluvial deposits or glacial action. Some can also be obtained by dredging of sea or river bed.

The properties of aggregate are function of its composition, grain size and texture. For example, granite has a low fire resistance because of high coefficient of expansion of its quartz (metamorphic) content. Sandstone has high porosity and as a result, it produces concrete of high drying shrinkage. Broken-brick aggregate has high fire resistance but should not be used for normal concrete if its sulfate content exceeds 1%. To maximize the potential of an aggregate, it should be washed to remove clay and silt before it is used. The chloride content of marine aggregate should be less than 1% before it can be used as aggregate for structural concrete (BS EN 206-1, 2003).

iii) Heavyweight aggregates:

Heavyweight concrete contains aggregates that are natural or synthetic which typically weigh more than 4,000 kg/m^3 and can range up to 5,500 kg/m^3(Shetty 2005). Heavy weight aggregate is most commonly used for radiation shielding, counterweights and other applications where a high mass-to-volume ratio is desired. It is usually very difficult to obtain a mix which is both workable and not prone to segregation using heavyweight aggregate.

b) Classification of Aggregates according to Particle Shape and Texture.

According to shapes, aggregate can be classified as; rounded, irregular, angular, flaky and elongated. The surface texture of an aggregate can be glassy, smooth, granular, rough, crystalline and honeycombed.

Aggregate shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. Consequently, the cement content must also be increased to maintain the water-cement ratio (Shetty 2005). However, with rough aggregates, there is better mechanical bond in the hardened concrete, so strength is higher (if concrete with the same w/c ratio is compared). Hence, when smooth aggregates are replaced with rough aggregates, concrete of similar flow properties and strength can be produced by adding a little bit more water. The external characteristics of aggregates can be assessed by observation and classification in accordance with BS 812, 1995. The particle shape can be assessed by direct measurement of the particles to determine the flakiness, elongation and angularity.

2.1.1.2.3 Strength Characteristic of Aggregate

a) Aggregate Abrasion

This is the measure of the ability of the aggregate to resist wearing or abrasive force.

Aggregate abrasion is tested for mostly in aggregates that will be used in the construction of the floors of warehouses and industrial buildings and aggregate that will be used in the construction of road pavements. The following methods can be used for the determination of abrasion value;Deval attrition Test, Dory Abrasion Test and Los Angeles Test (Shetty 2005).

b) Aggregate Modulus of Elasticity

Modulus of Elasticity of a body is the ratio of the stress applied to a body to the strain that results in the body in response to it. The modulus of elasticity of a material is a measure of its stiffness and for most materials remains constant over a range of stress. This depends on the aggregate composition, texture and structure. Modulus of elasticity of aggregate influences properties of concrete such as shrinkage, creep and the elastic behavior of concrete produced with it (Shetty 2005).

2.1.1.2.4 Weight and Moisture Content Characteristics

a) Bulk Density

The bulk density or unit weight of an aggregate provides useful information about shape and grading of the aggregate. This parameter shows how densely the aggregate is packed when filled in a standard manner and it is used in mix deign to convert weighed proportions into volumes in the site where weighing equipment is not available. A comprehensive test description for bulk density is found in BS 812-2: 1995.

b) Specific Gravity

This is the ratio of the weight in air of a given volume of a material at a standard temperatureto the weight in air of an equal volume of distilled water at the same stated temperature. Acomprehensive test description is found in BS 812-2: 1995.

c) Moisture Content

The amount of water that an aggregate can absorb tends to be an excellent indicator as to the strength or weakness of the aggregate. Strong aggregate will have an absorption Figure below 1%. Above 4%, you need to perform further test on the aggregate to determine its acceptability. A test for aggregate moisture absorption is described in BS EN 1097-6: 2000.

d) Bulking of Fine Aggregate

Bulking is the increase in volume of a given mass of sand caused by layer of water pushing the sand particles apart. This does not have any effect on the proportioning of materials when batching is by mass. In the case of volume batching, bulking results in the deficiency of fine aggregate and the mix will appear stony (Shetty 2005). The concrete produced in this case may be prone to segregation and honeycombing. The degree of bulking depends on the amount of moisture present in the sand and its fineness. Fine sand bulk more and a very fine sand bulk even up to 35- 40%. Maximum Bulking occur at particular moisture content as shown in the Figure 2.1.

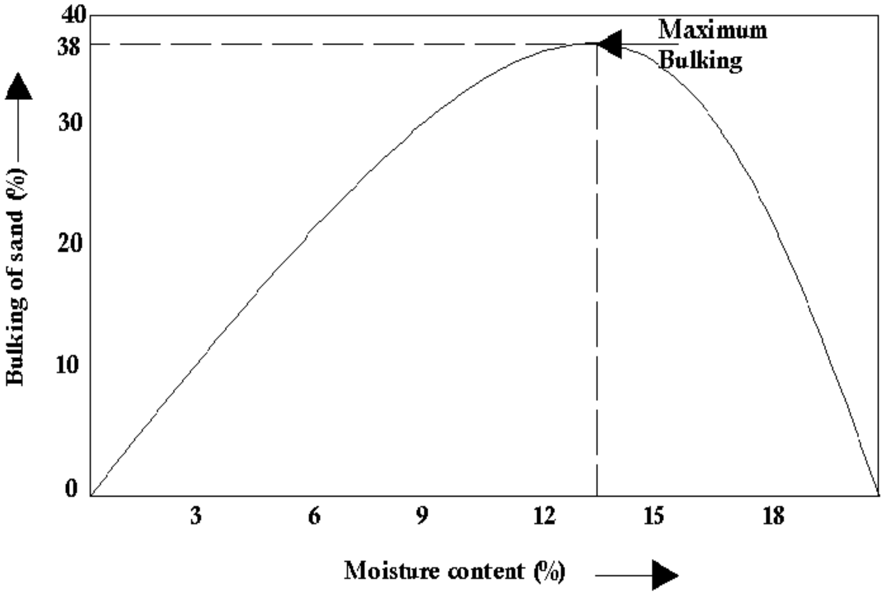


Figure 2.1: BULKING OF FINE AGGREGATE.Source: Shetty(2005)

2.1.1.2.5 Grading of Aggregates.

The particle size distribution of an aggregate (gradation), shape, and surface texture have an important effect on the workability and finishing of fresh concrete and definitely on the properties of hardened concrete. If an aggregate is well graded, that is, it contains all standard fractions of aggregate in the right proportion, such that the sample contain minimum void, minimum paste will be required to fill the void. Therefore, the concrete produced using suchaggregate will consume less cement, less water, which means increased economy, higher strength, lower shrinkage and greater durability (Shetty 2005). The size of aggregate particles normally used in making concrete varies from 37.5mm to 0.15 mm. BS 882; 1992 places aggregate in three different categories: fine aggregate (sand) containing particles majority of which are smaller than 5mm, coarse aggregate which has particles that are greater than 4.75mm and All-in aggregate which comprises of both fine and coarse aggregate. As stated above, grading of aggregate has a considerable influence on the workability and stability of concrete mix and it is an important factor in concrete mix design. BS 812: Part 103 1985 specifies that aggregate particle distribution should conform to one of the grading zones for it to be acceptable in concrete making.

a) Sieve Analysis.

This is a system of dividing a sample of aggregate into various fractions each consisting of particles of the same size in order to establish the particle size distribution of the sample of aggregate (grading). The aggregate fractions from 80mm to 4.75mm are referred to as coarse aggregate and those from 4.75mm to 150 microns are termed fine aggregate. The 4.75mm size is dividing fraction appearing in both coarse and fine aggregate.

The gradation of a sample is assessed by sieving a sample successively through the entire sieve mounted one on top of the other with larger sieve on top. The material retained on each sieve is bigger than it and finer than the one above. Sieving can be done manually or mechanically provided the shaking is done in all direction to give chance to all the particles to pass the sieve. Operation should continue until no particle passes anymore.

The quantity of materials retained on each sieve is weighed and recorded. Also the percentage retained, the percentage passed, cumulative weight retained, cumulative percentage retained and percentage passed are recorded for each sieve size. A specimen chart can be used to record the result graphically and the curves produced by plotting "nominal aperture size of test sieve against cumulative percentage passing" represent the grading pattern of the aggregate. The fineness modulus can be calculated by finding the sum of cumulative percentage of aggregate retained on each standard sieve between sizes 4.75 mm and 150 micron; and dividing the value by an arbitrary number 100. The coarser the material, the larger the fineness modulus.

The following limits may be taken as a guide to establishing the degree of fineness of an aggregate (Shetty 2005):

Fine sand : Fineness modulus : 2.2 – 2.6
Medium sand : Fineness modulus : 2.6 – 2.9
Coarse sand : Fineness modulus : 2.9 – 3.3.

Sand having a fineness modulus more than 3.3 will be unsuitable for making satisfactory concrete. The fineness modulus can be used to check the constancy of grading when relatively small change is expected; but it should not be used to compare the grading of aggregates from two different sources. The fineness modulus of fine aggregates is required for mix proportion since sand gradation has the largest effect on workability. Finer sands (low fineness modulus) need more water for good workability.

b) Standard Grading Curve

This is a graphic representation of the result of a sieve analysis. This curve makes the understanding of particle size distribution of a material very easy. By using chart it is possible to know at a glance whether the grading of a given sample conform to the specification or is too coarse or too fine or deficient in a particular size.

c) Grading Zones for Fine Aggregates

There have been several approaches to specifying the grading requirement for fine aggregate. BS 882:1992 introduced four grading zones for fine aggregate. The division being based primarily on the percentage passing the $600\mu m$ sieve size.

A grading zone is more easily explained when set down on logarithmic graph paper. It is the area contained between a line drawn through the maximum amounts permissible to pass any particular specified sieve, and a line drawn through the minimum amounts permissible to pass the same specified sieves. The area contained between these two lines is known as the "grading zone" (Shetty 2005). When plotting an actual grading result, provided the ‘‘plot’’ remains within the zone/envelope the aggregate tested is within specification. If the line of the ‘‘plot’’ leaves the grading zone the aggregate sample is out of specification. Recording the results of tested materials on a graphical basis makes it far easier to assess the quality of a material than looking at a string of numbers, and you are able to tell at a glance whether a material is well graded or gap graded. But results presented graphically are not easy to store on databases. The grading limits for the zones (I, II, III and IV) are shown in the table 2.2

Table 2.2: GRADING LIMITS FOR FINE AGGREGATE

Sieve Size	**Percentage passing**			
	ZoneI	**ZoneII**	**ZoneIII**	**ZoneIV**
10mm	100	100	100	100
4.75mm	90 – 100	90 – 100	90 – 100	95 – 100
2.36mm	60 – 95	75 – 100	85 – 100	95 – 100
1.18mm	30 – 70	55 – 90	75 – 100	90 – 100
$*$ **600μm**	**16 – 34**	**35 – 59**	**60 – 79**	**80 – 100**

300µm	5 – 20	8 – 30	12 – 40	15 – 50
150µm	0 – 10	0 – 10	0 – 10	0 – 15

Source:Shetty (2005)

Since the values for $600\mu m$ are not overlapping for different zones, it is used for confirming the zone for fine aggregate. Zone I represents coarse sand and Zone IV represents the finest sand in all the four zones. Fine aggregate that belong to Zone IV should not be used for reinforced concrete work unless test has been conducted for the suitability in the mix proportion.

2.1.1.3 Water

Water is an important ingredient for concrete. When mixed with cement, the hydration process which leads to strength development is initiated. Almost any natural water that is drinkable and has no pronounced taste or odor may be used as mixing water for concrete (Chen W.F., 1982). However, some waters that are not fit for drinking may be suitable for concrete. It is important that water used in concrete should be free from impurities; it should be of potable quality. Brackish water would need checking before using because it often contains impurities which affect setting times and reduce the strength of concrete. Sea water is not suitable for reinforced concrete as it causes corrosion of steel reinforcement. Excessive impurities in mixing water may not only affect setting time and concrete strength, but also may cause staining, corrosion of reinforcement, volume instability, and reduced durability. Specifications usually set limits on chlorides, sulfates, alkalis, and solids in mixing water unless tests can be performed to determine the effect the impurity has on various properties of concrete.

2.1.1.4 Admixtures

These are substances other than water, aggregate and hydraulic cement, used as ingredients for concrete and added to the batch before or during mixing to enhance specific performances of the concrete, mortar or plaster. Various categories of admixtures are available for use today. Some common types are plasticizers, retarders, accelerators, air-entrainers, etc (Shetty 2005).

a) Plasticizers (or Water Reducers)

These are applied to concrete for two different purposes (i) To reduce the water content of plastic concrete and increase its strength, and (ii) To obtain higher slump without adding more water. These admixtures disperse the cement content of concrete to make more efficient use of cement. They are also useful in pumping concrete and in hot weather to make up for high water demand. They increase strength or allow cement content to be reduced while maintaining the same strength (Shetty 2005).

Plasticizers are surface chemicals called surfactant. In the absence of plasticizers, cement particles being very fine tend to cling together and flocculate when water is added to cement. This flocculation entraps a lot of water within the cement particles thereby making it unavailable for workability. Plasticizers induce negative charges on the cement thereby causing the flocculated cement particles to disperse by repulsion. This makes the entrapped water free and available for workability (Shetty 2005). It should be noted that the use of admixture is not a substitute for bad construction practice or badly proportioned concrete mix. It should rather be considered as a compliment to good construction practice.

b) Retarders (or Retarding Plasticizers)

These admixtures delay the initial setting time of concrete by an hour or more. Retarders delay the hydration process without affecting the actual process. Retardersare used in hot weather to counter the false setting in concrete coursed by rapid evaporation of water in concrete. Some of the agents used as retarders are: Lignin, Borax, Sugar, Tartaric acid and salts.

c) Accelerators (or Accelerating Plasticizers)

This type of admixture is known by its potential to reduce the initial setting time of concrete and give high early strength. This early strength helps concrete to withstand damage from freezing in cold weather. Some materials used to accelerate setting in concrete include, Calcium chloride, Triethenolamine, Sodium thiocyanate, Calcium formate, Calcium nitrite and Calcium nitrate.

d) Air-Entraining Admixtures

These are admixtures that intentionally introduce air bubbles into the mixture in the form of minute air bubbles generally smaller than 1mm in diameter, called entrained air, in order to improve workability and frost resistance of the concrete and may also reduce bleeding and segregation of concrete mixture. This should be avoided in concrete flat work that need smooth troweled finish. In high cement concrete, air entrainment reduces strength by 5% for every 1% of entrained air, but for low cement concrete air entrainment has less significant effect and may even cause a modest increase on the concrete strength due to reduced water demand to achieve the required slump. Air entrained admixtures for use in concrete should meet the requirement for BS 5075-2:1982.

2.1.2 Properties of Fresh Concrete

2.1.2.1 Workability

Workability is often referred to as the ease with which a concrete can be transported, placed and consolidated without excessive bleeding or segregation. It can also be defined as the internal work required in overcoming the frictional forces between concrete ingredients for full compaction. It is obvious that no single test can evaluate all these factors. In fact, most of these cannot be easily assessed even though some standard tests have been established to evaluate them under specific conditions. In the case of concrete, consistence is sometimes taken to mean the degree of wetness; within limits, wet concretes are more workable than dry concrete, but concrete of same consistence may vary in workability.

Because the strength of concrete is adversely and significantly affected by the presence of voids in the compacted mass, it is vital to achieve a maximum possible density. This requires sufficient workability for virtually full compaction to be possible using a reasonable amount of work under the given conditions. Presence of voids in concrete reduces the density and greatly reduces the strength: 5% of voids can lower the strength by as much as 30%, and even 2% void can lower strength by as much as 10% (Neville 1996).

2.1.2.1.1 Factors that Affect Workability

a) Water Content

If the water-cement ratio is high, the workability will also be high. Since by simply adding water the inter-particle lubrication is increased, high water content results in a higher fluidity and greater workability. Increased water content also results in bleeding. Another effect of increased water content can also be that cement slurry will escape through joints of formwork through bleeding leaving the concrete with insufficient paste, thereby leading to a reduction in the strength of the resulting concrete.

b) Mix Proportions

An important factor that affects workability is the aggregate/cement ratio. It has been shown that the higher the aggregate/cement ratio, the leaner is the concrete (concrete of low cementitious material content). Lean concrete has low quantity of paste available for providing lubrication, per unit surface area of aggregate and hence the mobility of aggregate is restrained. Conversely, in the case of rich concrete with lower aggregate/cement ratio, there is more paste available to make the mix cohesive and fatty to give better workability.

c) Size of Aggregate

The bigger the size of aggregate, the lesser is the surface area and therefore, less amount of water required to wet the surface; extra water being available for workability and less cement paste being required for lubricating the aggregate surface to reduce internal friction. Therefore, for a given quantity of water and paste, bigger size of aggregate will give a higher workability.

d) Shape of Aggregate

Angular, elongated or flaky aggregate makes the concrete very harsh when compared to rounded aggregates or cubical shaped aggregates (Shetty, 2005). This is because cubical and rounded aggregate have less surface area and less void per unit volume of aggregate than flaky and angular aggregate. The frictional resistance also reduces as a result. This is the reason why natural sand or river sand and gravel sand provide more workability than crushed sand aggregate. This factor is very significant when high performance concrete is a priority, in which case a very low water/cement ratio, in the order of about 0.25, is used.

Due to high demand on natural sand, in the near future this aggregate will be very costly or even completely unavailable. This will shift attention to manufactured sand which presently has flaky and angular shapes, this makes it unsuitable for concrete production because it hampers workability but innovations in modern crusher makes it possible to produce a good shaped and well graded manufactured aggregate (Shetty, 2005).

e) Surface Texture of Aggregate

The effect of surface texture of aggregate on workability is due to the fact that the total surface area of rough textured aggregate is more than the surface area of smooth rounded aggregate of same volume. So it is established that rough textured aggregate will show poor workability and smooth or glassy textured aggregate will give better workability.

f) Grading of Aggregate

Grading of aggregate is one of the factors that will have maximum effect on workability. When aggregates are properly graded such that they have least amount of voids in a given volume, workability is improved. When other factors are constant, the total voids are less; excess paste is available to give better lubricating effect. With excess amount of paste available, the mixture becomes cohesive and fatty which prevents segregation of particles (Mehta P.K. and Monteiro P.J., 2006). With minimal amount of compacting efforts, aggregate particles will slide past each other. The better the grading, the less is the void content and higher the workability.

g) Use of Admixture

The use of admixtures is the most important factor amongst the above listed factors that affect workability. It has been reported that Plasticizers and Super-plasticizers greatly improve the workability many times as much as concrete that contain no such admixtures. Some other agents such as air-entraining agents provide ball bearing action between particles of aggregate thereby reducing the internal friction and in turn providing greater mobility (Shetty 2005).

g) Effect of Time and Temperature

The change in workability with time depends on the moisture condition of aggregate (at given total water content); the loss is greater with dry aggregate due to the absorption of water by aggregate. It is also affected by the ambient temperature (Shetty 2005). This is true because on a hot day the water content of the mix would have to be increased for a constant early workability to be maintained.

2.1.2.2 Curing of Concrete

This is the name given to procedures used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete. The effect of inadequate curing on strength is greater at higher water/cement ratio and is also greater in concretes with a lower rate of development of strength. Ben-Bassat, et al (1990)reported that the strength of concretes made with Ordinary Portland Cement is more affected by poor curing. Likewise, concretes containing fly ash or ground granulated blast furnace slag are more affected than concretes made with Portland Cement only. Curing of concrete can be done in two broad ways, viz; Water curing and Membrane curing

a) Water Curing

It is the best known method of curing concrete samples because it satisfies all the requirements of curing, which are; promotion of hydration, elimination of shrinkage andabsorption of the heat of hydration. This method can be achieved in the following ways, (i) Immersion, (ii) Ponding, (iii) Spraying or Fogging and (iv) Wet covering.

Precast concrete units are normally immersed in curing tanks for certain durations. Pavement slabs, roof slab, etc., are covered under water by making small ponds. Vertical retaining wall, plastered surfaces or concrete columns are cured by spraying water on them. Wet coverings such as wet gunny bags, hessian cloth, jute matting, straw, etc., can also be wrapped on vertical surfaces for keeping the concrete wet in some cases. Horizontal surfaces can be covered with saw dust, earth or sand, and subsequently kept wet to achieve curing (Shetty, 2005).

b) Membrane Curing

This second method of curing relies on the prevention of loss of water from the surface of the concrete, without the possibility of external water ingression into it. The method can as well be called water-barrier method. It implores the techniques of covering the surface of the concrete with overlapping polyethylene sheeting, laid flat, or with reinforced paper. The sheeting can appear either in black or white where the black is preferred in cold weather and the white in hot weather. The white has the advantage of reflecting solar radiation.

2.1.3 Properties ofHardened Concrete

2.1.3.1 Strength of Concrete

The strength of concrete isdefined as the maximum load the concrete can carry per unit area. Concrete is good in compression but weak in tension. The compressive strength of concrete is taken as the maximum compressive load it can carry per unit area.

$$f_c = \frac{F}{A} \qquad 2.1$$

Where F = maximum load applied, A = area of the specimen

The tensile strength of concrete is important in the design of concrete roads and railway. For example, flexural strength or modulus of rupture (tensile strength in bending) is used for distributing load over a wide area of road pavement or railway track. The method used in assessing the tensile strength of concrete is by the split cylinder test and this involves diametrically loading a cylinder along its entire length. The magnitude of the tensile strength at failure $f_t$is given as

$$f_t = \frac{2F}{\pi l d} \qquad 2.2$$

Where F is the maximum applied load, l and d is cylinder length and diameter respectively.

The flexural strength of concrete is another indirect tensile value which is also commonly used to determine its load bearing ability (BS 1881-118-1983). In this test, a simply supported plane concrete is loaded at its third points, the resulting bending moment inducing tensile and compressive stresses at the bottom and top of the beam respectively. The beam fails in tension and the flexural strength (modulus of rupture) is defined by;

$$f_f = \frac{FL}{bd^2} \qquad 2.3$$

Where F = the maximum applied load.

L = the distance between the supports

$b$and d are the beam breadth and depth respectively (Shetty 2005).

The tensile strength of concrete is usually taken to be about one tenth of its compressive strength value. This may vary, however, depending on the method used in measuring tensile strength and the type of concrete. Generally, the direct tensile strength and the split cylinder tensile strength vary from 5 to 13 % and flexural strength from 11 to 23% of the concrete cube compressive strength. In each case, as the compressive strength increases, the percentage variation of tensile strength decreases. As a guide, the modulus of rupture may be taken as $0.7\sqrt{f_{cu}} N/mm^2$ and the direct tensile strength as although where possible, values based on tests using the actual concrete in question should be obtained if more precise result is required (Jackson and Dhir, 1996).

The compressive strength is the most important property of concrete. The compressive strength test can be carried out on cube or cylinder specimens. This test is carried out after 28 days usually on test cubes with lengths of 150mm. The compressive strength is calculated from the maximum load on the test cube (before it breaks) in Newton's divided by the surface area of the specimen in mm^2 of the specimen.

2.1.3.2 Factors that Affect the Strength of Concrete

The strength developed by a given workable, properly placed concrete under the condition of mixing, curing and testing is influenced by the following; water/cement ratio, aggregate cement ratio, grading, shape, strength and stiffness of aggregate, maximum size of aggregate etc.

a) The Water/Cement Ratio.

The strength of concrete decreases with the increase of the water-cement ratio of the mix. Therefore, a concrete mix containing the minimum amount of water required for complete hydration of cement, if it could be compacted, would yield the maximum attainable strength at any given age. It should be noted that complete hydration may be achieved by a particular water-cement ratio but the resulting mixture may be completely dry and compaction of such concrete impossible. In 1918, Abrams postulated a law which states that the strength of concrete is only dependent on the water-cement ratio provided the mix is workable. He represented his classic law in the form(Neville 1996):

$$f_c = \mathrm{k}\left[\frac{vc}{v_c \quad v_w} + a\right]^2 \qquad 2.4$$

Where, f_c= concrete compressive strength,

K = constant,

Vc, Vw, a = absolute volumes of cement, water and entrapped air respectively.

The relationship between water-cement ratio and compressive strength of concrete can also be illustrated as in Figure 2.2.

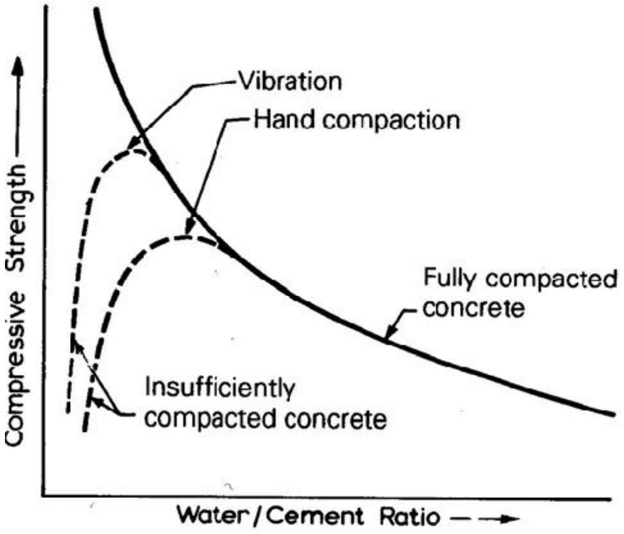


Figure 2.2: RELATIONSHIP BETWEEN W/C RATIO AND COMPRESSIVE STRENGTH OF CONCRETE. Source: Shetty (2005)

From previous studies it is evident that the strength attained by concrete is greatly influenced by the water-cement ratio (*w/c*) (Shetty, 2005), therefore the need to investigate this property (*w/c*) and its interaction with other performance characteristics of Quarry dust concrete.

Waziri, et al (2011) in their research on the effect of water-cement ratio on the strength properties of quarry-sand concrete (QSC), investigated the pattern of relationship between w/c and compressive strength. Two nominal mix proportions of 1:2:4 and 1:3:6 (Cement – Quarry/ Sand – Gravel) were used and it was found out that the compressive strength for all mixes decrease with increasing water/cement ratio. The more the free water content of the fresh concrete the greater would be the volume of pores left in the hardened concrete and therefore the less the gel/space ratio and this trend is true for quarry sand concrete (QSC), and is a useful parameter in practical field construction.

2.1.3.3 Characteristic Strength of Concrete

The only engineering property of concrete that is routinely specified is the characteristic compressive strength (Shetty 2005). This has a relationship to most other mechanical properties and provides the basis for estimating them.

When designing any form of reinforced concrete structure, the designer will specify the strength of concrete that has been assumed in the design. This strength of concrete is usually specified in terms of the characteristicstrength. This characteristic strength is based on statistical concepts and is the strength below which no more than 5% of all cubes tested from the chosen concrete mix will fall. Equally it can be expected that 95% of all cube samples will have strengths in excess of the design characteristic strength.

2.1.3.4 The Gain of Strength with Age

The development of strength in concrete is as a result of the hydration of cement. The rate of hydration determines the rate of strength development. At the early stage, the rate of strength gain is high but reduces with time. It is usually assumed that concrete will acquire about 75% of its final strength by the 28th day; and that further development of strength will continue beyond this 28th day. This pattern of behavior was more pronounced in older cement. Modern Ordinary Portland Cement is now graded, and the Grade 53 cement which has finer particles, gains strength more rapidly, achieving about 90% or more of its ultimate strength by the 28th day. Since most of the strength of a lot of modern cement now occur within 28 days, allowing for an age factor during design is therefore not generally found necessary (Shetty 2005). No doubt, there is a gain of strength after 28 days and the quantity of increase depend on the grade and type of cement, curing and environmental condition, etc. However, the design of concrete is still based on the 28th day strength unless there is an evidence to justify a higher strength for a particular concrete structure beyond 28 days.

2.1.3.5 Maturity Concept of Concrete

Generally, the compressive strength of concrete can be estimated by crushing a test cube or cylinder at 28 days. The need to have this result sooner so as to make decisions before it is too late have led researchers to look for new strategies of predicting 28 days strength within hours of casting. Maturity concept is one of the methods that have been found to have good field correlation. Since the strength development of concrete depends on both time and temperature, it can be said that strength is product of summation time and temperature. This summation is called maturity of concrete (Carino, N.J., 2004).

$$Maturity = \sum(time \times temperature) \qquad 2.5$$

The temperature is considered from an origin lying between -12 and -10℃ but from experiment, it was found that hydration process continues to take place up to -11℃. Therefore, -11℃is viewed as datum for the measurement of maturity. Maturity is measured in degree centigrade hours (℃ hrs)or degree centigrade days (℃ $days$). In standard calculations, the maturity of fully compacted concrete is taken as 19,800 ℃ hrs. If the period is divided into smaller intervals and the corresponding temperature is recorded for each interval, the summation of the product of time and temperature will give an accurate picture of maturity of concrete. In the absence of such detailed temperature history with respect to the time, the Figure can be arrived at by multiplying the duration in hours with the average temperature at which the concrete is cured. Obviously the maturity calculated as above will be less accurate (Shetty, 2005).

