

**EFFECT OF WATER-CEMENT RATIO ON
PROPERTIES OF NORMAL CONCRETE
(Using 19.50 mm maximum size granite aggregates)**

BY

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(PGD/CIVIL/2009/058)**

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ENGINEERING.**

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DECLARATION

I hereby declare that this thesis titled: Effect of water-cement ratio on the properties of normal concrete (using 19.50 mm maximum size aggregates), is a collection of my original research work and it has not been presented for any other qualification anywhere. Information derived from other sources (published and unpublished) has been duly acknowledged.



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CERTIFICATION

This is to certify that this thesis titled: Effect of water-cement ratio on the properties of normal concrete (using 19.50 mm maximum size aggregates) by IKEKPEAZU, Augustine Chibueze Reg. no PGD/CIVIL/2009/058, meets the regulations governing the award of PGD in Civil Engineering of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This project work is specifically dedicated to Almighty **GOD** for his mercy, loving kindness and favour bestowed upon me throughout my period of studies and to Nne Ikekpeazu [ACCA] – first among equals, RoseMary Asabe Musa who set the ball rolling for this course to be possible along with my other dear children – Engr. Gloria [B Eng, MNSE], Emeka, Ebere, Ladidi, Dr. Chinenye [MBBS], Uju [BSc], Chizzy, and Chisom.

May the almighty GOD pay them for their contributions and patience, endurance and cause them to eat from the fruit of their labour and sacrifice in **JESUS** name. Amen.

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ABSTRACT

The main purpose of this work is the investigations of the effect of water cement ratio on the properties of normal concrete using coarse aggregates of 19.50 mm maximum size. In all, thirty three concrete cubes were prepared, three each of different water cement ratios in the range of 0.40-0.60 while keeping the other concrete mix ingredients constant. The mix ratio adopted was 1:2:4, the cubes were cured for 28 days and were subsequently crushed to determine the compressive strength at the various water cement ratios. Other major tests conducted here are: Sieve analysis of the aggregates, Slump & Density test. Test results shows that an increase in water-cement ratio leads to an increase in the workability of concrete. Also an increase in water-cement ratio between 0.4 and 0.5 leads to an increase in compressive strength and density. An increase in water cement ratio in the range 0.5 – 0.6 leads to a decrease in compressive strength and density. The work provides a data bank for concrete properties within the limit of the scope considered in this work.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Concrete, a structural material (renowned for its compressive strength) is made by man from a mixture of natural materials – water, aggregates and cement which is also manufactured by man from natural occurring materials. Concrete has been in use by man even before the time of the old Roman empires. The purpose to which concrete is used as a structural material varies from one situation to another (light weight, heavy duty, shielding to nuclear reactor facility, chemical and salt resisting, etc) hence its strength in comparison with the proportion of the basic constituents and other inherent characteristics are predetermined in a process of design to produce concrete to the required properties, taking the economics of production into consideration. The task therefore is optimally designing a concrete mix consists of selecting suitable ingredients of the concrete and determining their correct proportions of the cement, fine and coarse aggregates and water to produce concrete having the specified properties (Neville & Brooks, 1987).

When water is added to the mixture of cement and aggregates (fine and coarse), hydration of cement takes place. This will cause the entire mixture to set homogenously and when hardened, forms a solid rock like mass known as concrete. According to Elices & Rocco (2008) in their write up on the effect of aggregate size on the fracture and mechanical properties of a simple concrete it is well known that the concrete strength is influenced by the ratio of mixing water, the ratio of cement to aggregates the bond between mortar and aggregates and the grading, shape, strength and size of the aggregate. The influence of water-cement ratio and to some extent, the aggregate size is the subject matter of this project.

The volume of water used in the mix should be such needed to ensure full hydration of cement and the full lubrication of the concrete constituents which makes the concrete workable. The excess

water left in the paste after hydration remains free and is redistributed in the paste and whole mass. This excess water (which must be kept to a minimum) is to enhance workability in concrete batching, placement and compaction.

In determining the total water cement ratio, the total mass of water absorbed by the aggregates in the batch is added to the volume of water introduced during the mixing. The total water-cement ratio is the total mass of water to the total mass of cement in the mix, hence when deciding how much water that is required, allowance must be made for the absorption by the dry and porous aggregates and for the free surface of water.

There are 2 types of aggregates used in concrete manufacturing – fine and coarse aggregates. The coarse aggregates compose mainly of gravel, crushed rock or granite, broken bricks, air cooled blast furnace slag, kennel shells etc while the fine aggregates are composed of sand and weathered rock. Each type of coarse aggregate also contributes to the special properties of concrete already predetermined.

The properties of coarse aggregates (which constitute the largest percentage of concrete constituents) is however affected by many factors such as shape and texture, strength, toughness, hardness, specific gravity, bulk density, porosity and absorption, moisture content; chemical reactivity, elastic modulus and thermal characteristics. These properties also control the concrete properties mainly specified thus:

- (i) Workability for fresh concrete
- (ii) The compressive strength at any specified age,
- (iii) The density and durability of the hardened concrete.

If the percentage of water used is less than sufficient, there will not be enough water for the cement hydration process. It will result in weak and porous concrete. If on the other hand too much water is used, it will result in segregation of the aggregates and bleeding which gives porous concrete of low strength, low density and poor durability.

Because the strength of concrete is significantly and adversely affected by the presence of voids in the compacted mass, it is vital to reduce these voids and achieve maximum possible density. This requires sufficient workability for virtually full compaction to be possible using a reasonable amount of work under given conditions. The presence of voids in concrete reduces its strength to the extent that 5% of voids can lower the strength of concrete by as much as 30%. The volume of voids in hardened concrete due to spaces left after excess water has been removed depends solely on the water-cement ratio of the mix.

The porosity of the aggregates affects both fresh and hardened concrete. The volume of void in hardened concrete due to bubbles of entrapped air is dependent on the grading of the fine aggregates. A uniformly graded aggregate has fewer voids unlike gap graded aggregates. This is an important fact in concrete mix design. This project deals with the analysis of the effects of water-cement ratio on the properties of normal concrete (here, we are talking about concrete with cement content of 350 kg/m³) especially the slump, density and compressive strength at 28 days using coarse aggregates of maximum size of 19.50 mm.

The compressive strength of concrete cured at a prescribed condition and temperature at a given age depends primarily on 2 factors only – the water-cement ratio and the degree of compaction (Rajput, 2008). The water-cement ratio is the ratio of water to cement in a concrete mix and is expressed as the ratio of the weight or ratio of volume of water to the weight or volume of cement in the concrete mix. Since the amount of water in the mix has a direct bearing on the compactibility and

workability of concrete hence the strength of the hardened concrete, there is need to study and ascertain the right quantity of water to use in a concrete mix to give the required maximum strength and other properties of the concrete.

1.2 AIM AND OBJECTIVES OF THE PROJECT.

The aim of this work is to determine the effect of water-cement ratio on the properties of normal concrete.

The objectives of this project work are to:

- (i) determine the physical properties of the mix composition of concrete.
- (ii) determine the properties (compressive strength, density, durability etc) of the concrete produced.

1.3 PROBLEM STATEMENT

1:2:4 mix is well known and mostly used in the construction of super structures in buildings. This mix ratio however, does not guarantee the target strength. The ingredients of concrete are variable and they in turn have effect on varying the properties of concrete such as slump and strength. The variation in the properties of concrete leads concrete mix proportioning adjustment and trial and error being done to come up with concrete of the designed strength.

1.4 SIGNIFICANCE OF THE STUDY

The most important property of concrete is the strength of the cured and hardened concrete. The major determinants of the strength are: the water-cement ratio and the degree of compaction. However, since the water-cement ratio also affects the degree of compaction, it follows that the water-cement ratio is of ultimate importance in the production of concrete hence the study of the effect of varied water-cement ratio on the other properties of normal concrete cannot be over emphasized.

In this work, concretes are produced at different water-cement ratios. This produces concrete of different properties. This work has the potential of producing a data bank of properties of concrete as a function of mix composition. This would be useful to the concrete community and users of concrete in deciding the appropriate mix ingredients required for specific job taking into cognizance the target strength.

1.5 SCOPE OF THE PROJECT

The scope of this project covers the following areas:

- (i) Procurement of cement (OPC) in 50kg bags, sampling, collection and grading of coarse and fine aggregates.
- (ii) Preparation of normal mix proportions of 1:2:4 mix using the graded aggregates.
- (iii) Performing slump and compaction factor tests of the various mixes.
- (iv) Preparation of cube samples (3No) each for the various mixes and curing same by submerging under water in a tank where they are left for 28 days.
- (v) Performing the compressive crushing strength tests on the samples after the curing period.

This research work does not cover the physical, mechanical and flexural strength properties of the materials, but performance of the concrete cubes at 28 days for each sample at the prescribed water-cement ratio.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concrete and its constituent materials

Concrete is a composite material made by man wherein a binding material (here ordinary Portland cement) is mixed with water and aggregates which on solidification, binds with the inert particles of well graded fine and coarse aggregates. The common cementing material used is cement. (Franklin & Cetrong 1975)

A number of cement types are available for use, some of these include ordinary Portland cement, blast furnace slag, high alumina cement, super sulphate cement among others but the most common and the one used in this project being the **Ordinary Portland cement (OPC)**.

Various types of aggregate are in use, the most common being the natural occurring sand and gravel. Manufactured aggregates are also used particularly those of low density, certain other aggregates are also used for special purposes such as the shielding for atomic or nuclear reactors.

Concrete is essentially a structural material and is used for a wide variety of purpose such as;

- (a) Foundation and structural elements.
- (b) Walling and cladding elements.
- (c) Light weight materials for insulation.
- (d) Construction of roads, piers and bridges, airfields, buildings, water retaining structures, dock yards, harbours and sea defences.

Special concrete properties will therefore be required to meet some special purposes. It follows therefore that various properties of concrete will be of interest to the engineer. These properties include strength at various ages and ultimate strength, density, permeability, durability, ability to resist various salts and other chemical attacks etc. Their relative importance depends on the use to

which the concrete is put to. Concrete is made through a mixture of water, binder (cement) and aggregates.

2.1.1 Water

Water is used to effect the chemical action in cement known as “hydration”. It is this action which causes the cement to set and harden. The quality of water used in concreting is therefore very important because impurities in water may interfere with and adversely affect the strength and other salient properties of the concrete including staining of its surface and the things it comes in contact with. It may also lead to the corrosion of the reinforcement used in the concrete with its attendant consequences. Hence the need for suitable water to be used in the production and curing of concrete cannot be overemphasized. Only good, clean water free from organic impurities should be used for concrete works. If stream water is to be used, care should be taken that it does not contain decaying, decayed and other organic matters.

In many cases, the quality of water is specified by indicating that water to be used must be water fit for drinking. Even then, portability of water as a reference standard is not absolute because even drinking water may sometimes be unsuitable for the production of concrete when such water has high concentration of sodium or potassium and there is the danger of alkali-aggregate reaction.

Sea water or any water containing large quantities of chlorides tend to cause persistent dampness and efflorescence. Such water should not be used where appearance of the finished concrete is of importance or where plaster finish is to be applied. In the case of reinforced concrete, sea water increases the risk of corrosion of the reinforcement. In rural areas, water from stream and pond may contain stagnant water, liquid manure, etc and should be regarded with suspicion and small trial mix of concrete should be tested before embarking on a larger mix with such water.

2.1.2 Cement

Cement can be defined in general terms as a material that has both cohesive and adhesive properties which enable it to effect strong bond with other mineral fragments to form a compact mass. The process of cement production is outside the scope of this project work. However, the basic materials for Portland cement manufacturing are the mixing together of calcareous and argillaceous or other silica, alumina and iron oxide bearing materials, burning them at a clinkering high temperatures and grinding the resulting clinker. From the above it can be seen that cement is made primarily from a combination of calcareous materials, such as limestone or chalk and of silica and alumina found in clay or shale. The process of manufacture consist essentially of grinding the raw materials into a very fine powder, mixing them intimately in predetermined proportion and burning them in a rotary kiln at a temperature of about 1400 degrees Celsius when the material sinters and partially fuses into clinker. The clinker is cooled and ground to a fine powder with gypsum added (to retard setting time), and the resulting product is the commercial Portland cement.

Table 2.1 Main compound and approximate percentage compositions in ordinary Portland cement (Neville and Brooks, 1987):

Name of compound	Oxide & % composition	Abbreviation
Tri-calcium silicate	3CaO.SiO ₂ (50%)	C3S
Di-calcium silicate	2CaO.SiO ₂ (25%)	C2S
Tri-calcium aluminate	3CaO.Al ₂ O ₃ (12%)	C3A
Tetra-calcium alumino-ferrite	4CaO.Al ₂ O ₃ .Fe ₂ O ₃ (8%)	C4AF
Gypsum	CaSO ₄ .H ₂ O (3.5%)	CSH ₂

In addition to the above, there exists other minor compounds like MgO, TiO₂, Mn₂O₃, K₂O and Na₂O; they usually amount to a few percent of the cement mass.

Tri-calcium silicate hydrates and hardens very quickly the more of it present in cement, the better. Cement having lesser aluminates shall have less initial strength but a higher ultimate strength. Tetracalcium alumino ferrite also hydrates very rapidly but contributes very little to the ultimate strength. For construction purpose, the meaning of cement is restricted to the bonding material used with stones, sand, brick, building block etc.

2.1.2.1 Types of cement

Different types of cement are manufactured with the addition of some additives in the course of production to suit the various predetermined specific requirements. Some of the different types of cement resulting from the addition of those additives are:

1. Ordinary Portland cement.
2. Rapid hardening Portland cement.
3. Portland blast furnace cement.
4. Low heat Portland cement.
5. High Alumina cement.
6. Sulphate resisting Portland cement.
7. Coloured cement.
8. Air entraining Portland cement.
9. Portland pozzolana cement.

Ordinary Portland cement: Ordinary Portland cement is the most common type of cement having medium rate of strength development and heat evolution. It is suitable for normal concrete work.

Rapid hardening Portland cement: This cement gains strength faster than ordinary Portland cement. Its initial and final setting times are the same as those of ordinary Portland cement. It contains more tri-calcium silicate and is more finely ground. It gives out more heat while setting and is as such

unsuitable for mass concreting. It is used for such structures as are to be subjected to early loads like in the repair of roads and bridges.

Portland Blast furnace cement: Portland blast furnace cement has very similar properties to ordinary Portland cement but evolves less heat and it is highly more resistant to chemical attack. It is made by grinding a mixture of cement clinker, gypsum and blast furnace slag in proper proportions and grinding it finely. This cement can advantageously be used in marine works; Manufacture of Portland slag cement is aimed primarily at profitably utilizing blast furnace slag – a waste product from the production of iron in blast furnace.