Maturity concept is useful for estimating the strength of concrete at any other maturity as a percentage of strength of concrete of known maturity. In other words, if we know the strength of concrete at full maturity (19,800 ℃ hrs), we can calculate the percentage strength of identical concrete sample at any other maturity by applying the Plowman's formula(Shetty 2005);

$$\text{Percentage Strength } (19{,}800\ ℃\ hrs) = A + B log_{10} \frac{(maturity)}{10^3} \qquad 2.6$$

The values of A and B depend on the strength level of concrete and are given in Table 2.3.

Table 2.3: PLOWMAN'S COEFFICIENTS F FOR MATURITY EQUATION

$\boldsymbol{Strength after 28 days at 18}$℃ ($\boldsymbol{Maturity\ of 19{,}800}$ ℃ $\boldsymbol{hrs}$): $\boldsymbol{MPa}$	$\boldsymbol{Coefficient}$	
	A	B
$Less than$ 17.5	10	68
17.5 – 35.0	21	61
35.0 – 52.5	32	54
52.5 – 70.0	42	46.5

Source:Shetty(2005)

2.1.4 Concrete Mix Design

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative quantities with the purpose of producing an economical concrete which has certain properties, notably workability, strength and durability (Neville, 1996).

Basically, the problem of designing a concrete mix consists of selecting the correct proportions of cement, fine and coarse aggregate and water to produce concrete having the specified properties. Sometimes additional ingredients such as chemical admixtures (Plasticizers, Retarders, Air-Entrainers, etc) or pozzolanic admixtures (Ground Granulated Blast-furnace Slag (GGBS), Pulverized-Fuel Ash (PFA), Silica Fume, etc) are used. There are many properties of concrete that can be specified, e.g. workability, strength, density, thermal characteristics, elastic modulus and durability requirements. The properties most usually specified being; a) The workability of the fresh concrete; b)

The compressive strength of hardened concrete at a specified age; and c) The durability of the concrete, specified in terms of minimum cement content and/or the maximum free-water/cement ratio, and in some cases, requiring the specification of types of materials to be used.

2.1.4.1 Basic Concepts of Mix Design by the British (DOE) Method

a) Strength Margin

Because of the variability of concrete strengths, the mix must be designed to have a considerably higher mean strength than the strength specified. The difference between the specified characteristic strength and the target mean strength is called the ‘margin’. This margin is based on the knowledge of the variability of the concrete strength obtained from previous production data expressed as a standard deviation, or alternatively a substantial margin is applied until an adequate number of site results are obtained.

b) Free-water Content

The total water in a concrete mix consists of the water absorbed by the aggregates to bring them to a ‘saturatedsurface-dry’condition, and the free-water available for the hydration of the cement and for the workability of the fresh concrete. In practice aggregates are often wet and they contain both absorbed water and free surface water so that the water added at the mixer is less than the free water required. The workability of concrete depends to a large extent on its free-water content; if the same total water content were used with dry aggregates having different absorptions, then the concrete would have different workability’s. Similarly, the strength of concrete is better related to the free-water/cementratio since on this basis the strength of the concrete does not depend on the absorption characteristics of the aggregates (Shetty 2005).

c) Workability

The workability that is considered desirable depends on two factors. The first of these is the size of the section to be concreted and the amount and spacing of reinforcements; the second is the method of compaction to be used. Therefore, if a section is narrow and compacted, the concrete must have higher workability so that full compaction can be achieved with a reasonable amount of effort (Mehta P.K and Monteiro P.J., 2006).

d) Cement Content

In designing a mix, it is sensible to aim at an economic cement content because cement is more expensive than aggregate. A moderate cement content also confers a technical advantage of a lower cracking potential, in the case of mass concrete and structural concrete. However, for durability considerations, cement content has to be at least equal to that laid down by specifications of relevant standards (Mehta P.K. and Monteiro P. J., 2006).

d) Choice of Aggregates

There is insufficient difference between the behavior of rounded and irregular aggregates in concrete to justify the use of separate classifications for these two shapes of aggregate, both of which are usually uncrushed and smooth textured aggregates. There are however significant differences between these aggregates and angular aggregates which are usually rough in texture and invariably produced by a crushing process (Shetty, 2005).

Two of the characteristics of aggregate particles that affect the properties of concrete are particle shape and surface texture. Particle shape affects the workability of the concrete, and the surface texture mainly affects the bond between the matrix and the aggregate particles and thus the strength of the concrete. Generally, crushed aggregates consist of rather angular particles having a rough surface texture resulting in a concrete of lower workability but higher strength compared with a similar mix made with uncrushed aggregates. However, in line with the principles of taking only major factors into account in designing the initial trial mix, only these two types of aggregate are considered, i.e. crushed and uncrushed.

The type of aggregate becomes of greater importance for concrete having a high specified strength. If the specified strength at 28 days is 50 N/mm^2 or more, it may become necessary to use crushed aggregate rather than uncrushed gravel (Shetty, 2005). The higher the specified strength the more critical is the selection of the source of the aggregate.

e) Durability

A durable concrete is one which gives a satisfactory performance during an adequate life in a given environment; this includes providing protection to the steel against corrosion in reinforced and prestressed concrete. There are some durability problems associated with the constituent materials and others due to the effect of hostile environments (Shetty 2005).

A major factor in providing durable concrete is the production of a dense, impermeable concrete, having adequate cement content and low free-water/cement ratio, which is fully compacted and properly cured. To be durable in hostile environments, Codes and Standards may specify the use of particular materials, or limits on the cement content or free-water/cement ratio. Provision is made in the DOE Mix Design Method for these to override the values obtained from strength and workability requirements.

To ensure adequate protection against durability challenges, BS 8110-1-1997 specifies higher grades of concrete as the severity of the exposure conditions increases; it also specifies minimum cement contents and maximum free-water/cement ratios, depending on the degree of exposure. Corrosion problems are aggravated by the presence of chlorides in either aggregates or admixtures. Limits are specified in BS 882 and BS 8110-1-1997 and materials complying with these requirements should be used.

Concrete in the ground may be subject to attack by sulfates. Minimizing the effect of such attacks requires the use of Sulfate-resisting Portland Cement or other materials, and the mix proportions should comply with the requirements given. Concrete that is exposed to freezing when wet and to the action of de-icing salts is liable to spalling and deterioration. The resistance of concrete to such deterioration is greatly improved if it contains entrained air as required in BS 5328: 1(1997).

f) Cost Considerations.

The cost of concreting just as any other type of construction procedure is composed of cost of constituent materials, plant and labor. Cement as a construction material is much costlier than other components, as a result, it is desirable to avoid high cement content during selection of mix proportion. This will make way for the production of economical concrete. Apart from economy, lean mixes bestow many other technical advantages on the concrete such as reduction in the heat generated in mass concrete structures such as dams (Shetty 2005). In structural concrete, lean mixes help in the reduction of high shrinkage and excessive cracking associated with rich mixes.

While trying to produce an economical concrete, it is important to note that the specified minimum or characteristic strength should not be compromised because that is the basis for acceptance or rejection of the concrete.

Other cost implications in concreting come from the quality control, due to the cost of supervision and batching equipment which are not necessary in most cases. Therefore, the extent of quality control should depend on the size and type of construction. It is essential that the degree of quality control is estimated at the onset of material selection to minimize the difference between the mean and characteristic strength (Neville, 1996). Labor is also another source of expenditure and this can be influenced much by workability of the mix. If the mix is stiff, the cost of effort required to compact it will be much or trying to save cost, insufficiently compacted concrete will result to failure. In all, the effective cost of concreting is controlled by planning of the job and equipment.

2.1.4.2 Factors Governing the Selection of Mix Proportions

a) Durability

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations where high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water-cement ratio to be used.

b) Workability.

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with numerous corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site condition.

c) Maximum Size of Aggregate.

Determine the maximum size of coarse aggregate that is economically available and consistent with dimensions of the structure. It is found that the larger the size of aggregate, the smaller is the cement requirement for a particular water cement ratio. Aggregates having a maximum nominal size of 20mm and smaller are generally considered satisfactory (Shetty, 2005).

d) Grading and Type of Aggregate.

The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio; the coarser the grading, the leaner will be mix which can be used, but this is true within certain limits only because a very lean mix that does not contain enough fine material will not produce a cohesive concrete. It is possible to reverse the direction of choice: for instance, if the cement content is fixed, then a grading may be chosen such that concrete of a given water/cement/aggregate proportion and a satisfactory workability can be made. It is worthy to note that there are limits on grading outside which it will be impossible to make a good concrete.

The type of aggregate, its surface texture, shape and properties influence strongly the aggregate-cement ratio for the desired workability and stipulated water cement/ratio. At the onset of selecting a mix proportion, the type of aggregate available and its grading should be known to enhance proper selection.

2.2 Use of Quarry Dust in Concrete Production

During the extraction and processing of mineral rock masses into aggregates and other saleable products, a significant proportion of the original material mass may not end up in the intended size range. This is largely due to the unavoidable generation of fines (generally defined as particles less than 4.75mm in size) and dust (a sub-section of fines generally particles less than 75µm) that occurs during mineral processing operations, such as crushing, screening and materials handling (Shetty, 2005).

While the exact percentage of material that gets collected into fines varies according to the type of process, operating conditions and type of rock; it is usually estimated to be between 10 and 30% by weight of the hundreds of millions of tones that get processed annually in the UK alone. Therefore, tens of millions of tones become fines by-products each year, adding to existing stored fines. This has been the case for many years and putting by-products such as these to use in other applications has long been considered as an important priority for the quarry industry. The opportunity to generate added value to an otherwise waste product would give quarry operators a significant commercial advantage.

Quarry Rock Dust can therefore be defined as residue, tailing or other non-valuable waste material left over after the extraction and processing of rocks in the form of fine particles less than 4.75mm. This waste apart from constituting an eyesore around the neighbourhood, is also associated with environmental and health risks. Increase in the infrastructure needs of the country has led to an increase in the demand for crushed rock. As the activities of stone mines and quarries increase, the turnout of quarry dust also increases. The need to absorb this waste product from the environment therefore becomes eminent.

The utilization of quarry rock dust, which can be called manufactured sand, has been accepted as a building material in the industrially advanced countries of the west for the past three decades (Nisnevich, et al, 2003). As a result of sustained research and developmental works undertaken with respect to increasing application of this industrial waste, the level of utilization of quarry rock dust in the industrialized nations like Australia, France, Germany and UK has reached more than 60% of its total production.

The use of manufactured sand in Nigeria has not been much when compared with the countries mentioned above. This may be as a result of lack information on the potency of this material as an alternative to natural sand in the production of concrete.

Several researches on the engineering properties of concrete produced with quarry dust as a partial replacement of sand has been carried out and the outcome of these researches are very encouraging. The cement content, workability, compressive strength and cost of concrete made with Quarry Rock Dust were studied by Babu, et al, (1997); Nagaraj and Zahida, (1996) and Narasimahan, et al, (1999). The mix design proposed by Nataraja, et al (2001) shows the possibilities of ensuring the workability by astute combination of rock dust and sand, use of super plasticizer and optimum water content using a generalized rule. Lohani, et al,(2012) reported significant increase in compressive strength, modulus of rupture and split tensile strength when 40 percent of sand is replaced by Quarry Rock Dust in concrete. Ilangovan and Nagamani (2006) reported that Natural Sand with Quarry Dust as full replacement in concrete is possible with proper treatment of Quarry Dust before utilization and adequate proportioning. Galetakis, et al (20012) studied the influence of varying replacement proportion of sand with quarry dust (20, 30 and 40%) on the properties of concrete in both fresh and hardened state (Neville, 1996).

Safiuddin,et al (2001) investigated the influence of partial replacement of sand with quarry dust and cement with mineral admixtures on the compressive strength of concrete (Gambhir, 1995), whereas Celik and Marar (1996) investigated the influence of partial replacement of fine aggregate with crushed stone dust at varying percentages on the properties of fresh and hardened concrete (Safiuddin, et al 2001; Celik and Marar, 1996).

2.2.1 Source and Classification of Quarry Dust

Quarry dust is primarily obtained from crushing of rocks and stones in the quarry industry. On the other hand, quarry dust is generally classified into two classes. According to Sivakumar, Prakash (2011) quarry fines can be classified into two distinct divisions – Unbound fines and Bound fines.

Unbound Fines are used in reclamation works and in bulk filling applications such as in mine fills. They are also used in road pavement construction and as soil additives. The latter is of particular significance where the geology and chemistry of the fines can alter soil acidity. Filler applications also have extensive usage in making Portland Cement concrete.

Bound Fineshave been used successfully as major constituents in pumpable infill grout, concrete and heavy duty ceramics such as bricks and tiles. Another use of bound fines has been developed in the manufacture of lightweight aggregates using waste plastic and quarry fines. Other applications include use as asphalt road paving materials and in shore protection.

2.2.2 Factors that Affect the Quality and Quantity of Quarry Dust

In general, the greater the number of unit operations used in processing rock, the greater the amount of fines generated. Thus, the products generated by mineral quarries, to a certain extent govern the quantities of fines. However, rock type also has a significant effect on the fines generated.

The quality of quarry dust obtain depends on the parent rock that was crushed and the gradation of the quarry dust. The quality of quarry dust that will be obtained by crushing granite will be quite different when compared to the quality of dust from quartzite and lime stone. The gradation of the particle has effect on the strength, and workability of concrete. Concrete does not give adequate workability with increase of quarry dust. It may be due to the extra fineness of quarry dust (Safiuddin, et al2001). In summary, the proportion of fines generated in a quarry production plant will depend on the following variables:

i. Geological parameters of the rock;

ii. Type of crushers used (jaw vs. core gyratory or compression vs. impact);
iii. Reduction ratio of the crusher used;
iv. Number of crushing processes;
v. Top size of feed;
vi. The technical details of the blasting process (if applicable);
vii. Number of materials handling stages involved (e.g. screening, conveying).

It can be deduced that the majority of the fines produced will be generated in the blasting and crushing stages of the process. The quantities of fines generated in the blasting process have been estimated to be as high as 20% (Nagaraj and Zahida 1996). Research has been carried out into the key blasting parameters associated with fines production, these are charge volume, detonation pattern and detonation timing

2.2.3 Uses of Quarry Dust

Quarry dust is used for different activities in the construction industry; it is used for making road pavement finishes, and manufacturing of building materials such as light weight aggregates, bricks, and tiles. In concrete production, quarry dust is used as fine aggregate to fully or partially replace sand. Higgins (2007) concludes that limestone fines can be used as an additive to concrete, contributing to the strength by the physical filling of the voids, as well as decreasing porosity.

Quarry dust exist in abundance in most parts of Nigeria, and their incorporation in structural concrete will likely reduce the cost of construction of buildings significantly. On the other hand, the use of these materials has some tendencies to reduce environmental problems such as that posed by the excessive mining of river sand, the depletion of conventional fine aggregate for concrete works in Nigeria and most parts of the world; and the environmental problems in quarry sites due to large heaps of quarry dust. Saghafi and Nageim (2011) have studied the possibility of reducing the demand for primary aggregate in the United Kingdom highways construction industry by incorporating limestone waste dust to replace some of the coarse and fine aggregate in road base materials. This tends to have significant impact on the demand for primary aggregate.

2.2.4 Chemical and Physical Properties of Quarry Dust

Understanding the key physical and chemical parameters of the specific quarry waste under consideration is of key importance when assessing its functionality. The parameters that are of importance here are; chemical characteristics, particle size distribution, aspect ratio of particles, bulk density, and abrasion resistance

Galetakis, et al 2012) in their study on utilizing quarry fines examined properties of fines from four quarries located as follows;

Dene: located near Matlock in Derbyshire; limestone dust sampled.

Croxden: located near Uttoxeter in Staffordshire; unused asphalt sand sampled.

Holme Hall: located near Maltby in Yorkshire; limestone dust sampled.

Bayston Hill: located near Shrewsbury in Shropshire; reclaimed filler dust sampled.

Typical properties measured were:

(Bolden)

The materials from Dene and Holme Hall were well graded with Dene a little coarser with a higher percentage of 0.3 mm aggregate.

By comparison the results from Croxden and Bayston Hill were contrasting. The original extraction process for sand includes a washing operation, which removes the vast majority of silt and clay sized particles hence the Croxden samples contained the least silt and clay sized particles. It is a uniformly graded material with a particle size in the medium sand range, and has a Coefficient of Uniformity of about1.6. Bayston Hill material has particle size that is smaller than coarse sand, with about 95% of the material below 0.1 mm in size. About 50% of the particles lie in the 0.01 mm to 0.1mm size fraction. Thus about 45% of the material is in the silt range.

(Bolden)

Bulk density determinations for materials from Croxden, Dene and Holme Hall are shown in Table 24 The reclaimed filler dust from Bayston hill exhibited the lowest bulk and particle density compared to the quarry fines from Bayston Hill, Croxden and Dene quarries.

Table 2.4: MOISTURE CONTENT, BULK DENSITY AND PARTICLE DENSITY RESULTS FOR THE FOUR SITES INVESTIGATED

Test	Bayston Hill	Croxden	Dene	Holme Hall
Moisture content (%)	10.3	4.2	7.5	4.25
Particle density (apparent) (Mgm-3)	2.79	2.63	2.75	2.66
Particle density (SSD) (Mgm-3)	2.74	2.61	2.71	2.56

Particle density (oven dry) (Mgm-3)	2.71	2.59	2.73	2.50
Bulk density (Mgm-3)	N/A	1.3-1.5	1.5-1.7	1.6-1.8

Source: BS 812, 1995

Table 2.5 shows that the aggregate crushing value of quarry dust is in the range of 52.7% to 60.8% as reported by (Lohani et al, 2012). The average crushing value was found to be 56.7%. Crushing value of quarry dust has significant effects on the strength and durability of concrete. The higher aggregate crushing value of quarry dust might be due to particle shape of dust, which is flaky and angular.

Table 2.5: THE AGGREGATE CRUSHING VALUE OF QUARRY DUST

Sample	ACV (%)
Quarry Dust 1	52.7
Quarry Dust 2	56.8
Quarry Dust 3	60.8
Average	56.7

Source: Shetty (2005)

2.2.5 Chemical Composition of Quarry Dust and Natural Sand

Illangovan and Nagamani (2006) reported on the chemical composition of quarry dust obtained from a local quarry in India and comparing it with natural sand and the result is shown in the Table 2.6.

Table 2.6: TYPICAL CHEMICAL COMPOSITION OF QUARRY ROCK DUST AND NATURAL SAND

Constituent	Quarry rock dust (%)	Natural sand (%)
SiO_2	62.48	80.78
Al_2O_3	18.72	10.52
Fe_2O_3	06.54	01.75
CaO	04.83	03.21
MgO	02.56	00.77
Na_2O	Nil	01.37
K_2O	03.18	01.23
TiO_2	01.21	Nil
Loss of ignition	00.48	00.37

Source: Illangovan and Nagamani (2006)

Illangovan and Nagamani (2006) through their research work on the strength and durability properties of concrete containing quarry rock dust as fine aggregate, attemptedto replace all the natural sand in concrete formulations with quarry dust. The cement used in this study was Portland Cement (43 grade).

The following conclusions were made:

The physical and chemical properties of quarry dust satisfied the requirements of code provision on the properties studied. Natural river sand, if replaced by hundred percent Quarry Rock Dust from quarries, may sometimes give equal or better than the reference concrete made with Natural Sand, in terms of compressive and flexural strength studied.

It was also concluded that the replacement of natural sand with Quarry Rock Dust, as full replacement in concrete is possible. However, it is advisable to carry out trial casting with Quarry Rock Dust proposed to be used, in order to arrive at the water content and mix proportion to suit the required workability levels and strength requirement. However, more research studies are being made on Quarry Rock Dust concrete necessary for the practical application of Quarry Rock Dust as Fine Aggregate.

2.2.6 Effect of Quarry Dust on Workability

The variation of workability of fresh concrete is measured in terms of slump, compaction factor or V-B time with water/cement ratio.

It has been reported that the substitution of sand with quarry dust increases the compressive and tensile strength of concrete, while as might be expected, its workability decreases (Achamfuor, 2002; Haque, 1980).

Illangovan and Nagamani (2006) investigated the strength and workability of different class of concrete proportioned by four different methods of mix design and found out that for the given water/cement ratio, the highest slumps and compaction factor were recorded for the mixes designed by British method. The overall workability value of Quarry Rock Dust concrete was less when compared to conventional concrete.

According to Lohani, et al (2012) on thier research on ‘Optimum utilization of Quarry dust as partial replacement of sand in Concrete’,it was observed that the slump value decreases with increase in percentage replacement of sand with quarry dust for the same w/c ratio. Concrete does not give adequate workability with increase of quarry dust. It can be due to the extra fineness of quarry dust (Safiuddin et al 2001). Increased fineness require greater amount of water for the mix ingredients to get closer packing, results in decreased workability of the mix.

2.2.7 Effect of Quarry Dust on the Compressive Strength of concrete

As reported bySivakumarmand Prakash(2011), the compressive strength of concrete cube containing 100% replacement of sand with quarry dust ranges between 21.3 to 33.63MPa for a binder content of 300 kg/m^3. The maximum compressive strength of concrete cube containing 100% replacement of sand with quarry dust was found to be 33.63 MPa at 56 days for a fine to coarse aggregate ratio of 0.7. The reference compressive strength of concrete cube ranged between 18.70 to 42.10 MPa for different fine to coarse aggregate ratio.

As the dust particles exceeds 30%, flaky particles or higher fines increase water demand which leads to higher water cement ratio and segregation of concrete results in non-uniform distribution of cement paste. This consequently leads to a decrease in compressive strength.

The strength of Quarry Rock Dust concrete is comparatively 10-12 percent more than that of similar mix of Conventional Concrete [Babu et al 1997, Nagaraj and Zahinda 1996 and Illangovan and Nagamani2006]. Also the result of the investigation by Illangovan and Nagamani(2006)shows that drying shrinkage strains of Quarry Rock Dust concrete are quite large in comparison to the shrinkage strain of Conventional Concrete.

2.2.8 Effect of Quarry Dust on the Durability of concrete

One of the major challenges facing the civil engineering community is to execute projects in harmony with nature using the concept of sustainable development involving the use of high performance, environmental friendly, and durable concrete materials produced at reasonable cost.

The Durability of Quarry Rock Dust concrete under sulphate and acid action is higher than the Conventional Concrete. Permeability Test results clearly demonstrates that the permeability of Quarry Rock Dust concrete is less compared to that of conventional concrete. The water absorption of Quarry Rock Dust concrete is slightly higher than Conventional Concrete. Therefore, these results provide a strong support for the use of Quarry Rock Dust as fine aggregate in Concrete Manufacturing (Illangovan and Nagamani, 2006).

The immersion of concrete made with partial replacement of sand with quarry dust in different solution shows that there is no loss of strength for immersion in magnesium sulphate solution ($MgSO_4$) and sodium chloride ($NaCl$) solution in comparison with immersion in normal water. Also gain of strength continues with age with no loss in weight. But in case of hydrochloric acid (HCl), there is a loss of strength and weight in comparison with immersion in normal water and the loss in strength increases with increase in days of immersion in Hcl solution. This indicates that $MgSO_4$, NaCl has no adverse effect on the concrete mix, but HCl highly deteriorate the strength of concrete (Aitcin, 2003).

The water absorption capacity of concrete containing quarry dust was investigated by Lohani et al (2012). From the result, it was noticed that Water absorption % of concrete decreased for dust contents from 0 to 20% and then it started to increase for 30% to 50% of dust contents. Quarry dust acts as filler in concrete and contributes to reduce the water absorption aptitude of concrete.

2.2.9 Effect of Quarry Dust on the Flexural and Tensile Strength of concrete

According to Elayesh (2009) flexural strength provides two useful parameters, namely: “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.” Flexural properties of structural materials are generally important to design engineers to guide appropriate selection of materials.

According toSivakumarmandPrakash(2011) maximum split tensile strength of 3.33 MPa was obtained for quarry dust concrete with an F/C ratio of 0.6. The addition of quarry dust has shown significant increase compared to plain cement concrete with natural sand. It was concluded thatquarry dust concrete can lead to significant improvement in microstructure due to different size fractions. Also, the filler effects of quarry dust can lead to significant increase (18.6%) in the split tensile strength compared toreference concrete.

The flexural and tensile strength properties of concrete containing quarry dust and lateritic sand as fine aggregate were found to compare closely with those for normal concrete. Thus, 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%.Both flexural and tensile strengths were found to increase with increase in laterite content. Further work is required to get data for long-term deformation characteristics and other structural properties of the experimental concrete. These include: shear strength, durability, resistance to impact, creep, etc. Also, it may be necessary to investigate the optimum contents of lateritic sand and quarry dust in relation to the structural properties of the concrete. These will assist engineers, builders and designers when using the materials for construction works (Ukpata, et al 2012).

The results for flexural strengths of concrete using lateritic sand and quarry dust were found to be3.28N/mm^2 for 50% laterite: 50% quarry dust and2.88N/mm^2 for 25% laterite to 75% quarry dust. The tensile splitting strengths on the other hand were2.91N/mm^2 for 50% laterite: 50% quarry dust and1.67N/mm^2 for 25% laterite: 75% quarry dust. It was observed that tensile and flexural strengths reduce with increase in quarry dust content which agrees with the results of Osunade (2002). The tensile strength values are higher than those of laterized concrete by Osunade (2002) which ranged from 1.44 to 2.0N/mm^2.

The tensile strength value of concrete decreases with increase in percentage of fine aggregate replacement with quarry dust but the split tensile strength increases with the age of curing (Aitcin, Mico, et al 1994).

2.2.10 Effect of quarry dust on modulus of elasticity

The modulus of elasticity increases with increase in percentage of quarry dust content (Baalbaki, et.al., 1992; Saffiuddin, et al 2001).

The modulus of elasticity of concrete with and without quarry dust for different binder content and F/C ratio was investigated bySivakumarmand Prakash (2011), at binder content of 300 kg/m^3, the maximum elastic modulus of 29.31 GPa was obtained for an F/C ratio of 0.6. The elasticity modulus of concrete for 100% replacement of sand with quarry dust varied from 14.27 to 29.31 GPa. For the reference concrete, the maximum modulus of elasticity is 33.03 GPa at 56 days for an F/C ratio of 0.7 At 350 kg/m^3, the maximum modulus of elasticity of concrete (100% replacement of sand with quarry dust) ranged from 14.27 to 28.87 GPa. It can be noted that the effects of quarry dust on elastic modulus was observed at a binder content of 400 kg/m^3 and had showed 15% higher than other concrete specimens. The effects of quarry dust on the elastic modulus property were found to be consistent with conventional concrete containing natural sand.

2.3 Optimization of Concrete Mix Design

2.3.1 Concrete Mix Design

Concrete mix design is the procedure for determining the mix proportions of a particular concrete, with the goal of producing an economic and durable concrete that will meet certain prescribed specification; like consistency, strength and durability. There are two major approaches to concrete mix design, namely the empirical method and statistical method (Simon et al, 1997).

In the empirical method, the guidelines established in Design Codes are followed; added to the historic data or any past experiences, the concrete designer might have acquired, working with the same or similar materials. There are a number of Codes of practices that have established guidelines for concrete mix design.The British Standards Institute has the Design of Normal Concrete Mixes (Teychenne, et al, 1975); the American Concrete Institute (ACI) has ACI Committee 211: standard practice for selecting proportions for Normal, Heavyweight, and Mass Concrete" (1995). In using the empirical methods, trial mixes and further trial mixes are inevitable until all the specified criteria are met. By this method, it is however difficult, if not impossible to achieve a truly optimal mixture for alldesired criteria. Optimization of multiple concrete criteria can only be attempted by using the more scientific statistical method.

The statistical method makes use of some vital theories of experimental statistics to formulate mathematical models, for the prediction of concrete mix ratios and their target strength, within a specified confidence interval – that is, an established probability of acceptance. While the statistical method will require initial technical and experimental investments; it produces an optimized concrete mix in which all specified factors are taken care of and at a much cheaper overall cost. The statistical method however has the limitation of being particularized. A model once determined, can only be used to design concrete within the chosen boundaries of the model space, as the model will effectively interpolate not extrapolate.

2.3.2 Statistical Design of Experiment (DOE)

Experiments have always been tools for tackling practical problems and for testing theoretical hypotheses in engineering. Concrete mix designs are certainly experimental processes and the principles of Design of Experiment can be applied to them. Traditionally, experimentation demands an investment of resources, effort and time, especially if they involve complex processes. An efficient way of enhancing the value of research and cutting down the process development time is through the Design of Experiment – a process that require the planning and optimization of experiment processes at every stage, from inception through research and development, to engineering and production.