High Alumina Cement: It is manufactured by fusing together, a mixture of bauxite and limestone in correct proportions and at high temperatures. The resulting product is finely grounded. It develops strength rapidly. It is black in colour and resists well, the attack of chemicals especially of sulphates and sea water. The ultimate strength is much higher than that of ordinary Portland cement. Its initial setting time is more than two hours. It is the most expensive of all cement. It is used extensively for refractory purposes – to line the furnace where moderately high temperature is likely to be encountered.

Low heat Portland cement: Heat generation by cement while setting may cause cracks in structures. In the case of concrete, heat generation is controlled by keeping the percentage of tri-calcium silicate low. Its initial and final setting times are nearly the same as those of ordinary Portland cement but the rate of its development of strength is very slow. It is used for large dam and other structures of mass concrete construction where there is danger of high temperature building up inside the concrete works.

Sulphate resisting Portland cement: Sulphate resisting Portland cement is very similar to ordinary Portland cement but as its name implies, has a much higher resistance to sulphate attack. In certain soils, there exist concentrations of sulphate chemical which will cause concrete made with ordinary Portland cement to crumble. Where such condition exists, the concrete in contact with the soil should be made with high alumina cement or with sulphate resisting Portland cement.

Air entraining Portland cement: This is ordinary Portland cement mixed with small quantities of air entraining materials at the time of grinding. These materials have the property of entraining air in the form of air bubbles in concrete. These bubbles render the concrete more plastic, more workable and more resistance to freezing. However, because air entraining, the strength of concrete reduces and as such the quantity of air so entrained should not exceed five percent.

Coloured cement: For architectural purposes, white concrete, or particularly in tropical countries, a pastel colour paint finish is sometimes required. For this purpose, white or coloured cement is used. It is also used because of its low content of soluble alkalis so that straining is avoided. Coloured cement is made from china clay which contains little iron oxide and manganese oxide together with chalk or limestone free from specified impurities.

Portland Pozzolana Cement: Portland pozzolana cement is produced either by grinding together Portland cement clinker and pozzolana or by intimately and uniformly blending Portland cement and fine pozzolana. This cement has properties similar to those of ordinary Portland cement and can therefore be used for all general purposes where the latter is employed with no change of proportion of fine or coarse aggregates and cement. Gypsum is added in both cases.

Portland pozzolana cement produces less heat of hydration and offer greater resistance to chemical attack. It takes little longer to gain strength. The ultimate strength of this cement is more than that of ordinary Portland cement but the initial and final setting times are the same.

2.1.2.2 Properties of cement.

Because the quality and properties of cement is vital for the production of good concrete, the following properties of cement are usually tested in the laboratory to ascertain the level of acceptability though no such test was carried out in this project:

- (a) **Setting time:** There are two setting times – initial and final setting times. Initial setting time indicates the beginning of noticeable stiffening of the fresh concrete. The final setting time on the other hand indicates the point from which the paste starts to harden and gain strength. Broadly speaking, setting refers to a change from fluid to a rigid state. It is mainly caused by selective hydration of C3A and C3S and is accompanied by temperature rise in the paste. These setting times should be distinguished from false set which occurs within a few minutes of mixing the cement with water.
- (b) **Soundness:** the soundness of cement refers to its ability to maintain a constant or consistent volume. Unsoundness occurs in cement by delayed or slowed hydration or the presence of free lime in hardened cement. The presence of magnesium or calcium sulphate which expands under restrained conditions can lead to destruction of hardened cement paste. The soundness of cement refers to its ability or otherwise to maintain a constant volume.
- (c) **Fineness:** Since hydration starts at the cement particles, it is the total surface area of cement that represents the material available for hydration. Thus the rate of hydration depends on the fineness of the cement particles and for a rapid development of strength, a high degree of fineness is necessary. However, the cost of grinding on the other properties like workability of fresh concrete must be borne in mind. Finer cement promotes stronger reaction with alkali reactive aggregates to produce a paste exhibiting a higher shrinkage and is liable to more cracking. The fineness of cement is specified in terms of specified surface, which is

the calculated surface area of the particles in square centimetre per gram of cement (cm^2/g).

A control of the fineness will help keep its properties uniform.

- (d) **Strength:** Strength tests are not carried out on neat cement paste because of difficulties in obtaining good specimen and in testing with a consequent large variability of test results. Cement sand mortar and in some cases, concrete of prescribed properties made with specified materials under strictly controlled conditions are used for the purpose of determining the strength of concrete. The strength of mortar or concrete depends on the cohesion of concrete paste and its adhesion to the aggregates.

2.1.3 Aggregates

Aggregates are the non-cementitious particles such as natural sand, gravel, crushed rock or a combination of these materials which are mixed with cement and water to produce concrete. Aggregate constitute the bulk of the volume of concrete and influence its main properties like strength and shrinkage. The properties of aggregates greatly affect the durability and confer considerable technical advantages of dimensional stability and better durability than the cement paste alone.

The characteristics of concrete aggregates include uniformity, specific gravity, grading, and resistance to weathering, frost action, liability to oxidation and hydration and coefficient of thermal expansion.

2.1.3.1 Classification of Aggregates.

Depending upon the size and grading of their particles, aggregates can be classified as fine, coarse, all in and cyclopean aggregates. Aggregates can also be classified according to the intended concrete properties and use like heavy weight, light weight concrete etc.

- 1) Fine aggregates: all that Particles of aggregates pass through the 4.75mm mesh and are entirely retained on the 0.15mm mesh are referred to as fine aggregates. Most commonly used fine aggregates are sand and crushed stones. Sand consists of small grain of silica and is formed by the disintegration of rocks caused by weather. Depending on the source from which sand is obtained, it is classified as; (i) Pit or quarry, (ii) River and (iii) Sea sand.

The following are the qualities of good sand for concrete production purposes:

- (a) Good sand should have coarse and angular grains of pure silica.
- (b) The grain of sand should be hard, strong and durable.
- (c) It should be free from silt, clay and salts.
- (d) It should be well graded, in other words, it should contain suitable proportion of all the various sizes.
- (e) It should not contain any organic or hygroscopic matter.

Quickly, the suitability of sand for being used in concrete, it may be subjected to the following tests:

- (i) Rub a little sand between the fingers; stain left on fingers will indicate presence of undesirable clay or silt impurities.
 - (ii) Taste of sand shall provide a suitable check for the presence of salts.
 - (iii) Vigorously stir a sample of sand in a glass of water and allow it to rest. Amount of clay or silt present in it will settle on the sand.
- 2) Coarse Aggregates: This is an aggregate that contains high proportion of large particles ranging from 4.75mm to 75mm. The various types and sources of coarse aggregates used in Nigeria are as follows:
 - (i) Gravel: They are obtained from riverbeds, quarries and seashore. It is hard and durable. They are extensively used as coarse aggregates in concrete work.