The statistical design of experiment (DOE) is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions. An experiment design is the laying out of a detailed experiment plan in advance of doing the experiment. Well-chosen experimental designs maximize the amount of information that can be obtained for a given amount of experimental effort. Experimental data are used to derive an empirical model linking the outputs and inputs. The data thus obtained are then processed by the methods of classical regression or correlation analysis (Nalomov, 1965; Akhnazarova, and Afarov, 1982; Himmelblov, 1970; Nalomov, 1960;Stepanov, 1976). Design of experiment can be used effectively in choosing between alternative outcomes (Objective Functions) of an experiment; select the key factors affecting an experimental response (the Objective Function); or foe response surface modelling (RSM).

A mixture experiment like concrete mix design, involves mixing various proportions of two or more components to make different compositions of an end product. Special issues arise when analyzing mixtures of component that must sum to a constant.
For example, if you wanted to optimize the taste of fruit-punch, consisting of the juices of five fruits, then the sum of the proportions of all juices in each mixture must be 100%.To attain our experimental goals in an optimal manner we must define the characteristic of the end product we want to optimize- that is, the Objective Function. Our objective function might be to minimize cost; to maximise profit; to achieve a certain compressive or tensile strength in the hardened concrete; or to achieve a certain workability index in the wet concrete, etc. The objective function is the dependent variable or the response variable in the experiment; while the other variables and inputs that affect its outcome are the independent variables. Most often, the independent variable fall into certain regions or limits; and they may be constrained to satisfy certain bounds or functional relationships; these are generally called constraints.

A typical optimization problem could be stated as follows: A Metallurgical Engineer owns a machine shop for producing concrete moulds. He produces cylinder and cube moulds. Each cylinder mould requires 4 hours of moulding and 3 hours of polishing whereas the cube mould requires 3 hours of moulding and 5 hours of polishing. The moulding staffs works for 60 hours in a week while the polishing staff work for 75hours in a week. Profit from the sale of one cylinder mould is ₦2400, while that from one cube mould is ₦2000. How would this manufacturer allocate his production capacity for the two moulds to maximize profit per week? We can formulate this optimization problem by letting x_1 be the number of cylinder moulds produced per week and x_z be the number of cube moulds produced per week. The profit generated per week in naira will then become (Mbajiorgu M, 2012)

$$z = 2400x_1 + 2000x_2 \qquad 2.7$$

Z is the objective function which will need to be maximised. However, the weekly resources(number of available hours) will constitute constraints as follows (Mbajiorgu M, 2012),

For molding $4x_1 + 3x_2 < 60$ 2.8

For polishing $3x_1 + 5x_2 < 75$ 2.9

Finally, a negative number of mouldscannot be produced, so

$$x_1 \geq 0 : x_2 \geq 0 \qquad 2.10$$

Equation 2.7 is therefore the objective function that needs to be maximized, subject to the constraints of equation 2.8 to 2.9(Mbajiorgu, 2012)

2.3.3 Scheffe's Simplex-Lattice Design

When studying the behaviour of multi-component mixtures like concrete, in which the properties of the resultant mixture will depend only on the component ratio (e.g. Water : Cement : Fine Aggregate : Coarse Aggregate); the space containing the factors is a regular simplex . Consider a two component mixture for example; the factor space of a mixture containing only components A and B is the straight line shown in Figure 2.3, with the ends representing (100% A ; 0% B) and (0% A ; 100% B). Every other possible mix of these two components is represented by

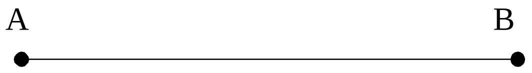


Figure 2.3: BINARY SYSTEM

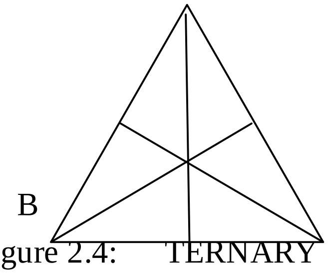


Figure 2.4: TERNARY SYSTEM

some point on that line. Figure 2.3 therefore depicts a binary system – a system with components A and B and its simplex is one dimensional simplex.

On the other hand, for a three component mixture – a ternary system – the factor space will be an equilateral triangle (a two-dimensional space), which is denoted as a regular 2-simplex. For the regular 2-simplex shown in Figure 2.4 for components A, B and C; every point in the triangle corresponds to a certain composition of the ternary system; and every possible composition is represented by one distinct point in the triangle. The composition may be expressed as molar, weight, volume fraction or even percentage. The vertices of the triangle in fig 2.4 represent simple compositions, e.g. (100% A ; 0% B ; 0% C) or (0% A ; 100% B ; 0% C) or (0% A ; 0% B ; 100% C). The sides of the triangle represent binary systems of only A and B; or B and C; or A and

C. The interior of the triangle represents three component compositions. A four component mixture – a quaternary system – yields a three dimensional factor space with the shape of a tetrahedron, as shown in Figure 2.5 – a regular 3-simplex – where each vertex of the tetrahedron represents a single components mixture; each

edge represents a binary system; a face represents a ternary system and points inside the tetrahedron correspond to the four component mixture.

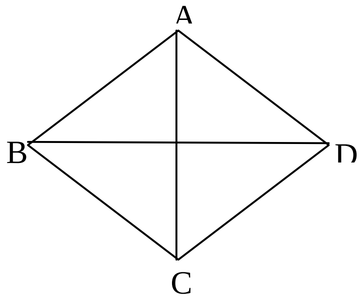


Figure 2.5: QUATERNARY SYSTEM

The two most important features of a simplex lattice can therefore be summarized as follows: For a q component mixture, the sum of the component ratios must be equal to unity; that is

$$\sum_{i=1}^{q} x_i = x_1 + x_2 + x_3 + \cdots + x_q = 1 \qquad 2.11$$

Where, $x_i \geq 0$ as no component can have a ratio less than zero. And the factor space will be a regular$(q-1)$ – simplex.

The response or objective function of any component mixture is a function of the independent variables, say; $y = f(x_1, x_2, x_3, \dots x_q)$; and analytically this function yields a response surface. The challenge of optimization is to locate the extremum or turning point on this response surface. Response surfaces can be represented and interpreted graphically for the one and two dimensional simplexes. The response surface of the regular 2-simplex being a surface over the equilateral triangular base. However, for the quaternary systems and higher, it is not possible to represent the response surface graphically. By far the more general approach to the study of multi-component mixtures is to develop a mathematical model for the response surface nomatter the number of components involved. In doing this, the response functionis assumed to be a continuous function of the independent variables, and with sufficient accuracy, it can be approximated by a polynomial. The response surfaces in multi-component systems are generally complex and high degree polynomials are usually required to adequately describe them. The complexity of the mathematical model will depend on the number of components, q, in the mixture and the degree, n, of the polynomial chosen for the model.

For a three-component system for example, if we chose to use a second-degree polynomial for the model; the response function will be of the form:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \qquad 2.12$$

The coefficient b_0 is the free term of the regression equation; the coefficients b_1, b_2andb_3 are the linear terms of the regression equation (corresponding to each of the independent variables); the coefficients b_{12}, b_{13}andb_{23} are the interaction terms of the regression equation (corresponding to the interaction between each pair of independent variables); and the coefficients b_{11}, b_{22}andb_{33} are the quadratic terms of the regression equation (corresponding to the quadratic effect of each independent variable). The constraint of the normalization condition of Equation 2.12 becomes, in this case;

$x_1 + x_2 + x_3 = 1$ 2.13

Equation 2.13can be used to eliminate the quadratic terms in Equation 2.12 by multiplying it in succession with $b_0, x_1, x_2, and x_3$ as follows;

$$\begin{aligned} b_0 &= b_0x_1 + b_0x_2 + b_0x_3 \\ x_1^2 &= x_1 - x_1x_2 - x_1x_3 \\ x_2^2 &= x_2 - x_1x_2 - x_2x_3 \\ x_3^2 &= x_3 - x_1x_3 - x_2x_3 \end{aligned} \quad 2.14$$

Substituting into Equation 2.12 yields;

$$\begin{aligned} y = (b_0 + b_1 + b_{11})x_1 + (b_0 + b_2 + b_{22})x_2 + (b_0 + b_3 + b_{33})x_3 \\ + (b_{12} - b_{11} - b_{22})x_1x_2 + (b_{13} - b_{11} - b_{33})x_1x_3 \\ + (b_{23} - b_{22} - b_{33})x_2x_3 \end{aligned} 2.15$$

Since the sum or difference of constant coefficients is another coefficient, we can redefine the coefficients of the regression equation thus;

$$y = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{23}x_2x_3 \quad 2.16$$

Equation 2.3 is the second-degree polynomial for the ternary system regression model and it has ten coefficients, and as a necessity, ten experimental trials will be required to determine the ten coefficients. Equation 2.7 however is the reduced second-degree polynomial for the same model, and as can be seen, has only six coefficients – thus, requiring only six trials to determine.

The complexity of the needed regression model and the number of experimental trials required to determine it will therefore vary with the number of components, (q), in a mixture and the degree of the polynomial, (n), chosen for the model – hence a

(q, n)Model or Simplex Lattice.The full regression equation for a $(4,2)$Simplex Lattice will be

$$\begin{aligned} y \\ = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 \\ + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{11}x_1^2 \\ + b_{22}x_2^2b_{33}x_3^2b_{44}x_4^2 \end{aligned} \quad 2.17$$

And $x_1 + x_2 + x_3 + x_4 = 1$ 2.18

This model has 15 coefficients and it will require 15 trials to determine the values of the coefficients. The reduced regression equation for the same $(4, 2)$Simplex Lattice will be;

$$y = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{14}x_1x_4 + \beta_{23}x_2x_3 + \beta_{24}x_2x_4 + \beta_{34}x_3x_4 \qquad 2.1$$

This model has 10 coefficients and it will require 10 trials to determine the values of the coefficients.

The reduced second-degree polynomial in q variables can therefore be expressed as

$$y = \sum_{1 \le i \le q} \beta_i x_i + \sum_{1 \le i < j \le q} \beta_{ij} x_i x_j \qquad 2.20$$

And it will contain C_{q+1}^2 coefficients. Following the procedure used above,it can be shown that the reduced third-degree polynomial for a ternary mixture will have the following regression model;

$$y = \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{23}x_2x_3 + \gamma_{12}x_1x_2(x_1 - x_2) + \gamma_{13}x_1x_3(x_1 - x_3) + \gamma_{23}x_2x_3(x_2 - x_3) + \beta_{123}x_1x_2x_3 \qquad 2.21$$

While the general expression for the reduced third-degree polynomial for a q-component mixture will be;

$$y = \sum_{1 \le i \le q} \beta_i x_i + \sum_{1 \le i < j \le q} \beta_{ij} x_i x_j \qquad 2.22$$

At present, the most common simplexes are the simplex-lattice proposed by Scheffe (1958; 1963). These designs provide a uniform scatter of points over the $(q - 1)$ −simplex (Novik, 1968). Simplex-lattice designs are saturated designs and the points form a (q, n) −lattice on the simplex. For each component, there exist $(n + 1)$ similar levels and all possible combinations are derived with such values of component concentrations. For a quadratic or $(q, 2)$ −lattice for example, every factor must be used at the following levels; $0; \frac{1}{2}$ *and* 1. On the other hand, for a cubic or $(q, 3)$ −lattice, every factor must be used at the levels $0; \frac{1}{3}; \frac{2}{3}$ *and* 1.Figure 2.4 show the factor levels for a $(3, 2)$ −lattice and a $(3, 3)$ −lattice, with their experimental design matrixes shown in Tables 2.7 and 2.8 respectively.

Table 2.7: THE SECOND-ORDER SIMPLEX-LATTICE DESIGN FOR A TERNARY MIXTURE –$(3, 2)$ −LATTICE

N	x_1	x_2	x_3	y
1	1	0	0	y_1

2	0	1	0	y_2
3	0	0	1	y_3
4	1/2	1/2	0	y_{12}
5	1/2	0	1/2	y_{13}
6	0	1/2	1/2	y_{23}

Table 2.8: THE THIRD-ORDER SIMPLEX-LATTICE DESIGN FOR A TERNARY MIXTURE – $(3, 3)$ −LATTICE

N	x_1	x_2	x_3	y
1	1	0	0	y_1
2	0	1	0	y_2
3	0	0	1	y_3
4	2/3	1/3	0	y_{112}
5	1/3	2/3	0	y_{122}
6	0	2/3	1/3	y_{223}
7	0	1/3	2/3	y_{233}
8	2/3	0	1/3	y_{113}
9	1/3	0	2/3	y_{133}
10	1/3	1/3	1/3	y_{123}

For a four component mixture, the factor levels for a second order, $(4, 2)$ −lattice and a third order, $(4, 3)$ −lattice, are shown in Figure 2.5. Of course this is the highest component mixture that can be shown pictorially since it will yield a three-dimensional Figure. Five component mixtures and higher cannot be shown graphically. The experimental design matrixes corresponding to the $(4, 2)$ −lattice and the $(4, 3)$ −lattice, are shown in Tables 2.9 and 2.10 respectively.

Table 2.9: THE SECOND-ORDER SIMPLEX-LATTICE DESIGN FOR A QUATERNARY MIXTURE – $(4, 2)$ −LATTICE

N	x_1	x_2	x_3	x_4	y
1	1	0	0	0	y_1
2	0	1	0	0	y_2
3	0	0	1	0	y_3
4	0	0	0	1	y_4

5	1/2	1/2	0	0	y_{12}
6	1/2	0	1/2	0	y_{13}
7	1/2	0	0	1/2	y_{14}
8	0	1/2	1/2	0	y_{23}
9	0	1/2	0	1/2	y_{24}
10	0	0	1/2	1/2	y_{34}

Table 2.10: THE THIRD-ORDER SIMPLEX-LATTICE DESIGN FOR A QUATERNARY MIXTURE – $(4,3)$ –LATTICE

N	x_1	x_2	x_3	x_4	y
1	1	0	0	0	y_1
2	0	1	0	0	y_2
3	0	0	1	0	y_3
4	0	0	0	1	y_4
5	2/3	1/3	0	0	y_{112}
6	1/3	2/3	0	0	y_{122}
7	0	2/3	1/3	0	y_{223}
8	0	1/3	2/3	0	y_{233}
9	0	0	2/3	1/3	y_{334}
10	0	0	1/3	2/3	y_{344}
11	2/3	0	1/3	0	y_{113}
12	1/3	0	2/3	0	y_{133}
13	2/3	0	0	1/3	y_{114}
14	1/3	0	0	2/3	y_{144}
15	0	2/3	0	1/3	y_{224}
16	0	1/3	0	2/3	y_{244}
17	1/3	1/3	1/3	0	y_{123}
18	1/3	1/3	0	1/3	y_{124}
19	1/3	0	1/3	1/3	y_{134}
20	0	1/3	1/3	1/3	y_{234}

Table 2.10: Contd.

The coefficients of the regression models are derived using the design saturation property of Scheffe's Simplex-Lattice designs. Considering a $(3,2)$ –lattice for example, Equation 2.16 gives

$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3$

with six model coefficients that need to be determined. Table 2.2 states the six component concentrations that should be used in the experimental design for this model. Taken at these levels, six different values, $y_i$and y_{ij}, of the response function are obtained. The design saturation property of this model enables the model coefficients $\beta_i$and β_{ij}, to be determined by substituting in succession the coordinates of all the six points at which the response function was determined.

At the first point, $N = 1$, $(x_1, x_2, x_3) = (1, 0, 0)$ therefore $y_1 = \beta_1$

At $N = 2$, $(x_1, x_2, x_3) = (0, 1, 0)$ therefore $y_2 = \beta_2$

At $N = 3$, $(x_1, x_2, x_3) = (0, 0, 1)$ therefore $y_3 = \beta_3$

At $N = 4$, $(x_1, x_2, x_3) = (1/2, 1/2, 0)$ therefore $y_{12} = \frac{\beta_1}{2} + \frac{\beta_2}{2} + \frac{\beta_{12}}{4}$

But, $y_1 = \beta_1$and $y_2 = \beta_2$; $\therefore y_{12} = \frac{y_1}{2} + \frac{y_2}{2} + \frac{\beta_{12}}{4}$;$\beta_{12} = 4y_{12} - 2y_1 - 2y_2$

Using $N = 5$and $N = 6$, we will obtain

$\beta_{13} = 4y_{13} - 2y_1 - 2y_3$; $\beta_{23} = 4y_{23} - 2y_2 - 2y_3$

We can show that for a $(q, 2)$ –lattice**,** the coefficients of the reduced second-degree polynomial model;

$$y = \sum_{1 \le i \le q} \beta_i x_i + \sum_{1 \le i < j \le q} \beta_{ij} x_i x_j \qquad 2.23$$

can be determined to give

$$\beta_i = y_i \text{and} \beta_{ij} = 4y_{ij} - 2y_i - 2y_j \qquad 2.24$$

For a third-order Simplex-Lattice; a $(\mathbf{3}, \mathbf{3})$ – model according to Equation 2.12 will have the regression equation;

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \gamma_{12} x_1 x_2 (x_1 - x_2) \\ + \gamma_{13} x_1 x_3 (x_1 - x_3) + \gamma_{23} x_2 x_3 (x_2 - x_3) + \beta_{123} x_1 x_2 x_3$$

Then ten coefficient of the model are determined by substituting the coordinates of the ten points, shown in Table 2.3, at which the response function are measured experimentally. As before, the first three experimental points will yield;

$$y_1 = \beta_1, \quad y_2 = \beta_2, \quad \text{and} \quad y_3 = \beta_3 \qquad 2.25$$

Points $N = 4$ and $N = 5$ will give

$$y_{112} = \frac{2y_1}{3} + \frac{y_2}{3} + \frac{2\beta_{12}}{9} + \frac{2\gamma_{12}}{27} \qquad 2.26$$

$$y_{122} = \frac{y_1}{3} + \frac{2y_2}{3} + \frac{2\beta_{12}}{9} - \frac{2\gamma_{12}}{27} \qquad 2.27$$

Adding Equations 2.26 and 2.27 and subtracting Equation 2.16 from 2.17, we obtain;

$$\beta_{12} = \frac{9(y_{112} + y_{122} - y_1 - y_2)}{4} \qquad 2.28$$

And

$$\gamma_{12} = \frac{9(3y_{112} - 3y_{122} - y_1 + y_2)}{4} \qquad 2.29$$

Using points $N = 6$ and $N = 7$ will yield on simplification,

$$\beta_{23} = \frac{9(y_{223} + y_{233} - y_2 - y_3)}{4} \qquad 2.30$$

And

$$\gamma_{23} = \frac{9(3y_{223} - 3y_{233} - y_2 + y_3)}{4} \qquad 2.31$$

Similarly, using points $N = 8$ and $N = 9$ will yield on simplification,

$$\beta_{13} = \frac{9(y_{113} + y_{133} - y_1 - y_3)}{4} \qquad 2.32$$

And

$$\gamma_{13} = \frac{9(y_{113} - 3y_{133} - y_1 + y_3)}{4} \qquad 2.33$$

Finally, at $N = 10$; $(x_1, x_2, x_3) = (1/3\,, 1/3\,, 1/3)$. Substituting into Equation 2.22 and taking into cognizance the coefficients already determined in Equation 2.25 to 2.33 gives;

$$y_{123} = \frac{y_1}{3} + \frac{y_2}{3} + \frac{y_3}{3} + \frac{(y_{112} + y_{122} - y_1 - y_2)}{4} + \frac{(y_{113} + y_{133} - y_1 - y_3)}{4}$$
$$+ \frac{(y_{223} + y_{233} - y_2 - y_3)}{4} + \frac{\beta_{123}}{27} \qquad 2.34A$$

$$\beta_{123} = 27y_{123} - \frac{27(y_{112} + y_{122} + y_{113} + y_{133} + y_{223} + y_{233})}{4}$$
$$+ \frac{9(y_1 + y_2 + y_3)}{2} \qquad 2.34$$

It can be shown that the procedure above can be extended to a $(q, 3) -$ lattice, so that the coefficients of the reduced third-degree polynomial regression model;

$$y = \sum_{1 \le i \le q} \beta_i x_i + \sum_{1 \le i < j \le q} \beta_{ij} x_i x_j + \sum_{1 \le i < j \le q} \gamma_{ij} x_i x_j \left(x_i - x_j\right) + \sum_{1 \le i < j < k \le q} \beta_{ijk} x_i x_j\, x_k$$

are determined to give;

$$\beta_i = y_i \quad 2.35$$

$$\beta_{ij} = \frac{9\left(y_{iij} + y_{ijj} - y_i - y_j\right)}{4} \quad 2.36$$

$$\gamma_{ij} = \frac{9\left(3y_{iij} - 3y_{ijj} - y_i + y_j\right)}{4} \quad 2.37$$

$$\beta_{ijk}$$

$$= 27y_{ijk} - + \frac{9\left(y_i + y_j + y_k\right)}{2} \quad 2.38$$

After determining the coefficients of the regression models, statistical analysis is necessary to establish the goodness of fit and the agreement of the variances of the predicted responses within a pre-determined confidence interval. In carrying out experimental tests following a simplex-lattice design, there are no extra degrees of freedom to test the model for adequacy because the designs are saturated. So, to test for adequacy, experiments are run at additional points called control points ortestpoints. The number of these control points and their coordinates are conditioned by the problem formulation and the nature of the experiment. However, the control points are sought so as to improve the model in case of inadequacy.

The accuracy with which the regression model predicts the values of the response variable differs from location to location in the simplex-lattice. Because of this, the most effective way of determining the variance of the predicted responses, s_y^2, is by assuming that the replication variance, s_y^2, is similar at all the design points in the simplex; then take replicate measurements at each of these locations, and then use the error accumulation law to obtain s_y^2.

We can illustrate the processes involved with a $(3,2)-$ system. We assume that the replicate variance, s_Y^2, is similar at all the design points and that the responses are the averages of n_i and n_{ij} replicate observations at the appropriate points in the simplex. Then the variances of the average values $\bar{y}_i$and $\bar{y}_{ij}$, of the responses at different locations on the simplex becomes;

$$s_{\bar{y}_i}^2 = \frac{s_Y^2}{n_i} \text{and} s_{\bar{y}_{ij}}^2 = \frac{s_Y^2}{n_{ij}} \quad 2.39$$

The reduced regression equation for the $(3,2)-$ Simplex Latticeis given in Equation 2.16 as;

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3$$

The coefficients of this equation are given in Equation 2.14 to be;

$\beta_i = y_i$and $\beta_{ij} = 4y_{ij} - 2y_i - 2y_j$

If we generate the coefficients in terms of the average values of the responses, $\bar{y}_i$and $\bar{y}_{ij}$, we get;

$$\beta_i = \bar{y}_i \text{ and } \beta_{ij} = 4\bar{y}_{ij} - 2\bar{y}_i - 2\bar{y}_j \qquad 2.40$$

The response function now becomes;

$$y = \bar{y}_1 x_1 + \bar{y}_2 x_2 + \bar{y}_3 x_3 + (4\bar{y}_{12} - 2\bar{y}_1 - 2\bar{y}_2)x_1x_2 + (4\bar{y}_{13} - 2\bar{y}_1 - 2\bar{y}_3)x_1x_3 + (4\bar{y}_{23} - 2\bar{y}_2 - 2\bar{y}_3)x_2x_3$$

$$y = \bar{y}_1(x_1 - 2x_1x_2 - 2x_1x_3) + \bar{y}_2(x_2 - 2x_1x_2 - 2x_2x_3) + \bar{y}_3(x_3 - 2x_1x_3 - 2x_2x_3) + 4\bar{y}_{12}x_1x_2 + 4\bar{y}_{13}x_1x_3 + 4\bar{y}_{23}x_2x_3 \qquad 2.41$$

Using the relationship $x_1 + x_2 + x_3 = 1$, we can simplify the coefficients of the $\bar{y}_1$ terms as follows;

$$x_1 - 2x_1x_2 - 2x_1x_3 = x_1 - 2x_1(x_2 + x_3) = x_1 - 2x_1(1 - x_1)$$
$$= x_1(-1) \qquad 2.42$$

$$x_2 - 2x_1x_2 - 2x_2x_3 = x_2 - 2x_2(x_1 + x_3) = x_2 - 2x_2(1 - x_2)$$
$$= x_2(2x_2 - 1) \qquad 2.43$$

$$x_3 - 2x_1x_3 - 2x_2x_3 = x_3 - 2x_3(x_1 + x_2) = x_3 - 2x_3(1 - x_3)$$
$$= x_3(2x_3 - 1) \qquad 2.44$$

Therefore,

$$y = x_1(2x_1 - 1)\bar{y}_1 + x_2(2x_2 - 1)\bar{y}_2 + x_3(2x_3 - 1)\bar{y}_3 + 4x_1x_2\bar{y}_{12} + 4x_1x_3\bar{y}_{13} + 4x_2x_3\bar{y}_{23} \qquad 2.45$$

We can therefore state the coefficients of the regression model for the $(q, 2)$ –lattice, in terms of the average values of the responses, $\bar{y}_i$and$\bar{y}_{ij}$, as;

$$a_i = x_i(2x_i - 1); \;\; a_{ij} = 4x_ix_j \qquad 2.46$$

Using the error accumulation law and Equation 2.29, the variance of the regression model, s_y^2, is obtained as;

$$s_y^2 = s_Y^2\left(\sum_{1\le i\le q}\frac{a_i^2}{n_i} + \sum_{1\le i<j\le q}\frac{a_{ij}^2}{n_{ij}}\right) \qquad 2.47$$

Following the same procedures, we can show that the variance of the regression model for a third degree polynomial will be;

$$s_y^2 = s_Y^2\left(\sum_{1\le i\le q}\frac{b_i^2}{n_i} + \sum_{1\le i<j\le q}\frac{b_{iij}^2}{n_{iij}} + \sum_{1\le i<j\le q}\frac{b_{ijj}^2}{n_{ijj}} + \sum_{1\le i<j<k\le q}\frac{b_{ijk}^2}{n_{ijk}}\right) \qquad 2.48$$

where

$$b_i = \frac{x_i(3x_i-1)(3x_i-2)}{2} \qquad 2.49$$

$$b_{iij} = \frac{9x_ix_j(3x_i-1)}{2} \qquad 2.50$$

$$b_{ijj} = \frac{9x_ix_j\left(3x_j-1\right)}{2} \qquad 2.51$$

$$b_{iij} = 27x_ix_jx_k \qquad 2.52$$

If the number of replicate observations at all points of the design is equal, that is if $n_i = n_i = n$, then the expressions for s_y^2 can be rewritten as

$$s_y^2 = s_Y^2\frac{\lambda}{n} \qquad 2.53$$

where for the second degree polynomial

$$\lambda = \left(\sum_{1\le i\le q} a_i^2 + \sum_{1\le i<j\le q} a_{ij}^2\right) \qquad 2.54$$

and for the third degree polynomial

$$\lambda = \left(\sum_{1\le i\le q} b_i^2 + \sum_{1\le i<j\le q} b_{iij}^2 + \sum_{1\le i<j\le q} b_{ijj}^2 + \sum_{1\le i<j<k\le q} b_{ijk}^2\right) \qquad 2.55$$

As can be seen from Equations 2.36, 2.39 to 2.42, the expression λ is only dependent on the mixture compositions, which vary only with the degree of the polynomial used. Once the composition at any point in the simplex is known, the λ value can be calculated. For ternary systems that can be shown fully on two dimensions, lines of constant λ can be plotted beforehand on the equilateral triangle that represent the simplex, for polynomials of various degress.

Given the replication variance, s_Y^2, and the number of replicate observations, n, the error of the predicted values of the response is easily calculated at any point of the composition-property diagram using the appropriateλ. Adequacyis then tested at each control point, using the following statistic

$$t = \frac{\left|\bar{y}_{exp} - y_{theory}\right|}{\sqrt{s_{\bar{y}}^2 + s_y^2}} = \frac{\left|\bar{y}_{exp} - y_{theory}\right|\sqrt{n}}{s_Y^2\sqrt{1 + \lambda}} \qquad 2.56$$

The $\boldsymbol{t}$statistic has the Student distribution and it is compared with the tabulated value of $ta/l(v)$ at the significance level α, where l is the number of control points and v is the number of degree of freedom for the replication variance.

The null hypothesis that the regression equation is adequate is accepted if $t_{exp} < t_{table}$ for all the control points. Adequacy can also be tested at several points using the chi-square (x^2) test.