- (ii) Stone Ballast: Stone that are free from undesirable mineral constituents are broken to stone ballast used in concrete production. It is a excellent coarse aggregate. It should be free from organic matter before being used.
 - (iii) Brick Ballast: It is reasonably a good substitute for stone aggregate when available in sufficient quantity. It is used as coarse granite in concrete where aggregates from natural resources are not available or expensive. It can also be used in places where lower strength is required or where it is exposed to less severe conditions of service. The brick ballast should be free from dust and also be thoroughly saturated with water before usage in concrete works.
 - (iv) Lateritic Rock: The lateritic rocks are those in which laterization is the dominant soil formation process. The process of their formation is through the leaching silica under hot and moist condition. They are residual soil from tropical regions.
 - (v) Granite: These are the most common and are also be obtained from quarries. They are hard, strong and durable. They are used extensively as coarse aggregates when making normal concrete. They should be free from impurities such as clay, salts.
 - (vi) All in aggregates are those that have the fine and coarse aggregates grouped together.
- 3) Cyclopean Aggregates: These are special aggregates whose size range from 7.5cm – 15cm. They are used for special foundation works.

Concrete aggregates can also be classified under the following heading:

- 1) Heavy weight: These may be defined as those having high specific gravity (usually high density concrete for radiation shielding construction of biological shield and for concrete counter weight. They include barites (barium sulphate) and steel shots.
- 2) Normal weight: The normal weight aggregates are the aggregates which have specific gravity of between 2.50 and 3.00 and bulk density in the range of 1450 to 1750kg/m³.

- 3) Light weight concrete: These are either natural or man made porous aggregates used for the production of light weight concrete. The light weight aggregates have lower thermal conductivity, density and strength.

Crushed granites whose sizes range from 4.75mm to 19.50mm are the coarse aggregates used in this project work.

2.1.3.2 Properties of Aggregates:

The properties of aggregates known to have significant effect on quality of concrete are its bond, strength, dimensional stability, durability, toughness, volume change, specific gravity, bulk density, porosity and moisture content.

- a) Bond: Both the shape and surface texture of aggregate influence considerably, the strength of concrete. Especially so for high strength concrete, flexural strength is more affected from compressive strength. A rough texture results in greater adhesion or bond between the particles and the cement matrix. Likewise the larger surface area of a more angular aggregate provides a greater bond. Generally, when the bond is good, a crushed specimen should show some aggregate particles broken right through, in addition to the more numerous ones separated from the paste matrix.
- b) Strength: Clearly, the compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. A few weak particles can certainly be rated; after all, air voids can be viewed as aggregate particles of zero strength. The required information about the aggregate particles has to be obtained from indirect tests: crushing strength of prepared rock samples, crushing value of bulk aggregate and performance of aggregate in concrete. The latter simply means either previous experience with the given aggregate or a trial use of the aggregate in a concrete mix known to have certain strength with previously proven aggregates.

- c) **Toughness:** Toughness can be defined as the resistance of aggregate to failure by impact, and it is usual to determine the aggregate impact value of bulk aggregate. Full details of the prescribed tests are given in BS 812: part 112 of 1990. The apparatus for the test is portable, cheap and simple to operate and it is rapid in application. It can be used in the field for quality control purposes. This property is mostly used in road pavement works.
- d) **Hardness:** Hardness or resistance to wear is an important property of aggregate used in roads and floor surfaces subjected to heavy traffic. The aggregate abrasion value of the bulk aggregate can be assessed using BS 812 part 113 of 1990. Aggregate particles between 14.0 and 20.0 mm are made up in a tray in a single layer, using a setting compound. The sample is subjected to abrasion in a standard machine. The aggregate abrasion value is defined as the percentage loss in mass on abrasion so that a high value denotes a low resistance to abrasion.
- e) **Durability:** This is the resistance of concrete to weathering, chemical attack, abrasion, frost and fire. It depends largely on the quality of mineral composition of the aggregate.
- f) **Volume Change:** Volume changes due to limestone movement in aggregate derived from sand stones and sand basalts may result in considerable shrinkage of concrete. If the concrete is restrained, it will produce internal tensile stresses thereby causing tensile cracking and subsequent deterioration of the concrete. If the coefficient of thermal expansion of the aggregate differs considerably from that of cement paste, it will cause cracking that may adversely affect the concrete performance.
- g) **Specific Gravity:** This is the ratio of the unit weight of the aggregate to the unit weight of water. The specific gravity affects the density of the resulting concrete. BS 812: part 107 uses the term particle density for the specific gravity or relative density. If the mass of the oven dried sample is D, the mass of the vessel full of water is C, and the mass of the vessel with the sample topped with water is B, then the mass of water occupying the same volume

as the liquid is D-(B-C). The apparent specific gravity or relative density is then: given as $RD = D/[D-(B-C)]$.

- h) Bulk Density: The bulk density of an aggregate is the ratio of the total mass or weight of aggregate to the volume disregarding the voids. The absolute density refers to the volume of the individual particles only, and of course it is not physically possible to pack these particles so that there are no voids between them. Thus when aggregate is to be batched by volume, it is necessary to know the bulk density which is the actual mass that would fill a container of unit volume and this density is used to convert quantities by mass to quantities by volume. The bulk density depends on how density of the aggregate is packed and consequently the size distribution and shape of the particles. BS 812 part 2: 1975 recognises two degrees of density; loose and compacted bulk density.
- i) Porosity: Porosity of aggregate affects the quality of both fresh and hardened concrete. The porosity, permeability and absorption of aggregate influence the bond between it and the cement paste, the resistance of concrete to freezing and thawing as well as chemical stability, resistance to abrasion and specific gravity.
- j) Moisture content: Since absorption represents the water contained in the aggregate in a saturated, surface dry condition, we can define the moisture content as the water in excess of the saturated surface dry condition. Thus the total water content of a moist aggregate is equal to the sum of the absorption and moisture content. The moisture content must be allowed for in the calculation of batch quantities and of the total water requirement of the mix. In effect, the mass of water added to the mix has to be decreased and the mass of aggregate must be increased by an equal amount of the moisture content. BS 812: part 109: 1990 prescribed the following method for determination of moisture content. If A is the mass of an airtight container, B the mass of the container and sample, and C the mass of container and sample after drying to a constant mass, the total moisture content (percent) of the dry mass of aggregate is given by; $M.C = (B-C)/(C-A)*100\%$

2.2 PROPERTIES OF CONCRETE.

2.2.1 Workability: workability can be defined as the amount of useful internal work necessary to produce full compaction. It is the ease with which concrete can be placed and compacted. Workability of concrete increases with the addition of water but it reduces the strength and as such it is not a very desirable way of increasing workability. Use of aggregates which are round and have smooth surface increases the workability. Slump test gives idea of only the flowing property of wet concrete and not of workability. Workability of concrete is better determined by compaction factor test.

2.2.2 Shrinkage: Shrinkage takes place principally in the cement paste as concrete dries. The amount of shrinkage depend on the amount of water added to the mixture, the cement content, the maximum size of the aggregate, its shape, grading and cleanliness. The lower the water content the lower the shrinkage.

2.2.3 Segregation: Segregation can be defined as the separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform. In this case of concrete, it is the differences in the size of particles (and sometimes in the specific gravity of the mix constituents) that are the primary cause of segregation, but its extent can be controlled by the suitable grading and by care of handling. Other causes of segregation are due to excess water in the mix and over compaction.

2.2.4 Bleeding: Bleeding is the separation water from the mix as a result of the natural tendency for solid particles depending on the size and specific weight to exhibit a down ward movement. It is known as water gain, it is a form of segregation in which some water in the mix tends to rise to the surface of freshly placed concrete. This caused by the inability of the solid constituents of the mix

to hold all the mixing water when they settle downwards. When the cement paste has stiffened sufficiently, bleeding of concrete ceases.