Actual Components and Pseudo Components

The fundamental idea of a simplex is that mixtures containing various component proportions are studied by a regression model for the prediction of optimal qualities and performances. For a q-component mixture, the vertices of the $(q-1)-$simplex represent the pure blends, that is, the theoretical mixture of only a single component. For a four component mixture, for example, these vertices will represent component mixtures of $(1{:}0 : 0 : 0)$, $(0 : 1 : 0 : 0)$, $(0 : 0 : 1 : 0)$and$(0 : 0 : 0 : 1)$. In component mixtures like concrete, pure blends like the ones represented above hardly make any sense – as we cannot have a concrete mix made of only coarse aggregate or only fine aggregate or even only cement. On the other hand, normal concrete mixes (W/C Ratio : Cement : Fine Aggregate : Coarse Aggregate) having values like $(0.5{:}\ 1{:}\ 2{:}\ 4)$, $(0.55{:}\ 1{:}\ 3{:}\ 6)$ and $(0.45{:}\ 1{:}\ 1.7{:}\ 3.6)$ do not readily meet the condition of $x_1 + x_2 + x_3 + x_4 = 1$.

This challenge is handled by taking the mix components x_i as Pseudo Components which are related and can be mapped into z_i the Actual Components. If X represents the column matrix of x_i and Z represents the column matrix of z_i, the transformation from pseudo components to actual components and vice versa can be presented as

$$Z = AX \qquad 2.57$$

and $X = A^{-1}Z$ 2.60

where A is a square matrix with size equal to the number of components in the mix. The matrix$A$is the coefficient of the relationship between $Z$and X.

Using a $(4, 2)$ – lattice as an example of generating the transformation matrix A, Equation 2.14 yields the second degree regression model as;

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{23} x_2 x_3$$

$$+\beta_{24}x_2x_4 + \beta_{34}x_3x_4 \qquad 2.61$$

Table 2.9 shows the ten design points that are required for this design, and the concentration of the pseudo components at these points. Assuming that actual mixture components at the vertices of our simplex are determined to be $(0.5{:}\,1{:}\,2{:}\,4)$, $(0.55{:}\,1{:}\,2.2{:}\,4.2)$, $(0.64{:}\,1{:}\,3{:}\,6)$and $(0.45{:}\,1{:}\,1.7{:}\,3.6)$. Then the relationship between the pseudo and actual components becomes;

$$\begin{pmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{pmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} \qquad 2.62$$

At point $N = 1$; $(x_1,\ x_2,\ x_3,\ x_4) = (1, 0, 0, 0)$and $(z_1, z_2, z_3, z_4) = (0.5{:}\,1{:}\,2{:}\,4)$, therefore

$$\begin{pmatrix} 0.5 \\ 1 \\ 2 \\ 4 \end{pmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

$a_{11} = 0.5;\ a_{21} = 1;\ a_{31} = 2\ and\ a_{41} = 4$

At $N = 2$; $(x_1, x_2, x_3, x_4) = (0, 1, 0, 0)$and $(z_1, z_2, z_3, z_4) = (0.55{:}\,1{:}\,2.2{:}\,4.2)$, therefore

$a_{12} = 0.55;\ a_{22} = 1;\ a_{32} = 2.2\ and\ a_{42} = 4.2$

Similarly$N = 3$ and $N = 4$ will give

$a_{13} = 0.64;\ a_{23} = 1;\ a_{33} = 3\ and\ a_{43} = 6$

$a_{14} = 0.45;\ a_{24} = 1;\ a_{34} = 1.7\ and\ a_{44} = 3.6$

We have thus obtained the transformation matrix to be,

$$\boldsymbol{A} = \begin{bmatrix} 0.5 & 0.55 & 0.64 & 0.45 \\ 1 & 1 & 1 & 1 \\ 2 & 2.2 & 3 & 1.7 \\ 4 & 4.2 & 6 & 3.6 \end{bmatrix} \qquad 2.63$$

This matrix can now be used to determine the actual components at points $N = 5$ to $N = 10$ where there are pseudo compositions but no actual values.

So, at $N = 5$, $(x_1, x_2, x_3, x_4) = (0.5, 0.5, 0, 0)$ and

$$\begin{pmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{pmatrix} = \begin{bmatrix} 0.5 & 0.55 & 0.64 & 0.45 \\ 1 & 1 & 1 & 1 \\ 2 & 2.2 & 3 & 1.7 \\ 4 & 4.2 & 6 & 3.6 \end{bmatrix} \begin{pmatrix} 0.5 \\ 0.5 \\ 0 \\ 0 \end{pmatrix} \therefore\ z_1 = 0.525;\ z_2 = 1;\ z_3 = 2.1\ and\ z_4 = 4.1$$

The remaining five points will give,

At $N = 6$; $(x_1, x_2, x_3, x_4) = (0.5, 0, 0.5, 0)$ and $z_1 = 0.57;\ z_2 = 1;\ z_3 = 2.5;\ z_4 = 5$

At $N = 7$; $(x_1, x_2, x_3, x_4) = (0.5, 0, 0, 0.5)$ and $z_1 = 0.475$; $z_2 = 1$; $z_3 = 1.85$; $z_4 = 3.8$

At $N = 8$; $(x_1, x_2, x_3, x_4) = (0, 0.5, 0.5, 0)$ and $z_1 = 0.595$; $z_2 = 1$; $z_3 = 2.6$; $z_4 = 5.1$

At $N = 9$; $(x_1, x_2, x_3, x_4) = (0, 0.5, 0, 0.5)$ and $z_1 = 0.5$; $z_2 = 1$; $z_3 = 1.95$; $z_4 = 3.9$

At $N = 10$; $(x_1, x_2, x_3, x_4) = (0, 0, 0.5, 0.5)$and $z_1 = 0.545$; $z_2 = 1$; $z_3 = 2.35$; $z_4 = 4.8$

Table 2.9can therefore be extended to include the actual components as in Table 2.11;

Table 2.11: PSEUDO AND ACTUAL COMPONENTS FOR A $(4, 2)$ – LATTICE DESIGN

N	PSEUDO COMPONENTS					ACTUAL COMPONENT			
	x_1	x_2	x_3	x_4	Resp. y	z_1	z_2	z_3	z_4
1	1	0	0	0	y_1	0.5	1	2	4
2	0	1	0	0	y_2	0.55	1	2.2	4.2
3	0	0	1	0	y_3	0.64	1	3	6
4	0	0	0	1	y_4	0.45	1	1.7	3.6
5	0.5	0.5	0	0	y_{12}	0.525	1	2.1	4.1
6	0.5	0	0.5	0	y_{13}	0.57	1	2.5	5
7	0.5	0	0	0.5	y_{14}	0.475	1	1.85	3.8
8	0	0.5	0.5	0	y_{23}	0.595	1	2.6	5.1
9	0	0.5	0	0.5	y_{24}	0.5	1	1.95	3.9
10	0	0	0.5	0.5	y_{34}	0.545	1	2.35	4.8

CHAPTER THREE
MATERIALS AND METHODS

3.1 Materials

The main materials in this research work are Ordinary Portland Cement (OPC), quarry dust, river sand, granite chippings and water. The materials and their sources are discussed below;

3.1.1 Water

The water used for the production of concrete samples is potable water obtained from the materials laboratory of Rivers State University of Science and Technology. The source of the portable water is a water borehole that provides the University Community drinking water.

3.1.2 Cement

The cement used is Ibeto branded Ordinary Portland Cement (OPC-43 grade) obtained from the open market.

3.1.3 River Sand

The River Sand was obtained from Otaku in Abia state about 12km from Imo River, the boundary between Rivers and Abia State.

3.1.4 Quarry Dust

The quarry dust for this research was obtained from Ishiagu, Ebonyi State.

3.1.5 Crushed Stone (Granite Chippings)

The crushed stone (granite chippings) used for the production of the concrete samples for this research was also obtained from Ishiagu, Ebonyi State.

3.2 Methods

The tests carried out during this project were done in accordance to specification of the appropriate BS codes, (BS 812 – 103.1 1985: method for determination of particle size distribution e.t.c).

3.2.1 Determination of Particle Size Distribution for Coarse and Fine Aggregate

This operation is used to divide a sample of aggregate into various fraction; each consisting of particles of the same size.

3.2.1.1 Apparatus

i. Set of test; 9.5mm, 4.75mm, 2.36mm, 1.18mm, $600\mu m$, $150\mu m$ (for fine aggregate), 33mm, 18mm, 9.5mm, 4.75mm (for coarse aggregate).
ii. Weighing balance
iii. Wire brush
iv. Oven

3.2.1.2 Procedure

Sufficient representative sample was collect from the stockpile and was reduced by quartering to obtain the quantity for test. The sample was washed with water several times until the water becomes clear; it was dried in the oven for 24hours. On the following day the sample was removed from the oven and allowed to cool; sieving commenced as soon as sample had cooled using 500g; the sieves were arranged in descending order starting with sieve 9.5mm down for the fine aggregate and sieve 22mm down for coarse aggregate. The sample was introduced into the arranged sieves with a receiver at the bottom and covered. It was shaken very well using hand, the sample retained in each sieves were then collected and weighed.

3.2.2 Determination of Specific Gravity of Aggregate (Fine and Coarse)

Specific gravity of aggregate is used in design calculations of concrete mixes. It is defined as the ratio of the density of a material to the density of distilled water. For this project the specific gravity of aggregate were determined on saturated and surface dry (SSD) basis.

3.2.2.1 Apparatus

i. Weighing balance
ii. Pychnometer bottle
iii. Sieves ($75\mu m$ for fine aggregate and 4.75mm for coarse aggregate)
iv. Absorbent cloth
v. Distilled water

3.2.2.2 Procedure

Sufficient representative sample was collected from the stockpile and quartered. The samples which were sieved using sieve $75\mu m$ and 4.75mm for the respective aggregates were collected and washed thoroughly until the water was clear. After washing, the samples were soaked in distilled water for 24hours, the following day the water was decanted and the samples were spread on a metal plate to surface dry.

Once the sample was dry, it was divided into four portions for the test. The weight of the pychnometer bottle with decanted and the bottle were dried with hand towel, then one portion of the sample was introduced into the empty bottle and weighed. The bottle with the sample was filled with water and weighed. The specific gravity is calculated from the results and the sequence is repeated for the second portion.

3.2.3 Mix Design

From the values obtained from particle size and specific gravity tests, several concrete mixes were designed using specific characteristic concrete strength of $25N/mm^2$, standard deviation of 4 N/mm^2 and slump ranges 10-40mm with the aid of scale 149 software.

3.2.4 Mix Ratio/Proportioning

After the trial mixes were cast and their slumps recorded, adjustments were made with respect to water and cement content per cylindrical mould. From these adjustments, 3 mix proportions were generated. It was decided that for this project, 45 cylinder specimens will be made per proportions.

3.2.5 Procedure for Production of Concrete Samples

3.2.5.1 Batching

The different components of the concrete, cement, water, fine aggregate(sand and quarry dust) and coarse aggregate(crushed stone) were measured out using weighing scale.

3.2.5.2 Mixing of Concrete

Cement was first mixed with the fine aggregate using masons trowel in a mixing pan. The mixing was to ensure thorough and consistent mixing. Coarse aggregate (granite stones) were added and the mixing continued. Lastly, water was added and mixed properly ensuring that the mix is consistent and uniform. This was done by observation ensuring that all the components are uniformly distributed throughout the mass.

3.2.5.3 Placement and Compaction of concrete

Some portion of the concrete were placed inside three different steel moulds measuring 150x150x150mm each. The placing was done using mason’s trowel ensuring as closer packing during placement as possible. Due to the small size of the cubes, aggregation of

the concrete is obviously not a problem. To ensure good compaction, the concrete was agitated using tamping rod and given 25 blow for each layer. Three layers were adopted. The surface is then finished, leveled and troweled. After the initial set (about 1hr) a slight identification mark was made on the concrete top surface. The process was repeated for each of the trial

mixes including the control mixes. A total ofsixtysix cubes were produced from 22 mixes. Each mix gave three cubes. The mix ratios are as shown in table 3.2.

3.2.5.4 Curing of Concrete

Twenty fourhours after the production of the cubes, they were placed in a drum filled with potable water obtained from the borehole water source of the laboratory. The cubes were totally immersed in water for twenty eight (28) days. After twenty eight (28) days, each of the cubes was removed and crushed at SSD condition to determine the strength.

3.2.6 Slump Test

A portion of the mixed concrete was placed in a slump frustum. The frustum was tapped gently on the sides all around the cone. This is to ensure the proper compaction of the concrete inside the cone. After the compaction, the cone was gently lifted up, the fresh concrete bulged sideways with a resultant reduction in the height of the concrete frustum. The new height was measured; the difference between the height of the frustum and the concrete frustum after removal was determined.

3.2.7 Compressive Strength Test

After curing for twenty eight days, the concrete cubes were removed from the water, cleaned and crushed at SSD conditionusing compression machine. The cube was placed in the concrete testing machine in between the crushing plates. The concrete testing machine was switched on and force was exerted on the cubes by the crushing plates. The force at which the cube fails was divided by the cross section area of the cube to obtain the compressive strength.

$$Compressive\ Strength = \frac{Failure\ load}{Gross\ section\ area} \qquad 3.1$$

This was done for each of the three samples for each mix. The mean value for each mix was recorded.

3.2.8 Water Absorption Test

The cured sample was brought out of the curing tank and its surface dry weight (w/w) was measured and recorded. The sample was then put into oven and left in the oven for twenty-four hours to become bone dry. The bone dryweight (wd) was measured and recorded.

The water absorption= $\frac{Ww-Wd}{Wd}$X 100 % 3.2

3.3 Formulation of Mathematical Model

3.3.1 Scheffe`s Factor Space

The components in the factors space are pseudo components and not actual (real) components. Furthermore, it should be noted that the total quantity (mass or volume) of the pseudo components at any point on the factor space is equal to one. This implies that no individual pseudo component in the mixture should be greater than one.

$Xi \leq 1$ (3.3)

Where Xi is the i^{th} pseudo component in the Scheffe`s factor space interacting with other pseudo components to form a mixture.Scheffe assumed that negative pseudo components never exist. Hence,

$Xi \geq 0$ (3.4)

Combining equations 3.3 and 3.4, one can see that

$0 \leq Xi \leq 1$ (3.5)

Since the total amount of the pseudo components of a mixture in a factor space is one then,

$X1 + X2 + X3 + \ldots + X_{q-1}+X_q = 1$ (3.6)

That is

$$\sum_{1-1}^{q} X_1 = 1$$

3.3.2 Relationship between Pseudo and Actual Components

In the Scheffe`s mixture design, the pseudo components have relationship with the actual components. This means that the actual components can be derived from the pseudo components in that relationship and vice versa. The pseudo components aredenoted as X and the actual components are denoted as Z. Hence, according to

Scheffe,

$Z = A * X$ (3.8)

Where A is the coefficient of the relationship

Rearranging equation 3.8 will give

$X = 1 / A * Z$ (3.9)

Assume $B = 1 / A$, then equation 3.9 becomes

$X = B * Z$ (3.10)

Equation 3.8will be used to determine the actual components of the mixture when the pseudo components are known. Also equations 3.9 and 3.10 will be used to determine the pseudo components of the mixture when the actual components are known.

3.3.3 Five Component Factor Space

This research work is dealing with a five component concrete mixture. The components that form the concrete mixture are water/cement (w/c) ratio, cement, river sand,quarry dust and granite. The number of component, q is equal to five. The space to be used in the analysis will be q-1, which is equal to four-dimensional factor space. A four-dimensional factor space is an imaginary dimensional space. The imaginary space used here is shown in Figure3.1.

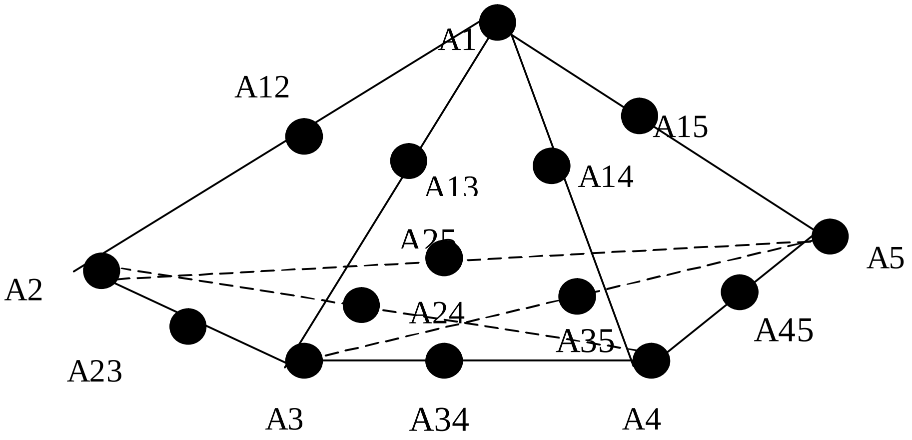


Figure 3.1: A FOUR-DIMENSIONAL FACTOR SPACE. Source: Ibearugbulem O. (2006)

Figure 3.1 shows fifteen points on the four-dimensional factor space. The various quantities of the pseudo components of the mixture at these fifteen points are not shown for clarity of the Figure. Let the arbitrary quantities of the five-pseudo components of the mixture at an arbitrary point on the factor space be designated as Ajk (Xijk). Where Ajk is an arbitrary point on the factor space and Xijk is the arbitrary quantities of all the pseudo components, Xi at an arbitrary point, Ajk.

Xijkcan otherwise be written as

Xijk = X1jk, X2jk, X3jk, X4jk, X5jk.

The quantities of the five-pseudo components at the fifteen points are follows:

A1 (1,0,0,0,0)

A2 (0,1,0,0,0)
A3 (0,0,1,0,0)
A4 (0,0,01,0)
A5 (0,0,0,0,1)
A12 (,½,½ ,0,00)
A13 (½,0,½,0,0,)
A14 (½,0,0,½,0)
A15 (½,O,0,0,½)
A23 (0,½,½,0,0)
A24 (0,½,0,½,O)
A25 (0,½,0,0,½)
A34 (0,0,½,½,0)
A35 (0,0,½,0,½)
A45 (0,0,0,½,½)

3.3.4 Responses

Responses, according to Simon et al (1997), are the properties of fresh and hardened concrete. These properties can be compressive strength, tensile strength, elastic modulus, shear modulus, modulus of rupture, slump, density etc. Thisresponse is a polynomial function of pseudo component of the mixture. The equation for response according to Simon et al (1997) is

$$Y = b_o + \sum bi\ Xi + \sum bij\ Xi\ Xj + \sum bijk\ Xi\ XjXk + - - - + \sum bi1,i2,\ldots,in\ Xi,\ Xi2,\ \ldots,\ Xin + e \qquad (3.11)$$

Where $1 \leq i \leq q$, $1 \leq i \leq j \leq q$, $1 \leq i \leq j \leq k \leq q$ and $1 \leq i1 \leq i2 \leq \ldots \leq in \leq q$ respectively, and b_0 = arbitrary constant, e = random error and Y = the response.

Response equation for a two-pseudo component mixture is

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{22}X_2^2 + e \qquad (3.12)$$

That for a three-pseudo component mixture is

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{22}X_2^2 + b_{23}X_2X_3 + b_{33}X_3^2 + e \qquad (3.13)$$

For a four-pseudo component mixture the equation is

$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{22}X_2^2 +$
$b_{23}X_2X_3 + b_{24}X_2X_4 + b_{33}X_3^2 + b_{34}X_3X_4 + b_{44}X_4^2 + e$ (3.14)

Now for a five-pseudo component mixture, which is what the research is dealing with the response equation is

$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_{11}X_1^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5$
$+ b_{22}X_2^2 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 + b_{33}X_3^2 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{44}X_4^2 + b_{45}X_4X_5 +$
$b_{55}X_5^2 + e$ (3.15)

The “e” term is the random error that represents the combined effects of variables not included in the model.

Equation 3.7 states that

$$\sum_{1=1}^{q} X_1 = 1$$

Hence,

$$\sum_{i=1}^{5} X_1 = 1$$

That is, $X_1 + X_2 + X_3 + X_4 + X_5 = 1$ (3.16)

Multiplying equation 3.16by b_o will give

$b_oX_1 + b_oX_2 + b_o+X_3 + b_oX_4 + b_oX_5 = b_o$ (3.17)

Multiplying equation 3.16 also by X_1 will give

$X_1^2 + X_1 X_2 + X_1 X_3 + X_1 X_4 + X_1 X_5 = X_1$ (3.18)

In similar manner multiplying equation 3.16 by

X_2, X_3, X_4 and X_5 will respectively give

$X_1X_2 + X_2^2 + X_2X_3 + X_2X_4 + X_2X_5 = X_2$ (3.19)

$X_1X_3 + X_2X_3 + X_3^2 + X_3X_4 + X_3X_5 = X_3$ (3.20)

$X_1X_4 + X_2X_4 + X_3X_4 + X_4^2 + X_4X_5 = X_4$ (3.21)

$X_1X_5 + X_2X_5 + X_3X_5 + X_4X_5 + X_5^2 = X_5$ (3.22)

Rearranging equations 3.18 -- 3.22 in terms of Xi^2 will give respectively

$X_1^2 = X_1 - X_1X_2 - X_1X_3 - X_1X_4 - X_1 X_5$ (3.23)

$X_2^2 = X_2 - X_1X_2 - X_2X_3 - X_2X_4 - X_2X_5$ (3.24)

$X_3^2 = X_3 - X_1X_3 - X_2X_3 – X_3X_4 – X_3X_5$ (3.25)

$X_4^2 = X_4 - X_1X_4 - X_2X_4 – X_3X_4 – X_4X_5$ (3.26)

$X_5^2 = X_5 - X_1X_5 - X_2X_5 – X_3X_5 – X_4X_5$ (3.27)

Substituting equation 3.17 and equations 3.23-3.27 into equation 3.15 will give

$$\begin{aligned}
&Y = b_0X_1 + b_0X_2 + b_0X_3 + b_0X_4 + b_0X_5 + b_1X_1 + b_1X_2 + b_1X_3 + b_1X_4 + b_1X_5 + b_{11}X_1 - b_{11}X_1X_2 \\
&-b_{11}X_1X_3 - b_{11}X_1X_4 - b_{11}X_1X_5 + b_{22}X_2 - b_{22}X_1X_2 - b_{22}X_2X_3 - b_{22}X_2X_4 - b_{22}X_2X_5 + b_{33}X_3 - \\
&b_{33}X_1X_3 - b_{33}X_2X_3 - b_{33}X_3X_4 - b_{33}X_3X_5 + b_{44}X_4 - b_{44}X_1X_4 - b_{44}X_2X_4 - b_{44}X_3X_4 - b_{44}X_4X_5 + \\
&b_{55}X_5 - b_{55}X_1X_5 - b_{55}X_2X_5 - b_{55}X_3X_5 - b_{55}X_4X_5 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5 + \\
&b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{45}X_4X_5 + e \qquad (3.28)
\end{aligned}$$

Rearranging equation 3.28 and bringing like terms together will give

$$\begin{aligned}
&Y = (b_0 + b_1 + b_{11})\,X_1 + (b_0 + b_1 + b_{22})\,X_2 + (b_0 + b_1 + b_{33})\,X_3 + \\
&(b_0 + b_1 + b_{44})\,X_4 + (b_0 + b_1 + b_{55})\,X_5 + (b_{12} - b_{11} - b_{22})\,X_1X_2 + \\
&(b_{13} - b_{11} - b_{33})\,X_1X_3 + (b_{14} - b_{11} - b_{44})\,X_1X_4 + (b_{15} - b_{11} - b_{55})\,X_1X_5 \\
&+ (b_{23} - b_{22} - b_{33})\,X_2X_3 + (b_{24} - b_{22} - b_{44})\,X_2X_4 + (b_{25} - b_{22} - b_{55})\,X_2X_5 \\
&+ (b_{34} - b_{35} - b_{44})\,X_3X_4 + (b_{35} - b_{33} - b_{55})\,X_3X_5 + (b_{45} - b_{44} - b_{55})\,X_4X_5 + e \qquad (3.29)
\end{aligned}$$

It is worthy of note here is that when constants are added together, another constant will result. Hence, the summation terms in parenthesis in equation 3.27 will be replaced with $\propto$ as:

$$\left.\begin{aligned}
\propto_1 &= b_0 + b_1 + b_{11} \\
\propto_2 &= b_0 + b_2 + b_{22} \\
\propto_3 &= b_0 + b_3 + b_{33} \\
\propto_4 &= b_0 + b_4 + b_{44} \\
\propto_5 &= b_0 + b_5 + b_{55} \\
\propto_{12} &= b_{12} - b_{11} - b_{22} \\
\propto_{13} &= b_{13} - b_{11} - b_{33} \\
\propto_{14} &= b_{14} - b_{11} - b_{44} \\
\propto_{15} &= b_{15} - b_{11} - b_{55} \\
\propto_{23} &= b_{23} - b_{22} - b_{33} \\
\propto_{24} &= b_{24} - b_{22} - b_{44} \\
\propto_{25} &= b_{25} - b_{22} - b_{55} \\
\propto_{34} &= b_{34} - b_{33} - b_{44} \\
\propto_{35} &= b_{35} - b_{33} - b_{55} \\
\propto_{45} &= b_{45} - b_{44} - b_{55}
\end{aligned}\right\} \qquad (3.30)$$

Substituting equation 3.39 into equation 3.29 will give

$Y = \propto_1 X_1 + \propto_2 X_2 + \propto_3 X_3 + \propto_4 X_4 + \propto_5 X_5 + \propto_{12} X_1 X_2 + \propto_{13} X_1 X_3 + \propto_{14} X_1 X_4 + \propto_{15} X_1 X_5$

$+ \propto_{23} X_2 X_3 + \propto_{24} X_2 X_4 + \propto_{25} X_2 X_5 + \propto_{34} X_3 X_4 + \propto_{35} X_3 X_5 + \propto_{45} X_4 X_5 + e$ (3.31)

Equation 3.31 can be rewritten as $Y = \ddot{Y} + e$ (3.32)

Where e = standard error or standard deviation and

$\ddot{Y} = \propto_1 X_1 + \propto_2 X_2 + \propto_3 X_3 + \propto_4 X_4 + \propto_5 X_5 + \propto_{12} X_1 X_2 + \propto_{13} X_1 X_3 +$

$\propto_{14} X_1 X_4 + \propto_{15} X_1 X_5 + \propto_{23} X_2 X_3 + \propto_{24} X_2 X_4 + \propto_{25} X_2 X_5 + \propto_{34} X_3 X_4 +$

$\propto_{35} X_3 X_5 + \propto_{45} X_4 X_5$

(3.33)Equation 3.33 can be rewritten in the form

$$\ddot{Y} = \sum_{i-1}^{5} \propto_i X_i = \sum_{1 \leq i < j \leq 5} \propto_{ij} X_i X_j \tag{3.34}$$

Equation 3.34 can be seen as response to the pure components "i" and the binary mixture components "ij".

At each vertex of the factor space, the component $X_i = 1$ while other components are all equal to zero. At the mid point of all the border lines of the factor space, the two components X_i and X_j are equal to ½ each, while the rest of the components are equal to zero. Assuming that the response function is represented by n, the response function for the pure component and that for the binary mixture components will be n_i and n_{ij} respectively. Using this to rewrite equation 3.34 will give

$$n_{ij} = \sum_{i-1}^{5} \propto_i X_i \ddot{Y} = \sum_{i-1}^{5} \propto_i X_i = \sum_{1 \leq i < j \leq 5} \propto_{ij} X_i X_j \text{(3.35)}$$

The response at a point on the factor space is n_1.At point 1, component $X_1 = 1$ while components X_2, X_3, X_4 and X_5 are all equal to zero. Substituting this into equation 3.35 will give

$n_1 = \propto_1$ (3.36)

Similarly,

$n_2 = \propto_2$ (3.37)

$n_3 = \propto_3$ (3.38)

$n_4 = \propto_4$ (3.39)

$n_5 = \propto_5$ (3.40)

Equation 3.36 – 3.40can be summarized as

$n_i = \propto_i$ (3.41)

At mid point of the borderline connecting points 1 and 2 of the factor space, component $X_1 = ½$ and that of $X_2 = ½$ and the rest (X_3, X_4 and X_5) are equal to zero. The response at this point is n_{12}. Substituting for the values of the components x_1, x_2, x_3, x_4 and x_5 into equation 3.35 will give

$$n_{12} = 1/2 \propto_1 + 1/2 \propto_2 + \propto_{12} * 1/2 * 1/2 = 1/2 \propto_1 + 1/2 \propto_2 + 1/4 \propto_{12} \qquad (3.42)$$

Similarly,

$$n_{13} = 1/2 \propto_1 + 1/2 \propto_3 + 1/4 \propto_{13} \qquad (3.43)$$
$$n_{14} = 1/2 \propto_1 + 1/2 \propto_3 + 1/4 \propto_{14} \qquad (3.44)$$
$$n_{45} = 1/2 \propto_4 + 1/2 \propto_5 + 1/4 \propto_{45} \qquad (3.45)$$

Summarising equations 3.42 – 3.45 will give

$$n_{ij} = 1/2 \propto_i + 1/2 \propto_j + 1/4 \propto_{ij} \qquad (3.46)$$

Rearranging equations 3.41 and 3.46 will give

$$\propto_i = n_i \qquad (3.47)$$
$$\propto_{ij} = 4n_{ij} - 2\propto_i - 2\propto_j \qquad (3.48)$$

Substituting equation 3.47into equation 4.48 gives

$$\propto_{ij} = 4n_{ij} - 2n_i - 2n_j \qquad (3.49)$$

Substituting equations 3.47 and 3.49 into equation 3.31 will give

$$Y = n_1 x_1 + n_2 X_2 + n_3 X_3 + n_4 X_4 + n_5 X_5 + (4n_{12} - 2n_1 - 2n_2) X_1X_2 + (4n_{13} - 2n_1 - 2n_3) X_1X_3 + (4n_{14} - 2n_1 - 2n_4) X_1X_4 + (4n_{15} - 2n_1 - 2n_5) X_1X_5 + (4n_{23} - 2n_2 - 2n_3) X_2X_3 + (4n_{24} - 2n_2 - 2n_4) X_2 X_4 + (4n_{25} - 2n_2 - 2n_5) X_2X_5 + (4n_{34} - 2n_3 - 2n_4) X_3X_4 + (4n_{35} - 2n_3 - 2n_5) X_3X_5 + (4n_{45} - 2n_4 - 2n_5) X_4X_5 + e \qquad (3.50)$$

Or

$$Y = n_1 X_1 - 2n_1 X_1X_2 - 2n_1 X_1X_3 - 2n_1 X_1X_4 - 2n_1 X_1X_5 + n_2X_2 - 2n_2 X_1X_2 - 2n_2 X_2 X_3 - 2n_2 X_2X_4 - 2n_2 X_2X_5 + n_3X_3 - 2n_3 X_1X_3 - 2n_3 X_2X_3 - 2n_3 X_3X_4 - 2n_3 X_3X_5 + n_4X_4 - 2n_4 X_1X_4 - 2n_4 X_2 X_4 - 2n_4 X_3 X_4 - 2n_4X_4X_5 + n_5X_5 - 2n_5 X_1X_5 - 2n_5 X_2 X_5 - 2n_5 X_3 X_5 - 2n_5X_4X_5 + 4n_{12} X_1X_2 + 4n_{13} X_1X_3 + 4n_{14} X_1 X_4 + 4n_{15} X_1 X_5 + 4n_{23} X_2X_3 + 4n_{24} X_2 X_4 + 4n_{25} X_2 X_5 + 4n_{34} X_3 X_4 + 4n_{35} X_3 X_5 + 4n_{45} X_4X_5 + e \qquad (3.50a)$$

or

$$Y = n_1X_1 (1 - 2X_2 - 2X_3 - 2X_4 - 2X_5) + n_2 X_2 (1 - 2X_1 - 2X_3 - 2X_4 - 2x_5) + n_3X_3 (1 - 2X_1 - 2X_2 - 2X_4 - 2X_5) + n_4X_4 (1 - 2X_1 - 2X_2 - 2X_3 - 2X_5) + n_5X_5 (1 - 2X_1 - 2x_2 - 2x_3 - 2X_4) + 4n_{12}X_1X_2 + 4n_{13}X_1X_3 + 4n_{14} X_1X_4 + 4n_{15}X_1X_5 + 4n_{23} X_2X_3 + 4n_{24} X_2X_4 + 4n_{25}X_2X_5 + 4n_{34}X_3X_4 + 4n_{35}X_3X_5 + 4n_{45} X_4 X_5 + e \qquad (3.50b)$$

Recall equation 3.16

$X_1 + X_2 + X_3 + X_4 + X_5 = 1$

Multiplying the equation by 2 will give

$$2X_1 + 2X_2 + 2X_3 + 2X_4 + 2X_5 = 2 \qquad (3.50c)$$

Subtracting 1 from both the *RHS* and *LHS*of equation 3.50c gives:

$(2X_1 + 2X_2 + 2X_3 + 2X_4 + 2X_5) - 1 = 1$

This equation can be written as

$$2X_1 - 1 = 1 - 2X_2 - 2X_3 - 2X_4 - 2X_5 \qquad (3.50d)$$

Similarly,

$$\left.\begin{aligned} 2X_2 - 1 &= 1 - 2X_1 - 2X_3 - 2X_4 - 2X_5 \\ 2X_3 - 1 &= 1 - 2X_1 - 2X_2 - 2X_4 - 2X_5 \\ 2X_4 - 1 &= 1 - 2X_1 - 2X_2 - 2X_3 - 2X_5 \\ 2X_5 - 1 &= 1 - 2X_1 - 2X_2 - 2X_3 - 2X_4 \end{aligned}\right\} \quad (3.50e)$$

Substituting equations 3.50d and 3.50e into equation 3.50b will give

$$Y = X_1 (2X_1 - 1) n_1 + X_2 (2X_2 - 1) n_2 + X_3 (2X_3 - 1) n_3 + X_4 (2X_4 - 1) n_4 + X_2 (2X_5 - 1) n_5 + 4n_{12} X_1X_2 + 4n_{13} X_1X_3 + 4n_{14} X_1 X_4 + 4n_{15} X_1 X_5 + 4n_{23} X_2 X_3 + 4n_{24}X_2 X_4 + 4n_{25} X_2 X_5 + 4n_{34} X_3 X_4 + 4n_{35} X_3 X_5 + 4n_{45} X_4 X_5 + e \qquad (3.50f)$$

Equation 3.50f is the mixture design model for the optimization of a concrete mixture that comprises five components. The terms n_i and n_{ij} are responses at the points i and ij. These responses are constants and are determined by carrying out laboratory practical. A total of fifteen such practical tests will be carried out to correspond to the fifteen coefficients of equation 3.50f.

3.3.5 Optimum Point

Optimum mixture is that mixture proportion that has the highest or most desired property. In a factor space different points exist. Each point in a factor space yields mixture proportion of a particular property. The point in the factor space that produces the mixture proportion that yields the most desired property is the optimum point. Different optimum points exist in the imaginary space. Many factors and considerations bring about a particular optimum point. For a particular optimum point desired to meet the considerations in mind, it is pertinent to use a defined factor space to enclose (trap) it. Failure to trap the desired optimum point means that the optimum point will fall outside the defined factor space. The consequence of this is that the model will not produce the optimum point. To define a factor space that will enclose the desire optimum point, previous experiments and past experience will come into play. Where there is no past experience or previous experimental data, trial mixes can be made, which can serve as fair guide of where the optimum point will be. The actual mixture proportions required at this point are the five mixture proportions that are located at the five vertices of the factor space. These five proportions will define the required factor space that will entrap or enclose the desired optimum point.

Listed below are the actual mixture proportion at the five vertices:

A1(1:0.6:2.7:0:3.5)
A2(1:0.6:2.1:0.6:3.5)
A3(1:0.55:2.0:0.4:3.2)
A4(1:0.50:1.5:0.7:2.9)
A5(1:0.50:2.0:0.2:29)

The proportions correspond to water/cement, cement, sand, periwinkle shell and granite.

3.3.6 Actual Components and Pseudo Components

It was mentioned in clause 3.3.2 that the actual components of a mixture are related with the pseudo components of the same mixture. The two are related with coefficient of relation, A. The relationship is defined according to equation 3.8 as Z = A X.

Now the actual components at the five vertices are known and that of

The pseudo components are also known. With these the coefficients of relation, A will be determined. Making “A” the subject of the equation from equation 3.8 gives

$$A = X^{-1} Z \qquad (3.51)$$

Equation 3.8 is a vector equation and will be better put in matrix form as

$$\begin{pmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ \ \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \end{pmatrix} \qquad (3.52)$$

Let N stand for any point on the factor space. This means that $1 \leq N \leq 15$.

When N = 1

$Z_1 = 1$, $Z_2 = 0.6$, $Z_3 = 0.7$, $Z_4 = 0$ and $Z_5 = 3.5$.

$X_1 = 1$, $X_2 = X_3 = X_4 = X_5 = 0$

Substituting, these values into equation 3.50 will give

$$\begin{pmatrix} 1 \\ 0.6 \\ 0.7 \\ 0 \\ 3.5 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad (3.53)$$

The mix proportions for different levels of sand replacement used for casting are as show

Table 3.1

Table 3.1: MIX PROPORTION FOR DIFFERENT LEVELS OF SAND REPLACEMENT

Test (g)	Cement (g)	Water (g)	Sand (g)	Quarry Rock Dust (g)	Coarse Aggregate (20mm) (g)	% Fine Aggregate (%)	% Quarry Dust (%)
Original Mix	230	150	635	0	1415	100	0
Mix 1	230	150	444.5	190.5	1415	70	30
Mix 2	230	150	412.75	222.25	1415	65	35
Mix 3	230	150	381.0	254.0	1415	60	40

Based on eqn. 3.52, the pseudo and actual components are shown in Table 3.2

Table 3.2: MIX DESIGN MATRIX FOR SCHEFFE'S $(5,2)$ LATTICE : - PSEUDO AND ACTUAL COMPONENTS

N	PSEUDO COMPONENTS						ACTUAL COMPONENT				
	x_1	x_2	x_3	x_4	x_5	Resp. y	z_1	z_2	z_3	z_4	z_5
1	1	0	0	0	0	y_1	1	0.6	2.7	0	3.5
2	0	1	0	0	0	y_2	1	0.6	2.1	0.6	3.5
3	0	0	1	0	0	y_3	1	0.55	2.0	0.4	3.2
4	0	0	0	1	0	y_4	1	0.5	1.5	0.7	2.9
5	0	0	0	0	1	y_5	1	0.5	2.0	0.2	2.9
6	0.5	0.5	0	0	0	y_{12}	1	0.6	2.4	0.3	3.5
7	0.5	0	0.5	0	0	y_{13}	1	0.575	2.35	0.2	3.35
8	0.5	0	0	0.5	0	y_{14}	1	0.55	2.1	0.35	3.2

9	0.5	0	0	0	0.5	y_{15}	1	0.55	2.35	0.1	3.2
10	0	0.5	0.5	0	0	y_{23}	1	0.575	2.05	0.5	3.35
11	0	0.5	0	0.5	0	y_{24}	1	0.55	1.8	0.65	3.2
12	0	0.5	0	0	0.5	y_{25}	1	0.55	2.05	0.4	3.2
13	0	0	0.5	0.5	0	y_{34}	1	0.525	1.75	0.55	3.05
14	0	0	0.5	0	0.5	y_{35}	1	0.525	2.0	0.3	3.05
15	0	0	0	0.5	0.5	y_{45}	1	0.5	1.75	0.45	2.9
CONTROL											
1	0.25	0.25	0.25	0.25	0	C_1	1	0.5625	2.075	0.425	3.275
2	0.25	0.25	0.25	0	0.25	C_2	1	0.5625	2.2	0.3	3.275
3	0.25	0.25	0	0.25	0.25	C_3	1	0.55	2.075	0.375	3.2
4	0.25	0	0.25	0.25	0.25	C_4	1	0.5375	2.05	0.325	3.125
5	0	0.25	0.25	0.25	0.25	C_5	1	0.5375	1.9	0.475	3.125
6	0.2	0.2	0.2	0.2	0.2	C_6	1	0.55	2.06	0.38	3.2
7	0.3	0.2	0.3	0.2	0	C_7	1	0.565	2.13	0.38	3.29
8	0	0.3	0.2	0.2	0.2	C_8	1	0.54	1.88	0.51	3.14

Z_1 = Cement

Z_2 = Water

Z_3 = Sand

Z_4 = Quarry dust

Z_5 = Coarse Aggregate

X_1, X_2, X_3, X_4, X_5 = Corresponding Pseudo Components.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Physical property test

The physical tests on the material used are presented thus:

4.1.1 Grain size distribution

i.) Sand

From the Figure 4.1 it was observed that 4% of aggregate (river sand)is larger than 4.75mm; 12.7% of aggregate content is larger than 2mm; 29% content is larger than 1.18mm; 72% content is larger than 0.6mm; 92.3% content is larger than 0.3mm. Also the fineness modules is 2.96 which shows the sand is granularand on the coarser end. The fineness modulus of fine aggregates ranges from 2.3 to 3.3. The sand falls under zone 1. The result of the sieve analysis is also presented in Table 4.1 in Appendix A.

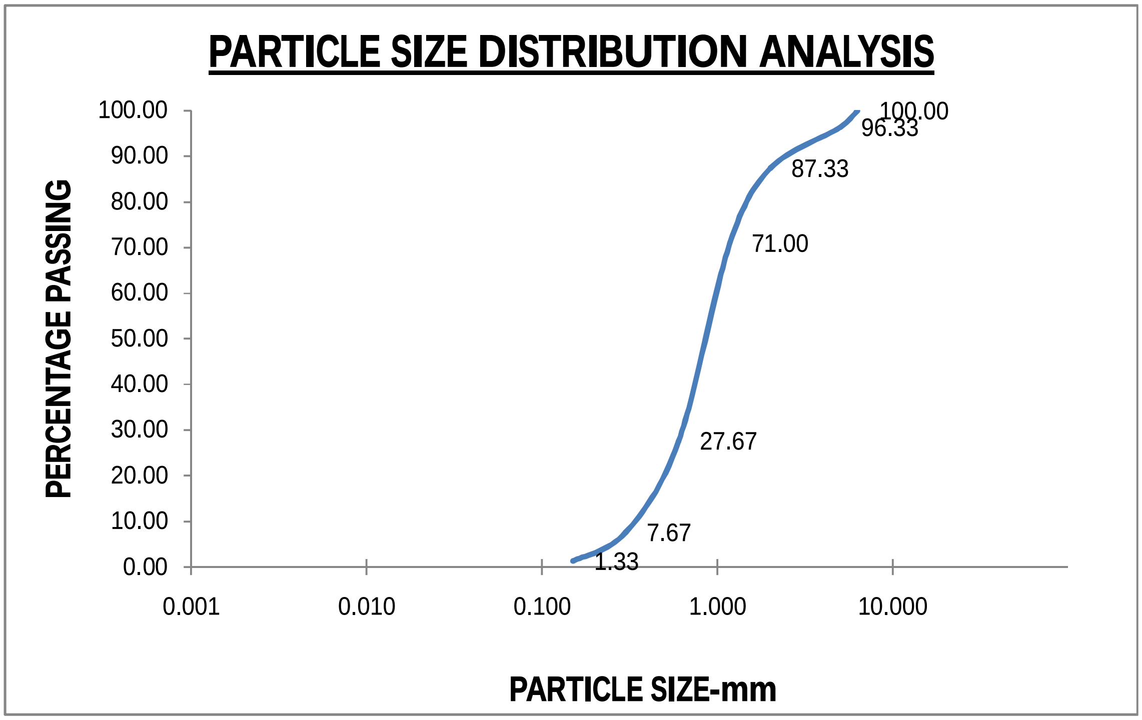


Figure 4.1:SIEVE ANALYSIS GRAPH (RIVER SAND)

ii.) Quarry dust

From Figure 4.2, Close observation showed that 2% content of the fine aggregate is larger than 5mm, 13% content is larger than 2.36mm, 33% content is larger than1.18mm, 52% larger than 0.6mm, 82% content is larger than 0.3mm; 98% is larger than 0.15mm. The fineness modulus is 2.7 indicating a fine aggregate on the finer side. The sieve analysis results is also presented in Table 4.2, Appendix A.

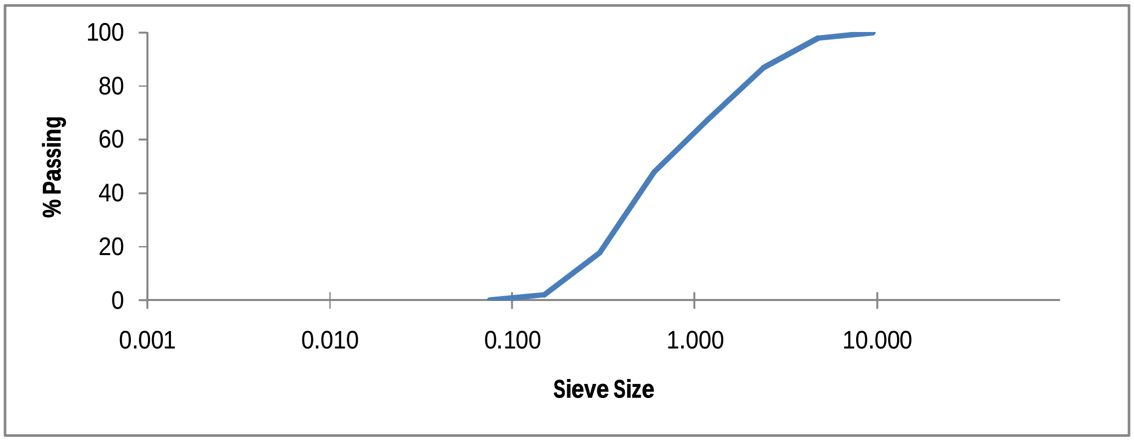


Figure 4.2: SIEVE ANALYSIS GRAPH (QUARRY DUST)
THE QUARRY DUST FALLS UNDER ZONE II.

iii.) Coarse Aggregate

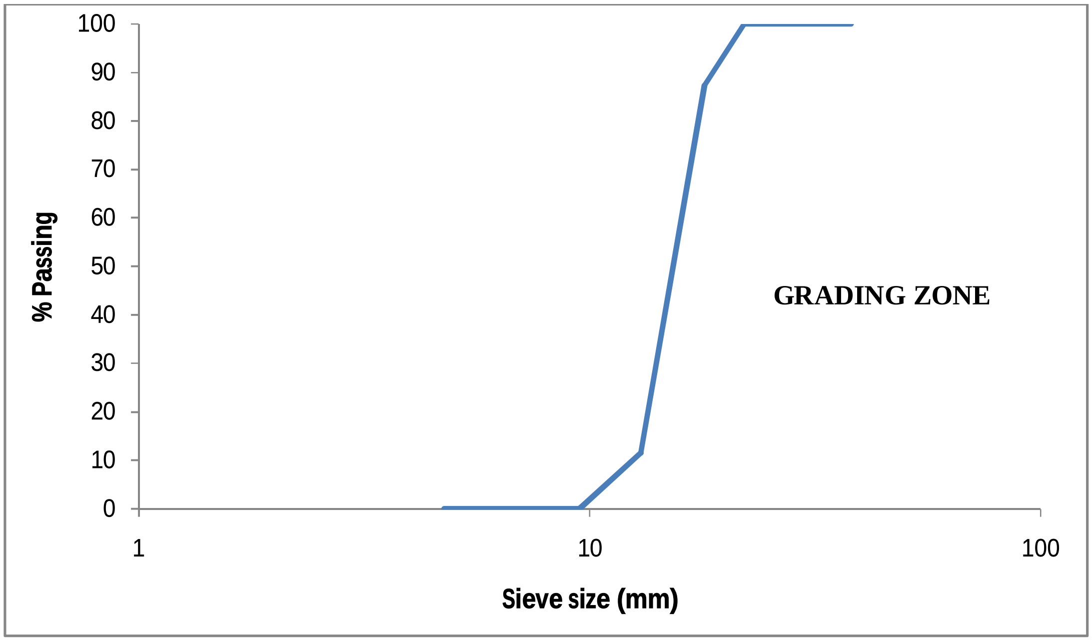


Figure 4.3:SIEVE ANALYSIS GRAPH (COARSE AGGREGATE)

From Figure 4.3 it was observed that the coarse aggregate hada 13% content larger than 18mm, 76% content of aggregate size larger than 13mm, and 12% content larger than 9.5mm. The fineness modulus is 4.01 which indicates coarse aggregate. Fineness modulus of fine aggregates ranges from 2.3 to 3.0. Any fineness modulus greater than 3.0 indicates coarse aggregate. The result is also presented in Table 4.2, Appendix A.

4.1.2: Water Absorption

From the test result it was observed that the water absorption of concrete decreased with increase in quarry dust content upto about 22% replacement after which the absorption increased.

Table 4.7: WATER ABSORPTION TEST RESULT

S/no	**Test Parameters**	**SAMPLES**										
		1	2	3	4	5	6	7	8	9	10	11
1	Natural water Absorption(%)	4.5	3.3	1.6	3.9	3.00	0.48	4.49	2.4	7.77	8.88	10.00
2	% Replacement of sand with quarry dust	0	22.2%	16.7	31.8	9.1	11.1	7.8	14.3	4.1	19.6	26.5

S/no	**Test Parameters**	**SAMPLES**										
		12	13	14	15	16	17	18	19	20	21	22
1	Natural water Absorption(%)	4.54	5.88	6.25	4.04	7.14	8.89	7.5	8.89	2.43	1.12	2.41
2	Absorption(%)	16.3	23.9	13	20.4	17	12	15.3	13.6	20	15.6	15.1

Table 4.7 shows that as the percentage replacement of river sand by quarry dust increases, the water absorption decreases upto 22% replacement.

This can be explained by the fact that well graded aggregate packs closely with the small particles filling the voids in between big particles. As the replacement increases, the finer quarry dust particles fill up more voids in between larger sand and crushed stone particles. The increase continues up to a maximum of 22%. Beyond 22% replacement the voids in between larger particles of sand and crushed stone are all filled up and the aggregates now tend to be uniformly graded and therefore the concrete does not get denser. The main reason why we use sand and graded aggregates is to achieve well graded aggregates and hence denser concrete. The partial replacement of sand with quarry dust improves the grading of the aggregates and hence the density which results in lower water absorption of the concrete up to 22% replacement.

4.1.3 Compressive Test Result

Table 4.8: CRUSHING STRENGTH OF CONCRETE AT 28 DAYS

Sample	*Repli –*	*Load*	*Area*	*Stress*	*Average*	%

ID	$cates$	(kg)	mm^2	(N/mm^2)	$Strength$	$Replacement$
1	1A	650.25	22500	28.90	30.80	0
	1B	704.25	22500	31.30		
	1C	724.50	22500	32.20		
2	2A	715.50	22500	31.80	32.40	22.2
	2B	747.00	22500	33.20		
	2C	724.50	22500	32.20		
3	3A	792.00	22500	35.20	34.53	16.7
	3B	812.25	22500	36.10		
	3C	726.75	22500	32.30		
4	4A	974.25	22500	43.30	42.00	31.8
	4B	933.75	22500	41.50		
	4C	927.00	22500	41.20		
5	5A	1019.25	22500	45.30	44.70	9.1
	5B	960.75	22500	42.70		
	5C	1037.25	22500	46.10		
6	6A	706.50	22500	31.40	30.30	11.1
	6B	702.00	22500	31.20		
	6C	636.75	22500	28.30		
7	7A	724.50	22500	32.20	30.80	7.8
	7B	706.50	22500	31.40		
	7C	648.00	22500	28.80		
8	8A	765.00	22500	34.00	32.50	14.3
	8B	758.25	22500	33.70		
	8C	670.50	22500	29.80		
9	9A	675.00	22500	30.00	31.70	4.1
	9B	722.25	22500	32.10		
	9C	742.50	22500	33.00		
10	10A	807.75	22500	35.90	34.20	19.6
	10B	789.75	22500	35.10		
	10C	711.00	22500	31.60		
11	11A	814.50	22500	36.20	35.80	26.5
	11B	825.75	22500	36.70		
	11C	776.25	22500	34.50		
12	12A	789.75	22500	35.10	33.67	16.3
	12B	769.50	22500	34.20		
	12C	713.25	22500	31.70		
13	13A	823.50	22500	36.60	35.50	23.9
	13B	812.25	22500	36.10		
	13C	760.50	22500	33.80		
14	14A	776.25	22500	34.50	33.30	13
	14B	783.00	22500	34.80		
	14C	688.50	22500	30.6		
15	15A	1053.0	22500	46.80	45.80	20.4
	15B	1071.0	22500	47.60		
	15C	967.50	22500	43.00		
CONTROLS						
16	16A	785.25	22500	34.90	34.70	17
	16B	807.75	22500	35.90		
	16C	749.25	22500	33.30		

17	17A	805.50	22500	35.80	34.20	12
	17B	740.25	22500	32.90		
	17C	762.75	22500	33.90		
18	18A	774.00	22500	34.40	34.33	15.3
	18B	787.50	22500	35.00		
	18C	756.00	22500	33.60		
19	19A	805.50	22500	35.80	35.83	13.6
	19B	780.75	22500	34.70		
	19C	832.50	22500	37.00		
20	20A	783.00	22500	34.80	33.73	20
	20B	686.25	22500	30.50		
	20C	807.75	22500	35.90		
21	21A	796.50	22500	35.40	33.30	15.6
	21B	717.75	22500	31.90		
	21C	733.50	22500	32.60		
22	22A	837.00	22500	37.20	35.30	15.1
	22B	789.75	22500	35.10		
	22C	756.00	22500	33.60		

The table shows that the compressive strength of concrete increases with increase in quarry dust replacement upto 31.8% even though it peaks at 9.8% replacement.

As discussed in section 4.1.2, the replacement of sand with finer quarry dust particles improves the grading of the aggregates in the concrete. This improvement in grading results in reduction of voids in the concrete and enhances the density of the concrete. This inturn results in increase in the strength of the concrete up to 31.8% replacement.