2.2.5 Density: It is common to determine the density of a compacted fresh concrete when measuring workability or the air content. Density is easily obtained by weighing the compacted fresh concrete in a standard container of known volume and mass. BS 1881: part 107: 1983 describe the procedure. If the density, D^* , is known, the volume of concrete can be found from the mass of the ingredients. When these are expressed as quantities in one batch put into the mixer, we can calculate the yield of concrete per batch. Let the masses of per batch of water, cement, fine aggregate and coarse aggregate be, respectively, W , C , A_f , and A_c . Then, the volume of the compacted concrete obtained from one batch is: $V = (C + A_f + A_c + W) / D^*$

Also, the cement content (mass of cement per unit volume concrete) is $C/V = D^* - (A_f + A_c + W) / D^*$

2.2.6 Durability: Durability of concrete is the property of concrete to withstand alternative weather conditions of wetness, dryness and frost.

2.2.7 Strength: Strength of concrete is commonly considered to be the most valuable property. Strength of concrete usually gives overall picture of the quality of concrete because it is directly related to the structure of the cement paste. The strength of concrete is usually measured in 7, 14, and 21 and 28 days respectively after it has been cast and thoroughly cured. The compressive strength of concrete is its ability to withstand squeezing and crushing forces. Flexural strength is the ability to withstand bending and resulting tension.

2.3.2 Mixing of concrete: Mixing can be manual or mechanical. The mechanical mixing operation consists essentially of rotation and stirring, the objective being to coat the surface of all the aggregate particles with cement paste and to blend all the ingredients of concrete into a uniform and homogeneous mass, this uniformity must not be disturbed during the process of discharging from the mixer.

The usual type of mechanical mixer is a batch mixer, which means that one batch of concrete is mixed and discharged before any more materials are put into the mixer. There are four types of mechanical mixers as follows:

- a. Tilting drum mixer.
- b. Non tilting drum mixer
- c. Dual drum mixer and
- d. Pan type mixer

In manual or hand mixing (for very small projects), the measured quantities of fine and coarse aggregates are placed on a platform or a layer of lean concrete worked to a flat surface. The measured cement is placed on the fine aggregate and mixed together to obtain even colour with the aid of shovel. The measured coarse aggregate is then spread evenly on the already mixed and spread sand and cement. Water is then added and the whole mixed with shovel into a plastic state without being too wet.

2.3.3 Mixing time: On site, there is often a tendency to mix concrete as rapidly as possible and hence, it is important to know the minimum mixing time necessary to produce a concrete of uniform composition and consequently of reliable strength. The optimum mixing time depends on the type and size of mixer, on the speed of rotation, and on the quality of blending of ingredients during charging of the mixer. Generally a mixing time of less than 1 or 1.25 minutes produce appreciable non uniformity in composition and significantly lower strength. In manual mixing, we talk about the number of turnings which should range from 4 to 6 turnings. Here we used six.

Table 2.3 below, gives recommended minimum mixing times for various capacities of mixers.

Capacity of mixer (m3)	Mixing time (minutes)
0.8	1
1.5	1.25
2.3	1.5
3.1	1.75
3.8	2
4.6	2.25
7.6	3.25

2.3.4 Conveyance of concrete

There are many methods of conveying concrete from the mixing point to where it is placed. Whatever may be used, it must ensure that the concrete is quickly and cheaply transported and that it does not change in proportion during drying out, by segregation or by bleeding. Some of the means by which concrete are being conveyed from the batching point to the point of placement are:

- 1) By the use of wheel barrows,
- 2) By steel skips and buckets,
- 3) By lorries,
- 4) By pipelines,
- 5) By cranes and even
- 6) By monorail transporters

2.3.5 Placing concrete

After mixing the concrete with water it should be used up within 30 minutes otherwise the initial setting of cement starts. Concrete should be properly placed to ensure that it can be well compacted into a homogeneous mass. For uniform result, the operation should be directed by an experienced

supervisor. Improper placing results in serious defects such as segregation, bleeding and honeycombing.

2.3.6 Compaction of concrete

The process of compacting concrete by vibration consists essentially of elimination of entrapped air and forcing the particles into a closer and denser configuration. Both compaction by hand and compaction by vibration can produce good quality concrete with the right mix, skill and workmanship. Adequate compaction increases the density of concrete and also prevents abrasion in concrete structures.

2.3.7 Curing of concrete

The condition under which concrete is allowed to set and harden after being placed and compacted in formwork is referred to as curing. After concrete has been placed and compacted, the construction cannot be regarded as finished until a period of time has elapsed to allow the concrete to reach a suitable strength. This can only be possible if the curing conditions after placing are suitable to allow strength to develop properly.

Control of curing conditions must be properly exercised to achieve the desired result. The conditions to be controlled are those which have effect on the hydration of concrete namely, temperature and moisture content. Concrete should be protected during the first stage of hardening, from low temperature in cold weather and from drying conditions such as wind and hot sunshine.

Curing may be done using any of the following methods:

- a) By submerging under water for small elements like cube samples,
- b) By sprinkling of water at intervals for exposed surfaces like beams,
- c) By spreading wet sand on the surface of the concrete slab until the curing period elapses,
- d) By spreading burlap on top of the slab until the curing period elapses and
- e) By drying under air at controlled ambient temperature.

CHAPTER THREE

MATERIALS AND METHODS

3.1 SOURCES OF MATERIALS

The materials used for the project were sourced locally thus:

S/N	Material	Source
1	Cement	Dangote brand of Ordinary Portland cement in 50 kg bags
2	Water	Pipe borne water from FUT Minna
3	Fine aggregates (sand)	From Gidan Kwano environment
4	Coarse aggregates	Crushed granite from a local quarry at Minna

3.2 TOOLS/EQUIPMENT

The following tools and equipment were used in the course concrete preparation, casting, curing, and laboratory investigations and testing.

- (i) Scale balance
- (ii) Shovel
- (iii) Head pan
- (iv) Wheel barrow
- (v) Hand trowel
- (vi) Tapping rod
- (vii) Calibrated ruler/metre rule
- (viii) Metal Cube moulds of 150x150x150mm
- (ix) Mould oil
- (x) Spanner
- (xi) Water bath for curing
- (xii) Hammer
- (xiii) Crushing machine

3.3 METHODS

3.3.1 Method of grading the aggregates

The grading of aggregates (both fine and coarse) was done using sieve analysis method. The British standard (BS) sieve of 4.75mm and 19.5mm diameters were used. The grading of fine aggregates (sand) was carried out by passing the aggregates through the 4.75mm sieve and those that passed through were used as fine aggregates. The coarse aggregates used were those that passed the 19.5mm sieve but were retained by the 4.75mm sieve.

Complete sieve analysis of both the fine and the coarse aggregates was completely carried out by passing a known weight of the various aggregates through a set of sieves and recording the weight retained on each sieve. The result of the sieve analysis was plotted on a graph with the particle size on the horizontal and the cumulative percentage passing on the vertical. The graph for both the fine aggregates and the coarse aggregates were plotted accordingly.

3.3.2 Measurements for Batching

By using the scale balance for weighing, the batching was carried out as by varying the water content while retaining the weight of the other ingredients. A total of 11 batches were made with mix proportions by weight – 1:2:4 and three (3No) cube samples were made from each batch.