Determination of Model Equation for Compressive Strength

From Equation 3.50f,

$$Y = X_1 (2X_1 - 1) n_1 + X_2 (2X_2 - 1) n_2 + X_3 (2X_3 - 1) n_3 + X_4 (2X_4 - 1) n_4 + X_2 (2X_5 - 1) n_5 + 4n_{12} X_1X_2 + 4n_{13} X_1X_3 + 4n_{14} X_1 X_4 + 4n_{15} X_1 X_5 + 4n_{23} X_2 X_3 + 4n_{24}X_2 X_4 + 4n_{25} X_2 X_5 + 4n_{34} X_3 X_4 + 4n_{35} X_3 X_5 + 4n_{45} X_4 X_5 + e \qquad 4.1$$

From table 4.1, the responses $y_i$are given as:

$y_1 = 30.80 N/mm^2$

$y_2 = 32.40 N/mm^2$

$y_3 = 34.53 N/mm^2$

$y_4 = 42.00 N/mm^2$

$y_5 = 44.70 N/mm^2$

$y_{12} = 30.30 N/mm^2$

$y_{13} = 30.80 N/mm^2$

$y_{14} = 32.50 N/mm^2$

y_{15} = 31.70N/mm^2

y_{23} = 34.20N/mm^2

y_{24} = 35.80N/mm^2

y_{25} = 33.67N/mm^2

y_{34} = 35.50N/mm^2

y_{35} = 33.30N/mm^2

y_{45} = 45.80N/mm^2

y_{C_1} = 34.70N/mm^2

y_{C_2} = 34.20N/mm^2

y_{C_3} = 34.33N/mm^2

y_{C_4} = 35.85N/mm^2

y_{C_5} = 33.73N/mm^2

y_{C_6} = 33.30N/mm^2

y_{C_7} = 35.30N/mm^2

Coefficients of the regression model were derived using Eqn 3.49

$n_i = y_i$ and $n_{ij} = 4y_{ij} - 2y_i - 2y_j$, therefore,

$n_1 = 30.80$ $n_2 = 32.40$, $n_3 = 34.53$, $n_4 = 42.00$, $n_5 = 44.70$

$n_{12} = 4y_{12} - 2y_1 - 2y_2 = (4 \times 30.30) - (2 \times 30.80) - (2 \times 32.40) = -5.20$

$n_{13} = -7.46$

$n_{14} = -15.6$

$n_{15} = -24.2$

$n_{23} = 2.94$

$n_{24} = -5.6$

$n_{25} = -19.52$

$n_{34} = -11.06$

$n_{35} = -25.26$

$n_{45} = 9.8$

Substituting the constants n_i and n_{ij} into $Equation$ 4.1, we $have$

$$Y = 30.8X_1 + 32.4X_2 + 34.53X_3 + 42.0X_4 + 44.7X_5 - 5.2X_1X_2 - 7.46X_1X_3 - 15.6X_1X_4 - 24.2X_1X_5 + 2.94X_2X_3 - 5.6X_2X_4 - 19.52X_2X_5 - 11.06X_3X_4 - 25.26X_3X_5 + 9.8X_4X_5 \quad 4.2$$

Table 4.9: COMPRESSIVE TEST RESULT AND REPLICATION VARIANCE

$Sample\ ID$	$Replicate$	$Response\ Y_i\ (N/mm^2)$	$Response\ Symbol$	$\sum Y_i$	$\bar{Y}$	$\sum Y_i^2$	$\left(\sum Y_i\right)^2$	S_i^2
1	1A	28.90	Y_1	92.4	30.80	2851.74	8537.76	2.91
	1B	31.30						
	1C	32.20						
2	2A	31.80	Y_2	97.2	32.40	3150.32	9447.84	0.52
	2B	33.20						
	2C	32.20						
3	3A	35.20	Y_3	103.6	34.53	3585.54	10732.96	3.943
	3B	36.10						
	3C	32.30						
4	4A	43.30	Y_4	126	42.00	5294.58	15876	1.29
	4B	41.50						
	4C	41.20						
5	5A	45.30	Y_5	134.1	44.70	6000.59	17982.81	3.16
	5B	42.70						
	5C	46.10						
6	6A	31.40	Y_{12}	90.9	30.30	2760.29	8262.81	3.01
	6B	31.20						
	6C	28.30						
7	7A	32.20	Y_{13}	92.4	30.80	2852.24	8537.76	3.16
	7B	31.40						
	7C	28.80						
8	8A	34.00	Y_{14}	97.5	32.50	3179.73	9506.25	5.49
	8B	33.70						
	8C	29.80						
9	9A	30.00	Y_{15}	95.1	31.70	3019.41	9044.01	2.37
	9B	32.10						
	9C	33.00						
10	10A	35.90	Y_{23}	102.6	34.20	3519.38	10526.76	5.23
	10B	35.10						
	10C	31.60						
11	11A	36.20	Y_{24}	107.4	35.80	3847.58	11534.76	1.33
	11B	36.70						
	11C	34.50						
12	12A	35.10	Y_{25}	101	33.67	3406.54	10201.00	3.103
	12B	34.20						
	12C	31.70						
13	13A	36.60	Y_{34}	106.5	35.50	3785.21	11342.25	2.23
	13B	36.10						
	13C	33.80						
14	14A	34.50	Y_{35}	99.9	33.30	3337.65	9980.01	5.49

	14B	34.80						
	14C	30.6						
15	15A	46.80	Y_{45}	137.4	45.80	6305	18878.76	6.04
	15B	47.60						
	15C	43.00						
CONTROL								
16	16A	34.90	Y_{C1}	104.1	34.70	3615.71	10836.81	1.72
	16B	35.90						
	16C	33.30						
17	17A	35.80	Y_{C2}	102.6	34.20	3513.26	10526.76	2.17
	17B	32.90						
	17C	33.90						
18	18A	34.40	Y_{C3}	103	34.33	3537.32	10609.00	0.493
	18B	35.00						
	18C	33.60						
19	19A	35.80	Y_{C4}	107.5	35.83	3854.73	11556.25	1.323
	19B	34.70						
	19C	37.00						
20	20A	34.80	Y_{C5}	101.2	33.73	3430.1	10241.44	8.143
	20B	30.50						
	20C	35.90						
21	21A	35.40	Y_{C6}	99.9	33.30	3333.53	9980.01	3.43
	21B	31.90						
	21C	32.60						
22	22A	37.20	Y_{C7}	105.9	35.30	3744.81	11214.81	3.27
	22B	35.10						
	22C	33.60						
$\sum$								69.827

Variance for each experimental point is given by the relationship

$$S_i^2 = \left[\frac{1}{n-1}\right]\left[\sum Y_i^2 - \left(\frac{1}{n}\left(\sum Y_i\right)^2\right)\right] \qquad 4.2a$$

For experimental point 1,

$$S_1^2 = \left[\frac{1}{3-1}\right]\left[2851.74 - \left(\frac{1}{3} \times 8537.76\right)\right] = 2.91$$

$$S_2^2 = \left[\frac{1}{3-1}\right]\left[3150.32 - \left(\frac{1}{3} \times 9447.84\right)\right] = 0.52$$

$$S_3^2 = \left[\frac{1}{3-1}\right]\left[3585.54 - \left(\frac{1}{3} \times 10732.96\right)\right] = 3.943$$

Hence, the replication variance S_y^2 is given as;

$$S_y^2 = \frac{\sum S_i^2}{n-1} = \frac{69.827}{21} = 3.325$$

The standard deviation of the replicates is given as;

$$S_y = \sqrt{\frac{\sum S_i^2}{n-1}} = \sqrt{3.325} = 1.823$$

The standard deviation S_y = 1:823. This means that the rate at which the compressive test results vary from their mean is low and hence the data appears reliable. This would be confirmed with F Test later.

Table 4.10: COMPARISON OF THE RESULT OF THE COMPRESSIVE STRENGTH MODEL AND THE EXPERIMENTAL RESULT.

$SampleID$	Y_{Exp}	Y_{Model}	% Difference
1	30.80	30.80	0
2	32.40	32.40	0
3	34.53	34.53	0
4	42.00	42.00	0
5	44.70	44.70	0
6	30.30	30.30	0
7	30.80	30.80	0
8	32.50	32.50	0
9	31.70	31.70	0
10	34.20	34.20	0
11	35.80	35.80	0
12	33.67	33.67	0
13	35.50	35.50	0
14	33.30	33.30	0
15	45.80	45.80	0
16	34.70	34.76	0.17
17	34.20	30.69	10.26
18	34.33	35.54	3.52
19	35.85	35.23	1.73
20	33.73	37.20	10.29
21	33.30	34.41	3.33
22	35.30	35.79	1.39

Table 4.10 shows that the results from the mathematical model compares very well with the laboratory test results.

Table 4.11: STUDENT’S T-TEST FOR THE CONTROL POINT OF THE COMPRESSIVE STRENGTH

ID	i	j	a_i	a_{ij}	${a_i}^2$	${a_{ij}}^2$	ε	$Y_{Exp.}$	Y_{Model}	Δy	t
16	1	2	-0.125	0.25	0.0156	0.0625	0.531	34.70	34.76	0.06	0.025
	1	3	-0.125	0.25	0.0156	0.0625					
	1	4	-0.125	0.25	0.0156	0.0625					
	1	5	-0.125	0	0.0156	0					
	2	3	-0.125	0.25	0.0156	0.0625					
	2	4	-0.125	0.25	0.0156	0.0625					
	2	5	-0.125	0	0.0156	0					
	3	4	-0.125	0.25	0.0156	0.0625					
	3	5	-0.125	0	0.0156	0					
	4	5	-0.125	0	0.0156	0					
					0.1562	0.375					

Table 4.11: Cond.

Table 4.11: Contd.

17	1	2	-0.125	0.25	0.015	0.0625	0.5156	34.20	30.69	3.51	1.485
	1	3	-0.125	0.25	0.0156	0.0625					
	1	4	-0.125	0	0.0156	0					
	1	5	-0.125	0.25	0.0156	0.0625					
	2	3	-0.125	0.25	0.0156	0.0625					
	2	4	-0.125	0	0.0156	0					
	2	5	-0.125	0.25	0.0156	0.0625					
	3	4	-0.125	0	0.0156	0					
	3	5	0	0.25	0.0156	0.0625					
	4	5	-0.125	0	0	0					
					0.1406	0.375					
18	1	2	-0.125	0.25	0.0156	0.0625	0.5	34.33	35.54	1.21	0.515
	1	3	-0.125	0	0.0156	0					
	1	4	-0.125	0.25	0.0156	0.0625					
	1	5	-0.125	0.25	0.0156	0.0625					
	2	3	-0.125	0	0.0156	0					
	2	4	-0.125	0.25	0.0156	0.0625					
	2	5	-0.125	0.25	0.0156	0.0625					
	3	4	0	0	0.0156	0					
	3	5	0	0	0.0156	0					
	4	5	-0.125	0.25	0.0156	0.0625					
					0.125	0.375					
19	1	2	0	0	0	0	0.46875	35.85	35.23	0.62	0.266
	1	3	0	0	0	0					
	1	4	0	0	0	0					
	1	5	0	0	0	0					
	2	3	-0.125	0.25	0.0156	0.0625					
	2	4	-0.125	0.25	0.0156	0.0625					
	2	5	-0.125	0.25	0.0156	0.0625					
	3	4	-0.125	0.25	0.0156	0.0625					
	3	5	-0.125	0.25	0.0156	0.0625					
	4	5	-0.125	0.25	0.0156	0.0625					
					0.0937	0.375					
20	1	2	-0.12	0.16	0.0144	0.0256	0.400	33.73	37.20	3.47	1.528
	1	3	-0.12	0.16	0.0144	0.0256					
	1	4	-0.12	0.16	0.0144	0.0256					
	1	5	-0.12	0.16	0.0144	0.0256					
	2	3	-0.12	0.16	0.0144	0.0256					
	2	4	-0.12	0.16	0.0144	0.0256					
	2	5	-0.12	0.16	0.0144	0.0256					
	3	4	-0.12	0.16	0.0144	0.0256					
	3	5	-0.12	0.16	0.0144	0.0256					
	4	5	-0.12	0.16	0.0144	0.0256					
					0.144	0.256					
21	1	2	-0.12	0.24	0.0144	0.0576	0.530	33.30	34.41	1.11	0.467
	1	3	-0.12	0.36	0.0144	0.1296					
	1	4	-0.12	0.24	0.0144	0.0576					

	1	5	-0.12	0	0.0144	0					
	2	3	-0.12	0.24	0.0144	0.0576					
	2	4	-0.12	0.16	0.0144	0.0256					
	2	5	-0.12	0	0.0144	0					
	3	4	-0.12	0.24	0.0144	0.0576					
	3	5	-0.12	0	0.0144	0					
	4	5	-0.12	0	0.0144	0					
					0.144	0.3856					
22	1	2	0	0	0	0	0.472	35.30	35.79	0.49	0.210
	1	3	0	0	0	0					
	1	4	0	0	0	0					
	1	5	0	0	0	0					
	2	3	-0.12	0.24	0.0144	0.0576					
	2	4	-0.12	0.36	0.0144	0.1296					
	2	5	-0.12	0.24	0.0144	0.0576					
	3	4	-0.12	0.24	0.0144	0.0576					
	3	5	-0.12	0.16	0.0144	0.0256					
	4	5	-0.12	0.24	0.0144	0.0576					

To test the adequacy of the model on each control point;

$$t = \frac{\Delta y\sqrt{n}}{{S_y}^2\sqrt{1+\varepsilon}} \qquad 4.2a$$

$$Where\ \Delta y = y_{Exp.} - y_{Model}$$

$$n = the\ number\ of\ parallel\ observations\ at\ every\ at\ every\ point$$

$$\varepsilon = \sum_{1\le i\le q} {a_i}^2 + \sum_{1\le i<j\le q} {a_{ij}}^2 \qquad 4.2b$$

$$a_i = x_i(2x_i - 1), \qquad a_{ij} = 4x_ix_j$$

For experimental point 11,

$$t = \frac{\Delta y\sqrt{n}}{{S_y}^2\sqrt{1+\varepsilon}} = \frac{0.06\sqrt{3}}{3.325\sqrt{1+0.531}} = 0.025 \qquad 4.2c$$

The values of t is low and shows that the difference in the compressive test results are insignificant and therefore the results are consistent and reliable.

Similarly, t can be calculated for other experimental points.

T- Value from Table

For a significant level of, $\alpha = 0.05$ for two tails,

$$V_e = n - 1 = 7 - 1 = 6$$

$$t_\alpha(V_e) = t_{0.05}(6) = 2.45, as\ seen\ in\ Appendix\ A, Table\ 4.24$$

This value of t is greater than any of the t values obtained from calculation as shown in the table 4.11. Therefore, the null hypothesis is acceptable and the model equation is reliable for making prediction at 95% confidence level.

Table 4.12: FISHER TEST

$Response\ ID$	$y_{Exp.}$	y_{Model}	$y_{Exp.} - \bar{y}_{Exp}$	$y_{mod.} - \bar{y}_{mod.}$	$(y_{Exp.} - \bar{y}_{Exp})^2$	$(y_{mod.} - \bar{y}_{mod.})^2$
16	34.7	34.76	0.212857	-0.04286	0.045308	0.001837
17	34.2	30.69	-0.28714	-4.11286	0.082451	16.91559
18	34.33	35.54	-0.15714	0.737143	0.024694	0.54338
19	35.85	35.23	1.362857	0.427143	1.85738	0.182451
20	33.73	37.2	-0.75714	2.397143	0.573265	5.746294
21	33.3	34.41	-1.18714	-0.39286	1.409308	0.154337
22	35.3	35.79	0.812857	0.987143	0.660737	0.974451
$\sum y$	**241.41**	**243.62**			**4.653**	**24.518**
$\bar{y}$	**34.49**	**34.80**				

$$\bar{y} = {\sum y}/{n} \qquad 4.2d$$

$$S_{Exp}{}^2 = \frac{4.653}{6} = 0.9694$$

$$S_{mod.}{}^2 = \frac{24.518}{6} = 4.086$$

$$F = \frac{S_{Mod}{}^2}{S_{Exp.}{}^2} = \frac{4.086}{0.9694} = 4.21$$

From fisher table, at a significant level of 0.05;

$F_{0.95}(6{,}6) = 4.28$ By interpolation. [$See\ \ Appendix\ A\ Table$ 4.25]

The value of F from the table is higher than the calculated value; therefore, the model equation is reliablefor use.

4.1.4 Density Test Results and Analysis

Table 4.13: DENSITY RESULT OF REPLICATE SAMPLES

$Sample\ ID$	$Replicate$	$Weigth\ (kg)$	$Volume\ (m^3)$	$Density\ (kg/m^3)$	$Average\ Density$	% Replacement
1	1A	9.10	0.003375	2696.296	2597.531	0
	1B	8.40	0.003375	2488.889		
	1C	8.80	0.003375	2607.407		
2	2A	9.20	0.003375	2725.926	2696.296	22.2
	2B	9.00	0.003375	2666.667		
	2C	9.10	0.003375	2696.296		
3	3A	9.20	0.003375	2725.926	2696.296	16.7
	3B	9.10	0.003375	2696.296		

	3C	9.00	0.003375	2666.667		
4	4A	8.90	0.003375	2637.037	2637.037	31.8
	4B	9.00	0.003375	2666.667		
	4C	8.80	0.003375	2607.407		
5	5A	9.30	0.003375	2755.556	2686.42	9.1
	5B	8.30	0.003375	2459.259		
	5C	9.60	0.003375	2844.444		
6	6A	8.60	0.003375	2548.148	2577.778	11.1
	6B	8.90	0.003375	2637.037		
	6C	8.60	0.003375	2548.148		
7	7A	9.20	0.003375	2725.926	2696.296	7.8
	7B	9.20	0.003375	2725.926		
	7C	8.90	0.003375	2637.037		
8	8A	9.00	0.003375	2666.667	2567.901	14.3
	8B	8.60	0.003375	2548.148		
	8C	8.40	0.003375	2488.889		
9	9A	9.00	0.003375	2666.667	2666.667	4.1
	9B	9.00	0.003375	2666.667		
	9C	9.00	0.003375	2666.667		
10	10A	8.60	0.003375	2548.148	2646.914	19.6
	10B	9.20	0.003375	2725.926		
	10C	9.00	0.003375	2666.667		
11	11A	8.60	0.003375	2548.148	2558.025	26.5
	11B	8.30	0.003375	2459.259		
	11C	9.00	0.003375	2666.667		
12	12A	9.00	0.003375	2666.667	2627.16	16.3
	12B	8.80	0.003375	2607.407		
	12C	8.80	0.003375	2607.407		
13	13A	9.00	0.003375	2666.667	2607.407	23.9
	13B	8.90	0.003375	2637.037		
	13C	8.50	0.003375	2518.519		
14	14A	8.30	0.003375	2459.259	2439.506	13
	14B	8.40	0.003375	2488.889		
	14C	8.00	0.003375	2370.37		
15	15A	9.20	0.003375	2725.926	2686.420	20.4
	15B	9.00	0.003375	2666.667		
	15C	9.00	0.003375	2666.667		
CONTROL						
16	16A	8.80	0.003375	2608.724	2521.546	17
	16B	8.34	0.003375	2470.273		
	16C	8.39	0.003375	2485.641		
17	17A	8.14	0.003375	2411.538	2552.326	12
	17B	9.05	0.003375	2680.781		
	17C	8.66	0.003375	2564.660		
18	18A	8.82	0.003375	2612.709	2556.079	15.3
	18B	8.63	0.003375	2558.026		
	18C	8.43	0.003375	2497.502		
19	19A	8.25	0.003375	2444.812	2502.150	13.6
	19B	8.54	0.003375	2529.277		

	19C	8.55	0.003375	2532.359		
20	20A	8.78	0.003375	2602.993	2526.559	20
	20B	8.32	0.003375	2463.927		
	20C	8.48	0.003375	2512.756		
21	21A	8.70	0.003375	2577.778	2508.642	15.6
	21B	8.40	0.003375	2488.889		
	21C	8.30	0.003375	2459.259		
22	22A	8.50	0.003375	2518.808	2511.704	15.1
	22B	8.83	0.003375	2615.234		
	22C	8.10	0.003375	2401.069		

The table shows that the density increases with increase in percentage replacement of river sand with quarry dust and peaks at between 9% and 10%.

The replacement of sand with the finer particles of quarry dusts results inbetter graded aggregates. The smaller finer particles of quarry dust fill up the voids in between larger particles of sand and crushed stone. This results in reduction of voids and hence increases the density of the concrete up to 9.8% replacement. Beyond this, the particles become more uniformly graded and therefore the densification of the concrete starts to reduce.

$$Density = \frac{Mass(kg)}{Volume(m^3)} \qquad 4.2e$$

$$Average\ Density = \frac{\sum Replicate\ Density}{n} \qquad 4.2f$$

Determination of Model Equation for Density

From Equation 3.50f.

$Y = X_1(2X_1 - 1)n_1 + X_2(2X_2 - 1)n_2 + X_3(2X_3 - 1)n_3 + X_4(2X_4 - 1)n_4 + X_2(2X_5 - 1)n_5 + 4n_{12}X_1X_2 + 4n_{13}X_1X_3 + 4n_{14}X_1X_4 + 4n_{15}X_1X_5 + 4n_{23}X_2X_3 + 4n_{24}X_2X_4 + 4n_{25}X_2X_5 + 4n_{34}X_3X_4 + 4n_{35}X_3X_5 + 4n_{45}X_4X_5 + e$ 4.3

From table 4.1, the responses $y_i$are given as:

y_1 = 2597.53 kg/m^3

y_2 = 2696.296 kg/m^3

y_3 = 2696.296 kg/m^3

y_4 = 2637.037 kg/m^3

y_5 = 2686.42 kg/m^3

y_{12} = 2577.78 kg/m^3

y_{13} = 2696.296 kg/m^3

y_{14} = 2567.90 kg/m^3

y_{15} = 2666.67 kg/m^3

y_{23} = 2646.91kg/m^3

y_{24} = 2558.025 kg/m^3

y_{25} = 2627.16 kg/m^3

y_{34} = 2607.41 kg/m^3

y_{35} = 2439.51 kg/m^3

y_{45} = 2686.42 kg/m^3

y_{C_1} = 2607.41 kg/m^3

y_{C_2} = 2627.16 kg/m^3

y_{C_3} = 2646.91 kg/m^3

y_{C_4} = 2390.12kg/m^3

y_{C_5} = 2607.40kg/m^3

y_{C_6} = 2508.64 kg/m^3

y_{C_7} = 2449.38 kg/m^3

Coefficients of the regression model were derived using Eqn 3.49

$n_i = y_i$ and $n_{ij} = 4y_{ij} - 2y_i - 2y_j$, therefore,

n_1 = 2597.53, n_2 = 2696.296, n_3 = 2696.296, n_4 = 2637.037, n_5 = 2686.42

$n_{12} = 4y_{12} - 2y_1 - 2y_2 = (4 \times 2577.78) - (2 \times 2597.53) - (2 \times 2696.296) = -276.53$

n_{13} = 197.532

$n_{14} = -197.53$

n_{15} = 98.768

$n_{23} = -197.528$

$n_{24} = -434.566$

$n_{25} = -256.792$

$n_{34} = -237.038$

$n_{35} = -1007.41$

n_{45} = 98.76

Substituting n_i, n_j *and* n_{ij} into $Equation$ 4.3, *we have*

$$\begin{aligned}
&Y \\
&= 2597.53X_1 + 2696.296X_2 + 2696.296X_3 + 2637.037X_4 + 2686.42X_5 - 276.53x_1X_2 \\
&+ 197.532X_1X_3 - 197.5X_1X_4 + 98.768X_1X_5 - 197.528X_2X_3 - 434.566X_2X_4 \\
&- 256.792X_2X_5 - 237.038X_3X_4 - 1007.41X_3X_5 \\
&+ 98.766X_4X_5 \qquad 4.4
\end{aligned}$$

Table 4.14: DENSITY RESULT AND REPLICATION VARIANCE

$Sample\ ID$	$Replicate$	$Response\ Y_i\ (N/mm^2)$	$Response\ Symbol$	$\sum Y_i$	$\bar{Y}$	$\sum {Y_i}^2$	$\left(\sum Y_i\right)^2$	${S_i}^2$
1	1A	2696.296	Y_1	7792.592	2597.531	20263155	60724490.08	10829.16
	1B	2488.889						
	1C	2607.407						
2	2A	2725.926	Y_2	8088.889	2696.296	21811797	65430125.25	877.6154
	2B	2666.667						
	2C	2696.296						
3	3A	2725.926	Y_3	8088.889	2696.296	21811797	65430125.25	877.6154
	3B	2696.296						
	3C	2666.667						
4	4A	2637.037	Y_4	7911.111	2637.037	20863648.8	62585677.25	878.208
	4B	2666.667						
	4C	2607.407						
5	5A	2755.556	Y_5	8059.259	2686.42	21731906.7	64951655.63	40677.42
	5B	2459.259						
	5C	2844.444						
6	6A	2548.148	Y_{12}	7733.333	2577.778	19940082.3	59804439.29	2634.604
	6B	2637.037						
	6C	2548.148						
7	7A	2725.926	Y_{13}	8088.889	2696.296	21815308.6	65430125.25	2633.445
	7B	2725.926						
	7C	2637.037						
8	8A	2666.667	Y_{14}	7703.704	2567.901	19798738	59347055.32	8193.112
	8B	2548.148						
	8C	2488.889						
9	9A	2666.667	Y_{15}	8000.001	2666.667	21333333.3	64000016	-2.66667
	9B	2666.667						
	9C	2666.667						
	10A	2548.148	Y_{23}	7940.741	2646.914			8193.187

Table 4.14: Contd.

	10B	2725.926				21034842.2	63055367.63	
	10C	2666.667						
11	11A	2548.148	Y_{24}	7674.074	2558.025	19652126.2	58891411.76	10827.81
	11B	2459.259						
	11C	2666.667						
12	12A	2666.667	Y_{25}	7881.481	2627.16	20708257.9	62117742.75	1171.818
	12B	2607.407						
	12C	2607.407						
13	13A	2666.667	Y_{34}	7822.223	2607.407	20408011	61187172.66	6143.377
	13B	2637.037						
	13C	2518.519						
14	14A	2459.259	Y_{35}	7318.51	2439.506	17861179.7	53560705.72	3805.563
	14B	2488.889						
	14C	2370.37						
15	15A	2725.926	Y_{45}	8059.26	2686.42	21652894.4	64951671.75	1168.563
	15B	2666.667						
	15C	2666.667						
CONTROL								
16	16A	2608.724	Y_{C1}	7564.638	2521.546	19086102	57223753	5759.034
	16B	2470.273						
	16C	2485.641						
17	17A	2411.538	Y_{C2}	7656.979	2552.326	19579584	58629331	18236.94
	17B	2680.781						
	17C	2564.660						
18	18A	2612.709	Y_{C3}	7668.236	2556.079	19607258	58801847	3320.984
	18B	2558.026						
	18C	2497.502						
19	19A	2444.812	Y_{C4}	7506.449	2502.15	18787195	56346776	2468.047
	19B	2529.277						
	19C	2532.359						
20	20A	2602.993	Y_{C5}	7579.676	2526.559	19160449	57451482	4977.735
	20B	2463.927						

Table 4.14: Contd.

	20C	2512.756						
21	21A	2577.778	Y_{C6}	7525.926	2508.642	18887462.3	56639562.16	3804.324
	21B	2488.889						
	21C	2459.259						
22	22A	2518.808	Y_{C7}	7535.111	2511.704	18948975.2	56777898.14	11504.575
	22B	2615.234						
	22C	2401.069						
$\sum$								148980.47

Variance for each experimental point is given by the relationship

$$S_i{}^2 = \left[\frac{1}{n-1}\right]\left[\sum Y_i{}^2 - \left(\frac{1}{n}\left(\sum Y_i\right)^2\right)\right]$$

For experimental point 1,

$$S_1{}^2 = \left[\frac{1}{3-1}\right]\left[20263155 - \left(\frac{1}{3} \times 60724490.0\right)\right] = 10{,}829.167$$

For Point 2,

$$S_2{}^2 = \left[\frac{1}{3-1}\right]\left[21811797 - \left(\frac{1}{3} \times 6543012.25\right)\right] = 877.6154$$

For Point 3,

$$S_3{}^2 = \left[\frac{1}{3-1}\right]\left[21811797 - \left(\frac{1}{3} \times 6543012.25\right)\right] = 877.6154$$

Hence the replication variance $S_y{}^2$is given as;

$$S_y{}^2 = \frac{\sum S_i{}^2}{n-1} = \frac{148980.474}{21} = 7094.31$$

The standard deviation of the replicates is given as;

$$S_y = \sqrt{\frac{\sum S_i{}^2}{n-1}} = \sqrt{7094.31} = 84.227$$

The standard deviation of 84.227 is less than 3.5% of the minimum value of the statistical data i.e. density test results. This shows a high degree of constituency in the test results.

Table 4.15: COMPARISON OF THE DENSITY RESULT OF THE MODEL AND THE EXPERIMENTAL DENSITY RESULT

$Sample\ ID$	Y_{Exp}	Y_{Model}
1	2597.531	2597.53
2	2696.296	2696.296
3	2696.296	2696.296
4	2637.037	2637.037
5	2686.420	2686.420
6	2577.778	2577.781
7	2696.296	2696.296
8	2567.901	2567.909
9	2666.667	2666.667
10	2646.914	2646.914
11	2558.025	2558.025
12	2627.100	2627.160

Table 4.15: Contd.

13	2607.407	2607.407
14	2439.500	2439.506
15	2686.420	2686.420
16	2521.546	2585.188
17	2552.326	2579.013
18	2556.079	2593.830
19	2502.150	2551.852
20	2552.326	2574.224
21	2508.642	2600.694
22	2511.704	2561.580

The table shows that density results obtained from the model compares very well with the laboratory test results.

Table 4.16: STUDENT'S T-TEST FOR THE CONTROL POINT OF THE DENSITY

ID	i	j	a_i	a_{ij}	a_i^2	a_{ij}^2	ε	$Y_{Exp.}$	Y_{Model}	Δy	t
16	1	2	-0.125	0.25	0.0156	0.0625	0.531	2607.41	2585.2	22.219	0.0030
	1	3	-0.125	0.25	0.0156	0.0625					
	1	4	-0.125	0.25	0.0156	0.0625					
	1	5	-0.125	0	0.0156	0					
	2	3	-0.125	0.25	0.0156	0.0625					
	2	4	-0.125	0.25	0.0156	0.0625					
	2	5	-0.125	0	0.0156	0					
	3	4	-0.125	0.25	0.0156	0.0625					
	3	5	-0.125	0	0.0156	0					
	4	5	-0.125	0	0.0156	0					
					0.1562	0.375					
17	1	2	-0.125	0.25	0.015	0.0625	0.516	2627.16	2579.0	48.147	0.0066
	1	3	-0.125	0.25	0.0156	0.0625					
	1	4	-0.125	0	0.0156	0					
	1	5	-0.125	0.25	0.0156	0.0625					
	2	3	-0.125	0.25	0.0156	0.0625					
	2	4	-0.125	0	0.0156	0					
	2	5	-0.125	0.25	0.0156	0.0625					
	3	4	-0.125	0	0.0156	0					
	3	5	0	0.25	0.0156	0.0625					
	4	5	-0.125	0	0	0					
					0.1406	0.375					
18	1	2	-0.125	0.25	0.0156	0.0625	0.5	2646.91	2593.8	53.084	0.0073
	1	3	-0.125	0	0.0156	0					
	1	4	-0.125	0.25	0.0156	0.0625					
	1	5	-0.125	0.25	0.0156	0.0625					
	2	3	-0.125	0	0.0156	0					
	2	4	-0.125	0.25	0.0156	0.0625					
	2	5	-0.125	0.25	0.0156	0.0625					
	3	4	0	0	0.0156	0					
	3	5	0	0	0.0156	0					
	4	5	-0.125	0.25	0.0156	0.0625					

Table 4.16: Contd

Table 4.16: Contd.