Table 3.1 – Batching constituents for the concrete

Batch No	Composition of concrete (kg)	
1, w/c = 0.40	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.00
2, w/c = 0.42	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.10

3, w/c = 0.44	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.20
4, w/c = 0.46	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.30
5, w/c = 0.48	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.40
6, w/c = 0.50	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.50
7, w/c = 0.52	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.60
8, w/c = 0.54	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.70

9, w/c = 0.56	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.80
10, w/c = 0.58	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	2.90
11, w/c = 0.60	Weight of cement	5.00
	Weight of fine aggregates	10.00
	Weight of coarse aggregates	20.00
	Weight of water	3.00

3.3.3 Moisture content test for sand: Three tests were carried out to ascertain the average natural moisture content for the fine aggregates to be used thus;

A container was weighed and recorded as (W1)g

Weight of container + wet sample = W2 (g)

Weight of container + oven dried sample = W3 (g)

Weight of moisture = (W2 – W3)g

Weight of oven dry sample = (W3 – W1)g

Moisture content = $(W2 - W3) / (W3 - W1) \times 100\%$

3.3.4 Water absorption test for coarse aggregates: Here too, three tests were carried out to ascertain the average water absorption for the coarse aggregates using the following procedure.

Weight of container	W1(g)
Wt of container + wet sample	W2(g)
Wt of container + dry sample	W3(g)
Wt of dry sample	(W3-W1)g
Increase in moisture	(W2-W3)g
Moisture absorption	$(W2-W3)/(W3-W1) \times 100\%$

3.3.5 Method of mixing and preparation

Hand mixing method was used. It was carried out by pouring the weighed fine aggregates on the mixing platform. The weighed cement is then spread on it and thoroughly mixed until the mixture is uniform grey in colour. The mixture is then evenly spread on the platform and the measured coarse aggregate (19.5mm crushed granite) is evenly spread on the cement sand mixture. The measured water is gradually poured evenly on the cement-aggregate mixture. The entire mixture is then turned evenly with the hand held shovel until a flowing concrete is achieved ready for placement. It is usually limited to six (6No) turnings.

3.3.6 Workability test.

The following two (2No) tests are used as a measure of workability of concrete – compaction factor test and slump test.

3.3.7 Compaction factor test:

The best method of measuring workability is the inverse approach of the degree of compaction achieved by a standard amount of work done in achieving full compaction.

The degree of compaction, called the compaction factor, is measured by the density ratio ie the ratio of density actually achieved in the test of density of the same concrete fully compacted.

The apparatus consist essentially of two hoppers and one cylinder, the former being above one another. The hoppers have hinged doors at the bottom. These are cleaned and oiled before carrying out the test set as detailed below.

The hopper is filled with concrete, this being gently so that, at this stage, no work is done on the concrete to produce compaction. The bottom door of the hopper is then released and the concrete falls into the lower hopper. This lower hopper is smaller than the upper one and is therefore filled to overflowing and this always contains approximately the same amount of concrete in a standard state.

The bottom door of the lower hopper is released and the concrete falls into the cylinder. Excess of concrete is cut by two floats slid across the top of the mould, and the net mass of concrete in the known volume of the cylinder is determined. The use of two hoppers helps to reduce any inconsistencies caused by the uneven loading of the hopper.

The weight of the concrete in the cylinder was found and referred to as compacted concrete. It is found by a refilling the container in layers of approximately 50mm each and each layer being compacted 25 blows using the standard compacting rod and trowel the concrete to level with the rim. The concrete in the cylinder is weighed again and the compacted weight is recorded. The higher the value of the compacted weights in comparison with that of uncompact weight, the greater the workability.

3.3.8 Slump test

Apparatus: The following apparatus were used for the slump tests

1	A grucated slump metal cone in form of a frustum
2	A metal base plate
3	A 600mm long rod
4	A steel rule for slump measurement
5	A straight edge

Procedure: The apparatus and the surrounding were properly cleaned to keep off impurities before the test commences. In making the test, the cone was oiled and then filled with concrete in three (3No) layers. Each layer is tapped 25 times with a standard 16mm diameter steel rod, rounded at the end, and top surface is struck off by means of a screeding and rolling motion of the tamping rod. The mould must be firmly held against its base during the entire operation. This is facilitated by handles or foot rest brazed to the mould.

Immediately after the filling, the cone is slowly lifted and the unsupported concrete will now slump. The decrease in the height of the centre (the highest part of the concrete BS 1881: part 102:83) of the slumped concrete is called the slump and is measured to the nearest 5mm.

3.4.0 STRENGTH TESTS

3.4.1 Density test

It is common to determine the density of compacted fresh concrete when measuring workability or the air content. It is obtained by weighing the compacted concrete in a standard container of known volume and mass.

Let mass container be	M1
Mass of container + fresh concrete	M2
Volume of container	V
Then mass of concrete	M2 – M1
Therefore density of concrete	(M2-M1)/V

3.4.2 Specific Gravity test

Two tests each were carried out to ascertain the specific gravity of both the fine and the coarse aggregates and the average value taken on each case.

Weight of cylinder	W1(g)
Wt of cylinder + sample	W2(g)
Wt of cylinder + Water + sample	W3(g)
Wt of cylinder + water	W4(g)
Wt of water	(W3-W2)g
Wt of sample	(W2-W1)g
Wt of water displaced by the sample	(W4-W1)-(W3-W2) = w(g)
Specific gravity	(W2-W1)/w

3.4.3 Bulk Density test on coarse aggregates

The test was carried out on compacted and un-compacted aggregate samples. Two tests were carried out in each case and a simple arithmetic average taken of the results.

Weight of empty container	W1 (kg)
Volume of container	V (m3)
Weight of container + sample	W2 (kg)
Weight of sample	(W2-W1)kg
Bulk density	(W2-W1)/V (kg/m3)

3.4.4 Test for aggregate crushing value (ACV)

Mass of mould + aggregates	M1 (g)
Mass of mould only	M2 (g)
Mass of Aggregates	(M1-M2)g
Mass of aggregate retained on 2.3mmsieve	M3(g)
Aggregate crushing value (ACV)	$M3/(M1-M2) \times 100\%$

3.4.4.1 Aggregate impact value (AIV) of granite: Two tests were carried out and the average value taken.

Mass of mould + aggregates	M1 (g)
Mass of mould only	M2 (g)
Mass of Aggregates	(M1-M2)g
Mass of aggregate passing the 2.3mmsieve	M3(g)
Aggregate crushing value (AIV)	$M3/(M1-M2) \times 100\%$

3.4.5 Mixing time

On mixing the concrete, it is ensured that the cubes were cast within a very short time to avoid the concrete from setting. To ensure a standard mix and mix time for all the batches, we regulated the mixing method and mix time to 6No turnings each.

3.4.6 Cube production

The following apparatus and equipment were used in the concrete cube production: steel mould, metal base, steel rod, metal float and trowel.

Procedure: The inner parts of the moulds were cleaned and oiled. The nuts and bolts were properly fastened to avoid leakage of mortar through the joints. Concrete was cast in the cube of 150X150X150 mm size in three (3No) layers and each layer is compacted with the steel rod. Each layer was rammed with 25 blows of the rod. The final layer of the cube is smoothened at the top with the use of the hand trowel. The cubes were allowed to set and harden for 24 hours before they are removed from the moulds. They were then transferred to bath tub filled with water where they are left to cure in the curing tray for 28 days. At the end of the 28 days of curing, the cubes are then removed and the crushing test is done.

3.4.7 Curing

The object of the curing under wet conditions at normal temperature is to keep the concrete saturated until the originally water filled space in the fresh cement paste has been occupied to the desired extent by the products of hydration of cement. This curing period lasted for 28 days.

3.4.8 Crushing

The crushing of the cubes was carried out using the electrically powered crushing machine in the concrete laboratory, Civil Engineering Department, Federal University of Technology Minna. The cubes were crushed on the 28th day and the readings were taken for further analysis.

CHAPTER 4

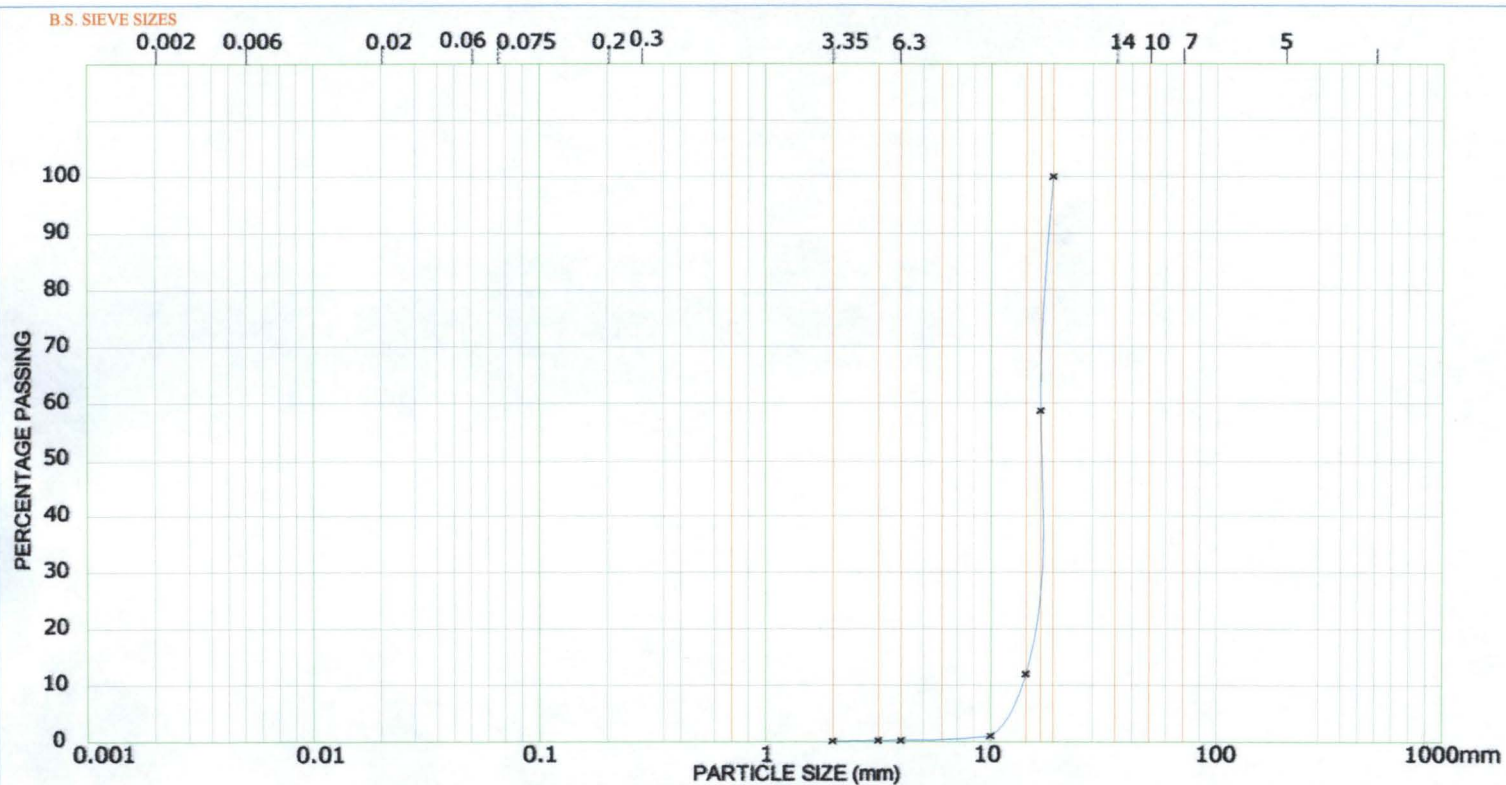
4.0

RESULTS AND DISCUSSION

4.1 Analysis of Results

Table 4.1 Sieve analysis of coarse 19.50 mm aggregates – total sample weight 1000g

Sieve No	Wt retained (g)	% retained	% passing
25mm	0.00	0.00	100.00
20mm	403.20	40.32	59.68
14mm	476.50	47.65	12.03
10mm	107.20	10.72	1.31
6.30mm	12.60	1.26	0.05
5.00mm	0.00	0.00	0.05
3.35mm	0.00	0.00	0.05
Pan	0.50	0.05	0.00