					0.125	0.375					
19	1	2	0	0	0	0	0.469	2390.12	2551.8	161.73	0.0225
	1	3	0	0	0	0					
	1	4	0	0	0	0					
	1	5	0	0	0	0					
	2	3	-0.125	0.25	0.0156	0.0625					
	2	4	-0.125	0.25	0.0156	0.0625					
	2	5	-0.125	0.25	0.0156	0.0625					
	3	4	-0.125	0.25	0.0156	0.0625					
	3	5	-0.125	0.25	0.0156	0.0625					
	4	5	-0.125	0.25	0.0156	0.0625					
					0.0937	0.375					
20	1	2	-0.12	0.16	0.0144	0.0256	0.400	2607.40	2574.2	33.183	0.0047
	1	3	-0.12	0.16	0.0144	0.0256					
	1	4	-0.12	0.16	0.0144	0.0256					
	1	5	-0.12	0.16	0.0144	0.0256					
	2	3	-0.12	0.16	0.0144	0.0256					
	2	4	-0.12	0.16	0.0144	0.0256					
	2	5	-0.12	0.16	0.0144	0.0256					
	3	4	-0.12	0.16	0.0144	0.0256					
	3	5	-0.12	0.16	0.0144	0.0256					
	4	5	-0.12	0.16	0.0144	0.0256					
					0.144	0.256					
21	1	2	-0.12	0.24	0.0144	0.0576	0.530	2508.64	2600.7	92.052	0.013
	1	3	-0.12	0.36	0.0144	0.1296					
	1	4	-0.12	0.24	0.0144	0.0576					
	1	5	-0.12	0	0.0144	0					
	2	3	-0.12	0.24	0.0144	0.0576					
	2	4	-0.12	0.16	0.0144	0.0256					
	2	5	-0.12	0	0.0144	0					
	3	4	-0.12	0.24	0.0144	0.0576					
	3	5	-0.12	0	0.0144	0					
	4	5	-0.12	0	0.0144	0					
					0.144	0.3856					
22	1	2	0	0	0	0	0.472	2449.38	2561.6	112.20	0.016
	1	3	0	0	0	0					
	1	4	0	0	0	0					
	1	5	0	0	0	0					
	2	3	-0.12	0.24	0.0144	0.0576					
	2	4	-0.12	0.36	0.0144	0.1296					
	2	5	-0.12	0.24	0.0144	0.0576					
	3	4	-0.12	0.24	0.0144	0.0576					
	3	5	-0.12	0.16	0.0144	0.0256					
	4	5	-0.12	0.24	0.0144	0.0576					

To test the adequacy of the model on each control point;

$$t = \frac{\Delta y\sqrt{n}}{{S_y}^2\sqrt{1+\varepsilon}}$$

$$Where\ \Delta y = y_{Exp.} - y_{Model}$$

$$n = the\ number\ of\ parallel\ observations\ at\ every\ at\ every\ point$$

$$\varepsilon = \sum_{1\le i\le q} {a_i}^2 + \sum_{1\le i<j\le q} {a_{ij}}^2$$

$$a_i = x_i(2x_i - 1), \qquad a_{ij} = 4x_ix_j$$

$${S_y}^2 = Replication\ variance$$

For experimental point C1,

$$t = \frac{\Delta y\sqrt{n}}{{S_y}^2\sqrt{1+\varepsilon}} = \frac{22.219\sqrt{3}}{10255.91\sqrt{1+0.531}} = 0.00303$$

The values of t is low and shows that the differences in the compressive test results are insignificant and therefore the results are consistent and reliable.

Similarly, t can be calculated for other experimental points.

T- Value from Table

For a significant level of, $\alpha = 0.05$,

$V_e = n - 1 = 7 - 1 = 6$

$t_\alpha(V_e) = t_{0.05}(6) = 2.45, as\ shown\ Appendix\ A, Table\ 4.24$

This value of t is greater than any of the t values obtained from calculation as shown in the table above. Therefore, the null hypothesis is acceptable and the model equation is reliable for predicting the density of quarry dust concrete at 95% confidence level.

Table 4.17: FISHER TEST

$Response\ ID$	$Y_{Exp.}$	Y_{Model}	$Y_{Exp.} - \bar{y}_{Exp}$	$Y_{mod.} - \bar{y}_{mod.}$	$(Y_{Exp.} - \bar{y}_{Exp})^2$	$(Y_{mod.} - \bar{y}_{mod.})^2$
16	2521.55	2585.2	-4.026	7.16	16.209	51.225
17	2552.33	2579	26.754	0.96	715.790	0.916
18	2556.08	2593.8	30.507	15.76	930.652	248.287
19	2502.15	2551.8	-23.422	-26.24	548.614	688.687
10	2526.56	2574.2	0.986	-3.84	0.9729	14.767
21	2508.64	2600.7	-16.93	22.66	286.630	513.346

Table 4.17: Contd.

22	2511.70	2561.6	-13.87	-16.44	192.335	270.367
$\sum$	17679.00	18046.3			2691.203	1787.597
$\bar{y}$	2525.57	2578.04				

$\bar{y} = {\sum Y}/{n}$

$$S_{Exp}{}^2 = \frac{2691.203}{6} = 448.53$$

$$S_{mod.}{}^2 = \frac{1785.872}{6} = 297.645$$

$$F = \frac{S_{Mod}{}^2}{S_{Exp.}{}^2} = \frac{448.53}{297.645} = 1.505$$

From fisher table, at a significant level of 0.05;

$F_{0.95}(6,6) = 4.28$ $[See\ \ Appendix\ A, Table$ 4.25]

The value of F from the table is higher than the calculated value; therefore, the model equation is reliable for use in predicting the density of concrete.

4.1.5 Slump Test Results

Table 4.18: SLUMP TEST RESULT OF REPLICATE SAMPLES

$SampleID$	$Replicate$	$Slump(cm)$	Average Slump (cm)
1	1A	2.31	2.08
	1B	2.02	
	1C	1.91	
2	2A	1.39	1.37
	2B	1.40	
	2C	1.32	
3	3A	1.30	1.28
	3B	1.28	
	3C	1.26	
4	4A	0.89	0.90
	4B	0.91	
	4C	0.90	
5	5A	1.82	1.84
	5B	1.84	
	5C	1.86	
6	6A	1.70	1.68
	6B	1.67	
	6C	1.68	
7	7A	1.72	1.70
	7B	1.68	
	7C	1.70	
8	8A	1.20	1.17

Table 4.18: Contd.

Table 4.18: Contd.

	8B	1.13	
	8C	1.18	
9	9A	1.34	1.35
	9B	1.36	
	9C	1.35	
10	10A	1.03	1.04
	10B	1.04	
	10C	1.05	
11	11A	0.99	1.00
	11B	1.01	
	11C	1.00	
12	12A	1.25	1.26
	12B	1.27	
	12C	1.26	
13	13A	1.10	1.13
	13B	1.15	
	13C	1.14	
14	14A	1.23	1.25
	14B	1.27	
	14C	1.26	
15	15A	1.04	1.03
	15B	1.02	
	15C	1.03	
CONTROL			
16	16A	1.24	1.23
	16B	1.48	
	16C	0.98	
17	17A	1.26	1.25
	17B	1.37	
	17C	1.12	
18	18A	0.99	1.10
	18B	1.09	
	18C	1.22	
19	19A	1.04	1.00
	19B	0.89	
	19C	1.12	
20	20A	1.15	1.12
	20B	1.05	
	20C	1.16	
21	21A	1.10	1.30
	21B	1.45	
	21C	1.35	
22	22A	0.99	0.98
	22B	1.00	
	22C	0.96	

The table shows that as percentage replacement of river sand with quarry dust increases, the slump decreases.

The introduction of the finer particles of quarry dust increases the overall surface area of aggregates and therefore requires more water to wet the surfaces of all the particles. For a given water/cement ratio, there is less water to go round the surfaces of the finer particles than concrete with larger particles thus the workability of the concrete decreases steadily as the percentage replacement of sand with quarry dust increases as shown in the test results.

Determination of TheModelEquation for Slump

From Equation 3.50,

$$Y = X_1 (2X_1 - 1) n_1 + X_2 (2X_2 - 1) n_2 + X_3 (2X_3 - 1) n_3 + X_4 (2X_4 - 1) n_4 + X_2 (2X_5 - 1) n_5 + 4n_{12} X_1X_2 + 4n_{13} X_1X_3 + 4n_{14} X_1 X_4 + 4n_{15} X_1 X_5 + 4n_{23} X_2 X_3 + 4n_{24}X_2 X_4 + 4n_{25} X_2 X_5 + 4n_{34} X_3 X_4 + 4n_{35} X_3 X_5 + 4n_{45} X_4 X_5 + e \qquad 4.5$$

From table 4.16, the responses $y_i$are given as:

$y_1 = 2.08cm$

$y_2 = 1.37cm$

$y_3 = 1.28cm$

$y_4 = 0.90cm$

$y_5 = 1.84cm$

$y_{12} = 1.68cm$

$y_{13} = 1.70cm$

$y_{14} = 1.17cm$

$y_{15} = 1.35cm$

$y_{23} = 1.04cm$

$y_{24} = 1.00cm$

$y_{25} = 1.26cm$

$y_{34} = 1.13cm$

$y_{35} = 1.25cm$

$y_{45} = 1.03cm$

$y_{C_1} = 1.20cm$

$y_{C_2} = 1.62cm$

$y_{C_3} = 1.29cm$

y_{C_4} = 1.20cm

y_{C_5} = 1.11cm

y_{C_6} = 1.24cm

y_{C_7} = 0.98cm

Coefficient of the regression model are derived using $Enqn$ 3.21, 3.22 and 3.23

$n_i = y_i$and $n_{ij} = 4y_{ij} - 2y_i - 2y_j$, therefore,

$n_1 = 2.08 n_2 = 1.37, n_3 = 1.28, n_4 = 0.90, n_5 = 1.84$

$n_{12} = 4y_{12} - 2y_1 - 2y_2 = (4 \times 1.68) - (2 \times 2.08) - (2 \times 1.37) = -0.18$

$n_{13} = 0.08$

$n_{14} = -1.28$

$n_{15} = -2.44$

$n_{23} = -1.14$

$n_{24} = -0.54$

$n_{25} = -1.38$

$n_{34} = 0.16$

$n_{35} = -1.24$

$n_{45} = -1.3$

Substituting n_i *and* n_{ij} into $Equation$ 4.5, $we\ have$

$$\begin{aligned} Y &= 2.08X_1 + 1.37X_2 + 1.28X_3 + 0.90X_4 + 1.84X_5 - 0.18X_1X_2 + 0.08X_1X_3 - 1.28X_1X_4 \\ &- 2.44X_1X_5 - 1.14X_2X_3 - 0.54X_2X_4 - 1.38X_2X_5 + 0.16X_3X_4 - 1.24X_3X_5 \\ &- 1.36X_4X_5 \end{aligned} \qquad 4.6$$

Table 4.19: SLUMP TEST RESULT AND REPLICATION VARIANCE

$Sample\ ID$	$Replicate$	$Response\ Y_i\ (cm)$	$Response\ Symbol$	$\sum Y_i$	$\bar{Y}$	$\sum Y_i^2$	$\left(\sum Y_i\right)^2$	S_i^2
1	1A	2.31	Y_1	6.24	2.08	13.0646	38.9376	0.0427
	1B	2.02						
	1C	1.91						
2	2A	1.39	Y_2	4.11	1.37	5.6345	16.8921	0.0019
	2B	1.40						
	2C	1.32						
3	3A	1.30	Y_3			4.916	14.7456	0.0004

	3B	1.28		3.84	1.28			
	3C	1.26						
4	4A	0.89	Y_4	2.7	0.90	2.4302	7.29	1E-04
	4B	0.91						
	4C	0.90						
5	5A	1.82	Y_5	5.52	1.84	10.1576	30.4704	0.0004
	5B	1.84						
	5C	1.86						
6	6A	1.70	Y_{12}	5.05	1.68	8.5013	25.5025	0.000233
	6B	1.67						
	6C	1.68						
7	7A	1.72	Y_{13}	5.1	1.70	8.6708	26.01	0.0004
	7B	1.68						
	7C	1.70						
8	8A	1.20	Y_{14}	3.51	1.17	4.1093	12.3201	0.0013
	8B	1.13						
	8C	1.18						
9	9A	1.34	Y_{15}	4.05	1.35	5.4677	16.4025	1E-04
	9B	1.36						
	9C	1.35						
10	10A	1.03	Y_{23}	3.12	1.04	3.245	9.7344	1E-04
	10B	1.04						
	10C	1.05						
11	11A	0.99	Y_{24}	3.00	1.00	3.0002	9	1E-04
	11B	1.01						
	11C	1.00						
12	12A	1.25	Y_{25}	3.78	1.26	4.763	14.2884	1E-04
	12B	1.27						
	12C	1.26						
13	13A	1.10	Y_{34}	3.39	1.13	3.8321	11.4921	0.0007
	13B	1.15						
	13C	1.14						
14	14A	1.23	Y_{35}	3.76	1.25	4.7134	14.1376	0.000433
	14B	1.27						
	14C	1.26						
15	15A	1.04	Y_{45}	3.09	1.03	3.1829	9.5481	1E-04
	15B	1.02						
	15C	1.03						
CONTROL								
16	16A	1.24	Y_{C1}	3.7	1.23	4.688	13.69	0.0625
	16B	1.48						
	16C	0.98						
17	17A	1.26	Y_{C2}	3.75	1.25	4.719	14.062	0.0157
	17B	1.37						
	17C	1.12						
18	18A	0.99	Y_{C3}	3.30	1.10	3.657	10.89	0.013
	18B	1.09						

	18C	1.22						
19	19A	1.04	Y_{C4}	3.01	1.00	3.046	9.060	0.013
	19B	0.89						
	19C	1.12						
20	20A	1.15	Y_{C5}	3.36	1.12	3.771	11.26	0.0037
	20B	1.05						
	20C	1.16						
21	21A	1.10	Y_{C6}	3.9	1.30	5.135	15.21	0.0325
	21B	1.45						
	21C	1.35						
22	22A	0.99	Y_{C7}	2.95	0.98	2.902	8.70	0.0004
	22B	1.00						
	22C	0.96						
			$\sum$					0.1905

Variance for each experimental point is given by the relationship

$$S_i{}^2 = \left[\frac{1}{n-1}\right]\left[\sum Y_i{}^2 - \left(\frac{1}{n}\left(\sum Y_i\right)^2\right)\right]$$

For experimental point 1,

$$S_1{}^2 = \left[\frac{1}{3-1}\right]\left[13.06 - \left(\frac{1}{3} \times 38.94\right)\right] = 0.0427$$

$$S_2{}^2 = \left[\frac{1}{3-1}\right]\left[5.63 - \left(\frac{1}{3} \times 16.89\right)\right] = 0.0019$$

$$S_3{}^2 = \left[\frac{1}{3-1}\right]\left[4.91 - \left(\frac{1}{3} \times 14.75\right)\right] = 0.0004$$

Hence the replication variance $S_y{}^2$ is given as;

$$S_y{}^2 = \frac{\sum S_i{}^2}{n-1} = \frac{0.0539}{21} = 0.0091$$

The standard deviation of the slump test results is low which shows that the test results vary insignificantly and appear reliable. These results will be tested further for reliability using the T and F tests.

The standard deviation of the replicates is given as;

$$S_y = \sqrt{\frac{\sum S_i{}^2}{n-1}} = \sqrt{0.0091} = 0.095$$

Table 4.20: COMPARISON OF THE SLUMP RESULT OF THE MODEL AND THE EXPERIMENT

$\boldsymbol{SampleID}$	$\boldsymbol{Y_{Exp}}$	$\boldsymbol{Y_{Model}}$	Percentage Different
1	2.08	2.08	0

2	1.37	1.37	0
3	1.28	1.28	0
4	0.90	0.90	0
5	1.84	1.84	0
6	1.68	1.68	0
7	1.70	1.70	0
8	1.17	1.17	0
9	1.35	1.35	0
10	1.04	1.04	0
11	1.00	1.00	0
12	1.26	1.26	0
13	1.13	1.13	0
14	1.25	1.25	0
15	1.03	1.03	0
16	1.23	1.226	0.4
17	1.25	1.249	0.1
18	1.10	1.099	0.1
19	1.00	1.004	0.4
20	1.12	1.121	0.1
21	1.30	1.301	0.1
22	0.98	0.984	0.4

Table 4.21: STUDENT`S T-TEST FOR THE CONTROL POINT OF THE SLUMP

ID	i	j	a_i	a_{ij}	${a_i}^2$	${a_{ij}}^2$	ε	$Y_{Exp.}$	Y_{Model}	Δy	**t**
C1	1	2	-0.125	0.25	0.0156	0.0625	0.531	1.23	1.226	0.004	0.615
	1	3	-0.125	0.25	0.0156	0.0625					
	1	4	-0.125	0.25	0.0156	0.0625					
	1	5	-0.125	0	0.0156	0					
	2	3	-0.125	0.25	0.0156	0.0625					
	2	4	-0.125	0.25	0.0156	0.0625					
	2	5	-0.125	0	0.0156	0					
	3	4	-0.125	0.25	0.0156	0.0625					
	3	5	-0.125	0	0.0156	0					
	4	5	-0.125	0	0.0156	0					
					0.1562	0.375					
C2	1	2	-0.125	0.25	0.015	0.0625	0.5156	1.25	1.249	0.001	0.155
	1	3	-0.125	0.25	0.0156	0.0625					
	1	4	-0.125	0	0.0156	0					
	1	5	-0.125	0.25	0.0156	0.0625					
	2	3	-0.125	0.25	0.0156	0.0625					
	2	4	-0.125	0	0.0156	0					
	2	5	-0.125	0.25	0.0156	0.0625					
	3	4	-0.125	0	0.0156	0					
	3	5	0	0.25	0.0156	0.0625					
	4	5	-0.125	0	0	0					

Table 4.21: Cond.

					0.1406	0.375					
C3	1	2	-0.125	0.25	0.0156	0.0625	0.5	1.1	1.099	0.001	0.155
	1	3	-0.125	0	0.0156	0					
	1	4	-0.125	0.25	0.0156	0.0625					
	1	5	-0.125	0.25	0.0156	0.0625					
	2	3	-0.125	0	0.0156	0					
	2	4	-0.125	0.25	0.0156	0.0625					
	2	5	-0.125	0.25	0.0156	0.0625					
	3	4	0	0	0.0156	0					
	3	5	0	0	0.0156	0					
	4	5	-0.125	0.25	0.0156	0.0625					
					0.125	0.375					
C4	1	2	0	0	0	0	0.46875	1.0	1.004	0.004	0.628
	1	3	0	0	0	0					
	1	4	0	0	0	0					
	1	5	0	0	0	0					
	2	3	-0.125	0.25	0.0156	0.0625					
	2	4	-0.125	0.25	0.0156	0.0625					
	2	5	-0.125	0.25	0.0156	0.0625					
	3	4	-0.125	0.25	0.0156	0.0625					
	3	5	-0.125	0.25	0.0156	0.0625					
	4	5	-0.125	0.25	0.0156	0.0625					
					0.0937	0.375					
C5	1	2	-0.12	0.16	0.0144	0.0256	0.400	1.12	1.121	0.001	0.1605
	1	3	-0.12	0.16	0.0144	0.0256					
	1	4	-0.12	0.16	0.0144	0.0256					
	1	5	-0.12	0.16	0.0144	0.0256					
	2	3	-0.12	0.16	0.0144	0.0256					
	2	4	-0.12	0.16	0.0144	0.0256					
	2	5	-0.12	0.16	0.0144	0.0256					
	3	4	-0.12	0.16	0.0144	0.0256					
	3	5	-0.12	0.16	0.0144	0.0256					
	4	5	-0.12	0.16	0.0144	0.0256					
					0.144	0.256					
C6	1	2	-0.12	0.24	0.0144	0.0576	0.530	1.3	1.301	0.001	0.154
	1	3	-0.12	0.36	0.0144	0.1296					
	1	4	-0.12	0.24	0.0144	0.0576					
	1	5	-0.12	0	0.0144	0					
	2	3	-0.12	0.24	0.0144	0.0576					
	2	4	-0.12	0.16	0.0144	0.0256					
	2	5	-0.12	0	0.0144	0					
	3	4	-0.12	0.24	0.0144	0.0576					
	3	5	-0.12	0	0.0144	0					
	4	5	-0.12	0	0.0144	0					

					0.144	0.3856					
C7	1	2	0	0	0	0	0.472	0.98	0.984	0.004	0.6275
	1	3	0	0	0	0					
	1	4	0	0	0	0					
	1	5	0	0	0	0					
	2	3	-0.12	0.24	0.0144	0.0576					
	2	4	-0.12	0.36	0.0144	0.1296					
	2	5	-0.12	0.24	0.0144	0.0576					
	3	4	-0.12	0.24	0.0144	0.0576					
	3	5	-0.12	0.16	0.0144	0.0256					
	4	5	-0.12	0.24	0.0144	0.0576					

To test the adequacy of the model on each control point;

$$t = \frac{\Delta y\sqrt{n}}{{S_y}^2\sqrt{1+\varepsilon}}$$

$$Where\Delta y = y_{Exp.} - y_{Model}$$

$$n = the\ number\ of\ parallel\ observations\ at\ every\ at\ every\ point$$

$$\varepsilon = \sum_{1\le i\le q} {a_i}^2 + \sum_{1\le i<j\le q} {a_{ij}}^2$$

$$a_i = x_i(2x_i - 1), \qquad a_{ij} = 4x_ix_j$$

$${S_y}^2 = Replication\ variance$$

For experimental point C1,

$$t = \frac{\Delta y\sqrt{n}}{{S_y}^2\sqrt{1+\varepsilon}} = \frac{0.004\sqrt{3}}{0.00917\sqrt{1+0.531}} = 0.615$$

The calculated t values are low and showthat there is no significant difference in the slump test results and therefore the results are reliable.

Similarly, t can be calculated for other experimental control points.

T- Value from Table

For a significant level of, $\alpha = 0.05$,

$$V_e = n - 1 = 7 - 1 = 6$$

$$t_\alpha(V_e) = t_{0.05}(6) = 2.45\ as\ shown\ Appendix\ A, Table\ 4.24$$

This value of t is Less than most of the t values obtained from calculation as shown in the table 4.15 above. Therefore, the null hypothesis is unacceptable and the model equation is reliable for use for the prediction of Slump of concrete made with sand-quarry dust.

Table 4.22: FISHER TEST FOR SLUMP MODEL

$\boldsymbol{Response\ ID}$	$\boldsymbol{Y_{Exp.}}$	$\boldsymbol{Y_{Model}}$	$\boldsymbol{Y_{Ep.} - \bar{y}_{Ep}}$	$\boldsymbol{Y_{md.} - \bar{y}_{md.}}$	$\boldsymbol{(Y_{Ep.} - \bar{y}_{Ep})^2}$	$\boldsymbol{(Y_{md.} - \bar{y}_{md.})^2}$
C1	1.23	1.226	0.09	0.085	0.0081	0.0073
C2	1.25	1.249	0.11	0.108	0.0121	0.0118
C3	1.1	1.099	-0.04	-0.042	0.0016	0.0017
C4	1	1.004	-0.14	-0.137	0.0196	0.0186
C5	1.12	1.121	-0.02	-0.020	0.0004	0.0004
C6	1.3	1.301	0.16	0.160	0.0256	0.0257
C7	0.98	0.984	-0.16	-0.157	0.0256	0.0245
$\sum$	7.98	7.984			0.093	0.0901
$\boldsymbol{\bar{y}}$	1.14	1.1405				

$\bar{y} = {\sum Y}/{n}$

$$S_{Exp}{}^2 = \frac{0.093}{6} = 0.0155$$

$$S_{mod.}{}^2 = \frac{0.0901}{6} = 0.015$$

$$F = \frac{S_{Mod}{}^2}{S_{Exp.}{}^2} = \frac{0.0155}{0.015} = 1.03$$

From fisher table, at a significant level of 0.05;

$F_{0.95}(6,6) = 4.28, \mathit{as\ shown\ in\ Appendix\ A, Table}\ 4.25$

The value of F from the table is higher than the calculated value; therefore, the model equation is reliable at 95% confidence level for use in the prediction of Slump value of concrete made with partial replacement of sand with quarry dust

4.2: Discussion of Results

The test results for the arbitrary mix ratios prescribed for the vertices concrete made with water, cement, river sand, quarry dust and granite are presentedin Table 4.23. The results of the tests are shown graphically in Figure 4.4.

4.2.1: Effect of different percentage replacement of sand with quarry dust on the compressive strength of concrete:

Figure 4.4 shows that as the percentage of quarry dust replacement increased, the compressive strength increased and peaked at between 9 and 10% and then declined. With 0% replacement, the 28th day compressive strength was 30.8KN/m^2, with 4% replacement, the compressive strength on the 28th day was 31.7N/mm^2, with 9% replacement, the compressive strength peaked at 44.7N/mm^2 with 24% replacement, the compressive strength was 35.5N/mm^{2}while the compressive strength was 42N/mm^2 with 32% replacement. This shows that the compressive strength of concrete is enhanced up to 32% replacement of river sand with quarry dust. This can be explained by the fact that the finer particles of quarry dust fill up the voids in the concrete between the cement paste and the aggregate and this densification continued up to 32% replacement.

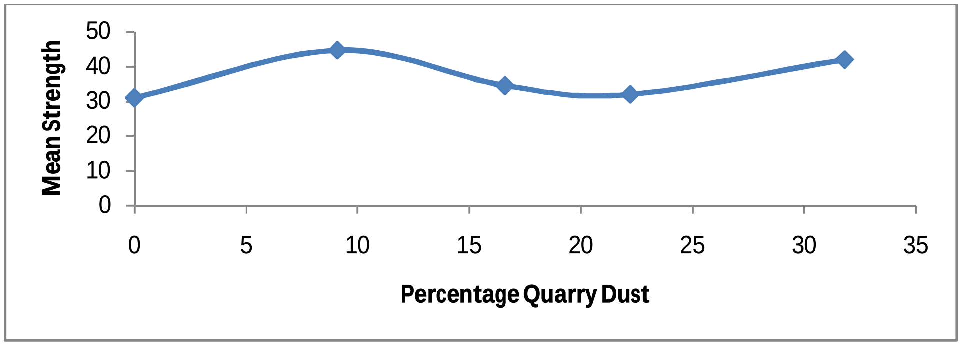


Figure 4.4: EFFECT OF DIFFERENT PERCENTAGE REPLACEMENT OF SAND WITH QUARRY DUST ON THE COMPRESSIVE STRENGTH OF CONCRETE.

4.2.2 Effect of different percentage replacement of sand with quarry dust on the workability of concrete.

Figure 4.5above shows that as the percentage replacement of sand with quarry dust increased, the slump decreased. With 0% replacement of river sand with quarry dust, the slump of the concrete was highest measuring 20.8mm with 4% replacement, the slump was 13.5mm, with 24% replacement, the slump was 11.3mm and with 32% replacement, the slump measured 9mm. There was a steady declined in the slump value of the concrete as the replacement of river sand with quarry dust increased. This is explained by the fact that water requirement is more for increased fineness and angular quarry dust shape. This results in decreased workability of the quarry dust concretefor the same w/c ratio.

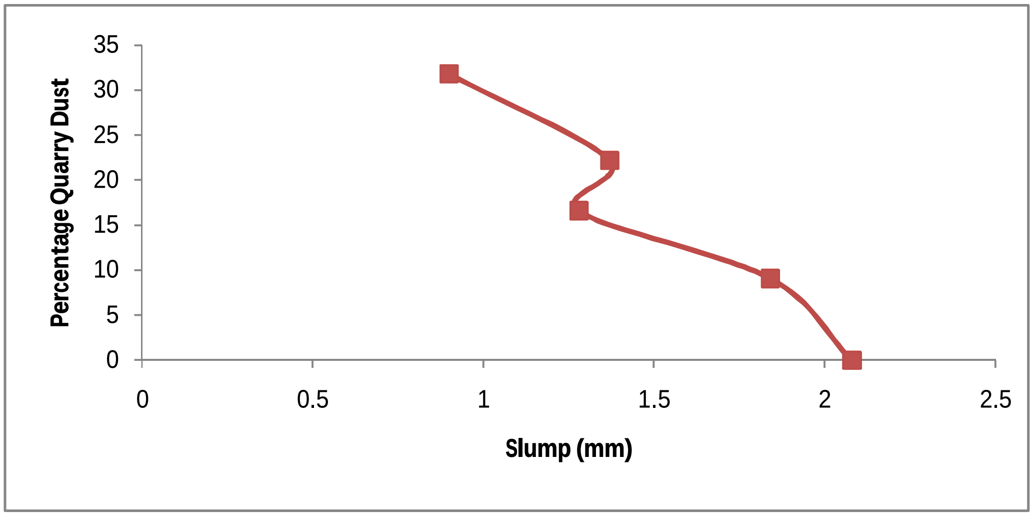
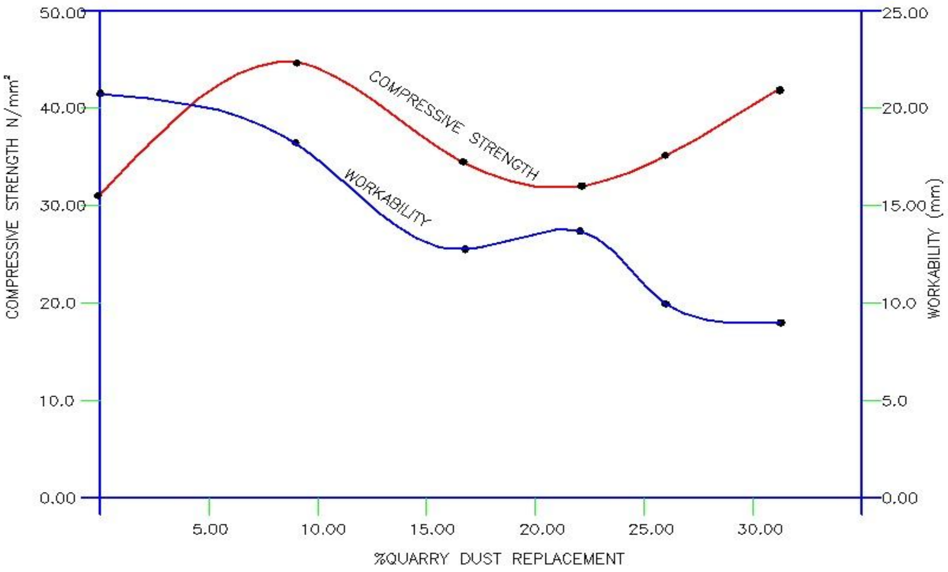


Figure 4.5: THE EFFECT OF DIFFERENT PERCENTAGE REPLACEMENT OF RIVER SAND ON THE WORKABILITY OF QUARRY DUST



sive strength of

Figure 4.6: RELATIONSHIP BETWEEN QUARRY DUST REPLACEMENT, WORKABILITY AND COMPRESSIVE STRENGTH OF CONCRETE

Figure 4.6 shows that while the compressive strength of concrete increased with increase in replacement of river sand with quarry dust, the workability decreased. The point at which the two lines representing compressive strength and workability meet can be regarded as the optimum point where the enhancement of compressive strength minimally affects the workability of the concrete and this is at 4.5% replacement of river sand with quarry dust.

4.2.4 Relationship between Percentage Fine Aggregate to Total Aggregate and Compressive Strength of Concrete:Figure 4.7 shows that initially, as the percentage of the total aggregate increased, the compressive strengthening the concrete increased. However, beyond 43%, the compressive strength of concrete start to decrease. This is explained by the fact that naturally the increase in fine aggregate resulted in denser concrete as the fines fill up void in the concrete. However, 43%, the increase in density is heavily contended by decrease in workability which require increase in water/cement ratio and consequently lead to a decrease in compressive strength.

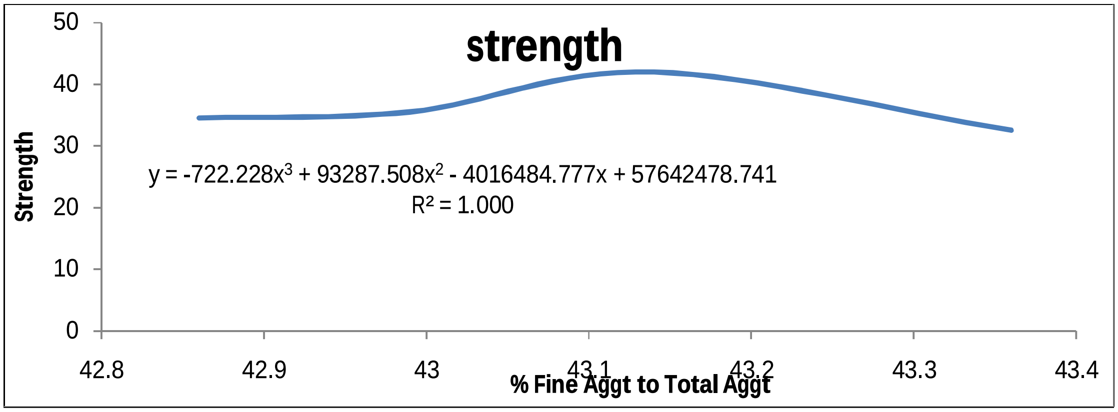


Figure 4.7: RELATIONSHIP BETWEEN PERCENTAGE FINE AGGREGATE TO TOTAL AGGREGATE AND COMPRESSIVE STRENGTH OF CONCRETE

4.2.5 Relationship between Percentage Fine Aggregate to Total Aggregate and Workability.

Figure 4.8 shows that as the percentage of five is increased, the workability of the concrete decreases. As explained in section 4.1.5, increase in fine increases the overall surface area of aggregates and therefore requires more water to wet and lubricate. The surfaces of the aggregate. For the same water/cement ratio, resultant effect is a decrease in workability.

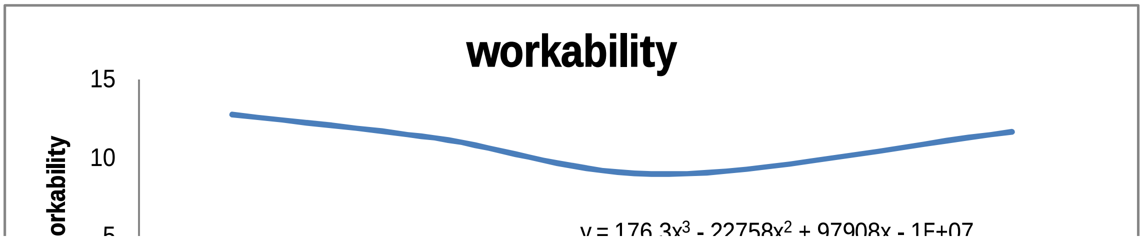


Figure 4.8: RELATIONSHIP BETWEEN PERCENTAGE FINE AGGREGATE TO TOTAL AGGREGATE AND WORKABILITY.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Quarry dust concrete as a structural concrete from this study is feasible. The introduction of quarry dust as partial replacement for river sand also improves some engineering properties of concrete like compressive strength and density. However, quarry dust in concrete reduces workability.

As the percentage replacement of sand with quarry dust increases, the compressive strength of the concrete also increases. This peaks at about 9.1% but remains higher up to 31.8% replacement. The density also increases with increase in percentage replacement of the quarry dust up to 31.8% replacement even though it peaks at between 16% and 17% replacement. The workability of concrete however decreases with increase in percentage replacement of sand with quarry dust. Quarry dust replacement is therefore inversely related to the workability of the concrete.

The compressive strength and workability of the concrete are optimized at 4.5% quarry dust replacement. Beyond this point while the compressive strength increases the workability continues to decrease.

The results obtained from the regressionalmodel for predicting the compressive strength of quarry dust concrete compared very well with actual laboratory test results and passed the T test and Fisher test.

The results obtained from the regressional model for predicting the density of quarry dust concrete compared well with the actual laboratory test results and passed the T Test and F Test.

The results obtained from the regressional model for predicting the slump of the quarry dust concrete compared well with the actual laboratory test results andpassed Tab Test.

Finally, the objectives of this study were achieved. The engineering properties; compressive strength, density and slump of sand-quarry dust concrete were determined. The percentage replacement at which these engineering properties are optimized were also determined while models for predicting these properties were developed, tested and found reliable.

5.2 Recommendations

i. The use of quarry dust as replacement for river sand up to 31% should be encouraged as a means of using up this by-product of the quarry industry, which constitutes environmental hazard.

ii. Quarry dust should be used as partial replacement for river sand where workability of the concrete does not pose a major problem. It should be used in non-congested re-inforced concrete and mass concrete works.

iii. Further research should be carried out to determine the effects of quarry dust replacement on other properties of concrete including the flexural strength and the durability of concrete.

iv. Further research should also be carried out to determine the exact point at which increase in quarry dust replacement reduces the compressive strength of concrete.

v. The partial replacement of river sand with quarry dust should be commercialized and used in concrete construction especially in places close to the quarry industry.

5.3 Contributions to Knowledge

i. The regressional models developed can be used to predict the compressive strength, density and slump of a given concrete mix containing quarry dust. Thus this serves as a tool for mix design of quarry dust concrete.

ii. Some mechanical properties of concrete such as the compressive strength and density of concrete are improved with partial replacement of river sand with quarry dust. However, the workability declines with increase in replacement of river sand with quarry dust.

iii. The compressive strength of concrete containing quarry dust peaks at between 9.1% replacement of river sand with quarry dust.However, the workability decreases with increase in replacement of river sand with quarry dust. These two properties are optimized at 4.5% replacement of river sand with quarry dust.

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Appendices

Appendix A

Table 4.1: SIEVE ANALYSIS RESULT FOR RIVER SAND

SIEVE SIZE	MASS RETAINED	TOTAL MASS RETAINED	TOTAL MASS PASSING	TOTAL %PASSING
6.300			300.00	100.00
5.000	11.00	11.00	289.00	96.33
3.350				
2.000	27.00	38.00	262.00	87.33
1.180	49.00	87.00	213.00	71.00
0.600	130.00	217.00	83.00	27.67
0.425				
0.300	60.00	227.00	23.00	7.67
0.212				
0.150	19.00	296.00	4.00	1.33
0.063				

Table4.2:SIEVE ANALYSIS RESULT FOR QUARRY DUST AGGREGATE

SIEVE SIZE (mm)	WEIGHT RETAINED (g)	CUMULATIVE WEIGHT RETAINED	CUMMULATIVE % RETAINED	CUMMULATIVE % PASSING
9.500	0	0	0	100
4.750	10	10	2.00	97.99
2.380	55	65	13.00	86.92
1.180	97	162	32.40	67.40
0.600	97	259	51.80	47.85
0.300	149	408	81.60	17.9
0.150	75	483	96.60	2.01
0.075	17	500	100	0
$\sum$	500		277.4	

$FinenessModulus \frac{277.4}{100} = 2.77$

Percentage passing sieve 600 Sieve is 47.85%, the aggregate falls under zone 2.

Table4.3:SIEVE ANALYSIS RESULT FOR COARSE AGGREGATE

Sieve Size (mm)	Mass retained (g)	Cumulative Mass Retained	Cum % retained	Cum % passing

Table 4.3: Contd.

22	0	0	0	100
18	157.9	157.9	12.63	87
13	951.9	1,109.8	88.78	12
9.5	145.5	1,250	100	-
4.75	0	1,250	100	-
2.36	0	1,250	100	-
Σ	1,250		401.41	

Fineness Modulus = $\frac{401.41}{100}$ = 4.01

Table 4.4:SPECIFIC GRAVITY RESULT FOR FINE SAND

DATA	A	B	C	D	E
Empty wt. Of bottle, X (g)	435	430	435	430	435
Wt of bottle. + sample, K (g)	1015	1135	1070	1090	1035
Sample weight: K-X =A (g)	580	705	635	660	600
Wt of bottle. + sample + H_2O = B (g)	1825	1875	1855	1850	1835
Wt of bottle. + H_2O = C (g)	1465	1445	1465	1445	1465
Oven dry sample wt. = D (g)	560	675	610	625	570

$$SPECIFIC\ GRAVITY\ ON\ SSD\ BASIS = \frac{A}{A-(B-C)}$$

$$S.G == \frac{3180}{3180-(9240-7285)} = 2.6$$

Table 4.5: SPECIFIC GRAVITY RESULT FOR QUARRY DUST

DATA	A	B	C	D	E
Empty wt. Of bottle, X (g)	435	435	435	435	435
Wt of bottle. + sample, K (g)	965	970	925	1020	980
Sample weight: K-X =A (g)	530	535	490	585	545
Wt of bottle. + sample + H_2O = B (g)	1800	1810	1780	1845	1820
Wt of bottle. + H_2O = C (g)	1470	1470	1470	1470	1470
Oven dry sample wt. = D (g)	485	505	435	550	515

Table 4.5: Contd.

$$SPECIFIC\ GRAVITY\ ON\ \ SSD\ BASIS = \frac{A}{A-(B-C)}$$

$$S.G = \frac{2685}{2685-(9058-7350)} = 2.7$$

Average specific gravity of Quarry Dust is 2.7.

Table 4.6:SPECIFIC GRAVITY TEST RESULT FOR COARSE AGGREGATE (5 SAMPLES)

Sample ID	Weight (*g*)				
	Sample A	Sample B	Sample C	Sample D	Sample E
X	445	445	445	445	445
K	1335	1245	1220	1285	1330
A	890	800	775	840	885
B	2020	1980	1965	1970	2015
C	1465	1465	1465	1465	1465

Specific gravity on SSD basis

$$A = \frac{A}{A-(B-C)}$$

$$Average = \frac{2.66 + 2.81 + 2.82 + 2.67 + 2.64}{5} = 2.72$$

The laboratory tests results on the aggregates and concrete samples are presented and analyzed in this chapter. It is represented by the use of line graph, tables and histograms to aid visualization.

Table4.7A: WATER ABSORPTION TEST RESULT FOR CONCRETE SAMPLES

S/N	Test Parameters	Sample TCM 1	Sample TCM 2	Sample TCM 3	Sample TCM 4	Sample TCM 5	Sample TCM 6	Sample TCM 7	Sample TCM 8	Sample TCM 9	Sample TCM 10
1	Wet-weight (After 24 hrssoaking) gm	9.200	9.400	9.300	9.150	9.320	8.200	9.300	8.600	9.300	9.700
2	Weight oven dry sample gm	8.800	9.100	9.150	8.800	9.600		8.90	8.400	9.000	9.000
3	Weight of water absorbed gm	0.4	0.3	0.15	0.35	0.28	0.4	0.40	0.20	0.70	0.80
4	**Natural absorption by weight =** $\frac{wet-Wt-Dry-Wt}{Dry-Wt}$ x 100 %	4.50	3.30	1.60	3.90	3.00	0.48	4.49	2.4	7.77	8.88

S/N	Test Parameters	Sample	Sample	Sample	Sample	Sample	Sample	Sample	Sample	Sample	Sample

Table 4.7A: Contd.

		TCM 11	**TCM 12**	**TCM 13**	**TCM 14**	**TCM 15**	**TCM 16**	**TCM 17**	**TCM 18**	**TCM 19**	**TCM 20**
1	Wet-weight (After 24hrs soaking) gm	9.900	9.200	9.000	8.500	9.400	9.000	9.200	8.600	9.800	8.400
2	Weight oven dry samplegm	9.000	8.800	8.500	8.000	9.000	8.400	8.600	8.000	9.000	8.200
3	Weight of water absorbedgm	0.90	0.40	0.5	0.5	0.44	0.6	0.6	0.6	0.80	0.20
4	**Natural absorption by weight =** $\frac{\text{wet}-\text{Wt}-\text{Dry}-\text{Wt}}{\text{Dry}-\text{Wt}}$ x 100 %	10.00	4.54	5.88	6.25	4.44	7.14	6.98	7.50	8.89	2.43

Table 4.7A: Contd.

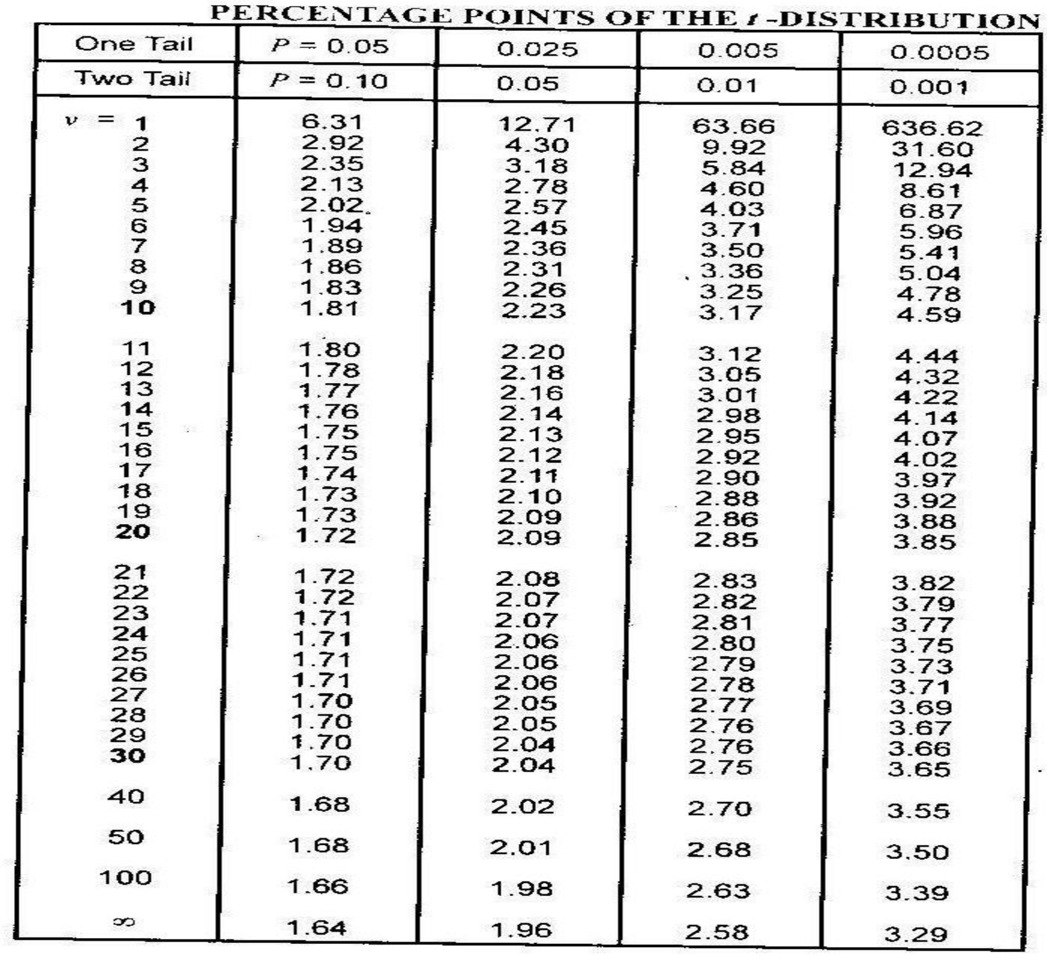
S/N	**Test Parameters**	**Sample TCM 21**	**Sample TCM 22**
1	Wet-weight (After 24hrs soaking) gm	9.000	8.500
2	Weight oven dry sample gm	8.900	8.300
3	Weight of water absorbed gm	0.10	0.20
4	**Natural absorption by weight =** $\frac{\text{wet}-\text{Wt}-\text{Dry}-\text{Wt}}{\text{Dry}-\text{Wt}}$ x 100%	1.12	2.41

Table 4.23:EFFECT OF DIFFERENT PERCENTAGE REPLACEMENT OF SAND WITH QUARRY DUST ON COMPRESSIVE STRENGTH, SLUMP AND DENSITY OF CONCRETE

S/N	Cement	w/c ratio	Rivers sand	Quarry Dust	Coarse Aggregate	% age Q/D	Strength (N/mm^2)	Slump (cm)	Density
1	1	0.6	2.7	0	3.5	0.0	31.00	2.08	2.59
2	1	0.6	2.1	0.6	3.5	23.9	35.50	1.13	2.702
3	1	0.55	2.0	0.4	3.2	16.1	33.70	1.26	2.713
4	1	0.50	1.5	0.7	2.9	26.5	35.00	1.00	2.624
5	1	0.5	2.0	0.2	2.9	4.1	31.70	1.35	2.61

4.2.1 Effect of partial replacement of sand with quarry dust on the Compressive strength of Concrete.

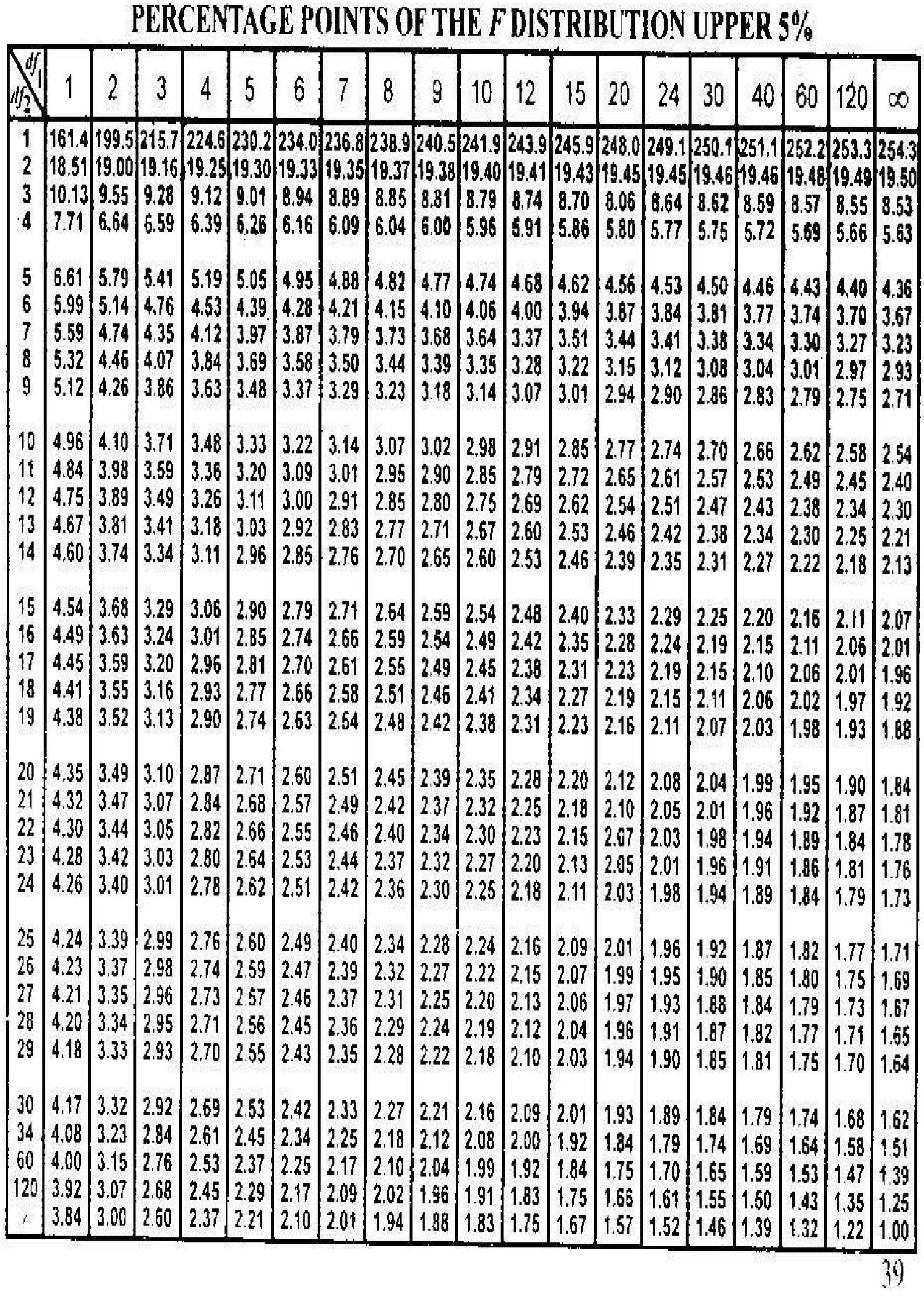
Table 4.24 : T TABLE



PERCENTAGE POINTS OF THE t-DISTRIBUTION

One Tail	$P = 0.05$	0.025	0.005	0.0005
Two Tail	$P = 0.10$	0.05	0.01	0.001
ν = 1	6.31	12.71	63.66	636.62
2	2.92	4.30	9.92	31.60
3	2.35	3.18	5.84	12.94
4	2.13	2.78	4.60	8.61
5	2.02	2.57	4.03	6.87
6	1.94	2.45	3.71	5.96
7	1.89	2.36	3.50	5.41
8	1.86	2.31	3.36	5.04
9	1.83	2.26	3.25	4.78
10	1.81	2.23	3.17	4.59
11	1.80	2.20	3.12	4.44
12	1.78	2.18	3.05	4.32
13	1.77	2.16	3.01	4.22
14	1.76	2.14	2.98	4.14
15	1.75	2.13	2.95	4.07
16	1.75	2.12	2.92	4.02
17	1.74	2.11	2.90	3.97
18	1.73	2.10	2.88	3.92
19	1.73	2.09	2.86	3.88
20	1.72	2.09	2.85	3.85
21	1.72	2.08	2.83	3.82
22	1.72	2.07	2.82	3.79
23	1.71	2.07	2.81	3.77
24	1.71	2.06	2.80	3.75
25	1.71	2.06	2.79	3.73
26	1.71	2.06	2.78	3.71
27	1.70	2.05	2.77	3.69
28	1.70	2.05	2.76	3.67
29	1.70	2.04	2.76	3.66
30	1.70	2.04	2.75	3.65
40	1.68	2.02	2.70	3.55
50	1.68	2.01	2.68	3.50
100	1.66	1.98	2.63	3.39
∞	1.64	1.96	2.58	3.29

Table 4.25: Fisher Table



PERCENTAGE POINTS OF THE *F* DISTRIBUTION UPPER 5%

df_2 \ df_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	19.46	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	8.06	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.64	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	3.37	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
34	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

APPENDIX B

Computer Program 0for Predicting Compressive Strength, Density and Slump of Sand-Quarrydust Concrete

```
10 REM "POLYNOMIAL EQUATION USING 5 BY 5 MATRIX@
20 REM"VARIABLES USED"
30 REM"Z1,Z2,Z3,X1,X2,X3,YMAX,YOUT,YIN"
40 REM"BEGIN MAIN PROGRAM"
50 LET Count = 0
60 CLS
70 GOSUB 100
80 END
90 REM"END MAIN PROGRAM"
100 REM"PROCEDUR BEGIN"
110 LET YMAX = 0
120 PRINT
130 PRINT
140 PRINT "COMPUTER PROGRAM OF CONCRETE MIX"
150 PRINT "CORRESPONDING TO DESIRE STRESS"
160 PRINT "BY ENGR. V EZUGU"
170 PRINT
180 INPUT "ENTER DESIRE STRESS"; YIN
190 GOSUB 400
200 FOR X1 = 0 TO 1 STEP .01
210 FOR X2 = 0 TO 1 - X1 STEP .01
220 FOR X3 = 0 TO 1 - X1 - X2 STEP .01
225 FOR X4 = 0 TO 1 - X1 - X2 - X3 STEP .01
230 FOR X5 = 0 TO 1 - X1 - X2 - X3 - X4 STEP .01
240 LET YOUT = ((30.8 * X1) + (32.4 * X2) + (34.53 * X3) + (42 * X4) + (44.7 * X5) -
(5.2 * X1 * X2) - (7.46 * X1 * X3) - (15.6 * X1 * X4) - (24.2 * X1 * X5) + (2.94 * X2 * X3)
- (5.6 * X2 * X4) - (19.52 * X2 * X5) - (11.06 * X3 * X4) - (25.26 * X3 * X5) + (9.8 * X4 *
X5))
250 GOSUB 500
260 IF (ABS(YIN - YOUT) <= .001) THEN GOTO 270 ELSE GOTO 282
270 LET Count = Count + 1
280 GOSUB 600
282 NEXT X5
285 NEXT X4
290 NEXT X3
291 NEXT X2
292 NEXT X1
295 PRINT "THE POLYNOMIAL OUTPUT IS"; YOUT
300 IF (Count > 0) THEN GOTO 310 ELSE GOTO 340
310 PRINT "THE MAXIMUM VALUE OF STRESS IS"; YMAX; "N/SQ.MM"
320 SLEEP (2)
330 GOTO 360
340 PRINT "SORRY DESIRE STRESS OUT OF RANGE"
350 SLEEP 2
```

```
360 RETURN
400 REM"PROCEDURE PRINT HEADING"
410 PRINT
420 PRINT "COUNT X1 X2 X3 X4 X5 Y Z1 Z2 Z3 Z4 Z5"
430 PRINT
440 RETURN
500 REM PROCEDURE CHECKMAX
510 IF YMAX < YOUT THEN YMAX = YOUT ELSE YMAX = YMAX
520 RETURN
600 REM PROCEDURE OUTRESULTS
601 Z1 = 1
611 LET Z1 = 1 * X1 + 1 * X2 + 1 * X3 + 1 * X4 + 1 * X5
620 LET Z2 = .6 * X1 + .6 * X2 + .55 * X3 + .5 * X4 + .5 * X5
630 LET Z3 = 2.7 * X1 + 2.1 * X2 + 2 * X3 + 1.5 * X4 + 2 * X5
635 LET Z4 = 0 * X1 + .6 * X2 + .4 * X3 + .7 * X4 + .2 * X5
640 LET Z5 = 3.5 * X1 + 3.5 * X2 + 3.2 * X3 + 2.9 * X4 + 2.9 * X5
650 PRINT TAB(1); Count; USING "####.###"; X1; X2; X3; X4; X5; YOUT; Z1; Z2; Z3;
Z4; Z5
660 RETURN
670 PRINT "OUTPUT"
```