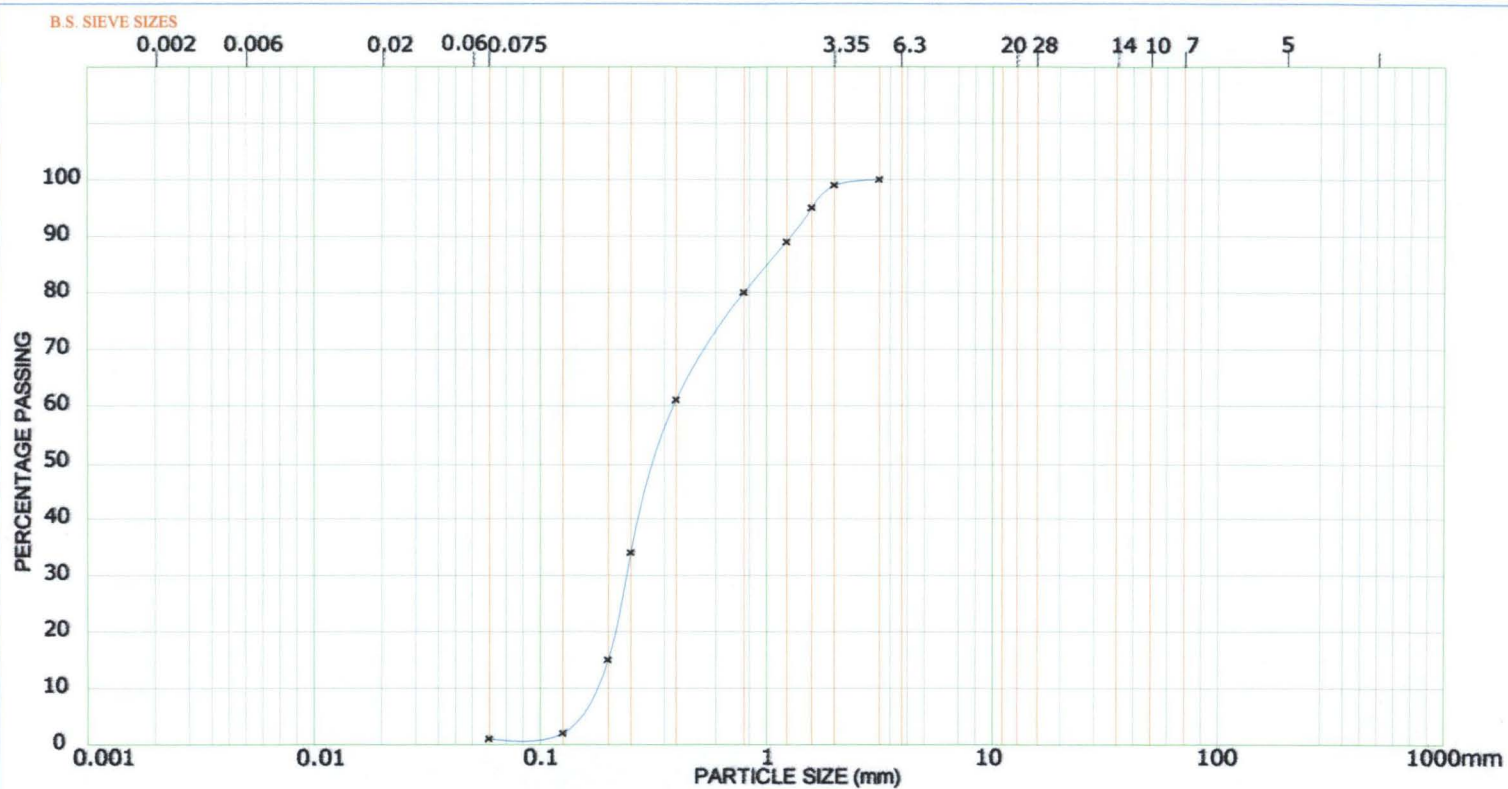


CLAY	FINE SILT	MEDIUM SILT	COARSE SILT	FINE SAND				MEDIUM SAND		COARSE SAND		FINE GRAVEL		MEDIUM GRAVEL		COARSE GRAVEL		COBBLES		BOULDERS				
Specimen Identification	Description of sample		Sample Depth (m)	EMC %	LL %	PL %	PI %	No. 5	No. 7	No. 10	No. 14	No. 18	No. 25	No. 36	No. 52	No. 72	No. 100	No. 150	No. 200	CLAY %	C KN/m	Ø	Permeability mm/sec	Specific Gravity (mg/m³)
GRAVEL	CRUSHED GRAVEL		0.6						93.7	89.0	86.9		81.3	80.8		73.1	71.2		67.7					2.58

APPENDIX A: PARTICLE SIZE DISTRIBUTION CURVE

Table 4.2 sieve analysis of fine aggregates – total sample weight 500g

Sieve No	Wt retained (g)	% retained	% passing
5.0mm	0.00	0.00	100.00
3.25mm	4.40	0.88	99.12
2.00mm	17.40	3.48	95.64
1.18mm	34.40	6.88	88.76
850um	41.20	8.24	80.52
600um	98.10	19.62	60.90
425um	137.00	27.40	33.50
300um	95.00	19.00	14.50
150um	64.40	12.88	1.62
75um	5.00	1.00	0.62
Pan	3.10	0.62	0.00



CLAY	FINE SILT	MEDIUM SILT	COARSE SILT	FINE SAND	MEDIUM SAND	COARSE SAND	FINE GRAVEL	MEDIUM GRAVEL	COARSE GRAVEL	COBBLES	BOULDERS													
Specimen Identification	Description of sample		Sample Depth (m)	EMC %	LL %	PL %	PI %	No. 5	No. 7	No. 10	No. 14	No. 18	No. 25	No. 36	No. 52	No. 72	No. 100	No. 150	No. 200	CLAY %	C KN/m	Ø	Permeability mm/sec	Specific Gravity (mg/m³)
SAND	SHARP SAND		0.6						93.7	89.0	86.9		81.3	80.8		73.1	71.2		67.7					2.58

APPENDIX B: PARTICLE SIZE DISTRIBUTION CURVE

Table 4.3 Computations for Specific Gravity Test – Coarse Aggregates

	Test 1	Test 2
Wt of cylinder (W1)g	552.30	552.30
Wt of cylinder + sample (W2)g	827.00	799.10
Wt of cylinder + H2O + sample (W3)g	1718.30	1700.10
Wt of cylinder + H2O (W3)g	1547.00	1547.00
Wt of H2O (W4 – W1)g	994.70	994.70
Wt of sample (W2 – W1)g	274.70	246.80
Wt of H2O displaced by sample (W4-W1)-(W3-W2) = (w)g	103.40	93.70
Specific gravity = (W2-W1)/w	2.66	2.63
Arithmetic average of specific Gravity SG =	2.65	

Table 4.4 computations for Specific gravity test – Fine Aggregates

	Test 1	Test 2
Wt of cylinder (W1)g	114.40	114.40
Wt of cylinder + sample (W2)g	172.00	168.20
Wt of cylinder + H2O + sample (W3)g	398.20	390.80
Wt of cylinder + H2O (W3)g	362.50	360.50
Wt of H2O (W4 – W1)g	248.10	246.10
Wt of sample (W2 – W1)g	57.60	53.80
Wt of H2O displaced by sample (W4-W1)-(W3-W2) = (w)g	21.90	23.5
Specific gravity = (W2-W1)/w	2.63	2.29
Arithmetic average of specific gravity SG =	2.46	

Table 4.5 computations for Bulk Density test for 19.50 mm aggregates

Test details	Compacted		Un compacted	
	1	2	1	2
Wt of cylinder (W1)g	1.073	1.073	1.073	1.073
Vol. of vessel (Vo)/1000	1.7289	1.7289	1.7289	1.7289
Wt of vessel + sample (W2)g	3.870	3.992	3.598	3.690
Wt of sample (W2-W1)g	2.7969	2.918	2.5241	2.617
Bulk density Wt/Vol. Kg/m ³	1617	1688	1460	1513
Arithmetic average density Kg/M ³	1652		1486	

Table 4.6 computations for Moisture content test for fine aggregates

Details	Test 1	Test 2	Test 3
Wt of container (W1)g	21.30	31.20	25.20
Wt of container + wet sample (W2)g	55.60	68.30	82.18
Wt of container + oven dry sample (W3)g	55.20	67.90	81.56
Wt of moisture (H ₂ O), (W2-W3)g	0.40	0.40	0.62
Moisture content (W2-W3)/(W3-W1)x100%	1.18	1.09	1.10
Average MC = 1.12%		1.12%	

Table 4.7 computations for Water Absorption test for 19.50 mm aggregates

Details	Test 1	Test 2	Test 3
Wt of container (W1)g	22.70	27.90	19.90
Wt of container + wet sample (W2)g	91.70	65.80	63.90
Wt of container + dry sample (W3)g	91.30	65.50	63.60
Wt of dry sample (W3-W1)g	68.60	37.60	44.00
Increase in Weight (W2-W3)g	0.40	0.30	0.30
Absorption $(W2-W3)/(W3-W1) \times 100\%$	0.73	0.80	0.68
Average Absorption	0.74%		

Table 4.8 computations for Aggregate crushing Value (ACV) Test

Wt of mould + aggregates (W1)g	15,807.00
Wt of mould (W2)g	12,670.00
Wt of Aggregates (W1-W2)g	3,137.00
Wt retained on sieve 2.3mm (W3)	757.00
Aggregate Crushing Value $W3/(W1-W2) \times 100\%$	24.13

Table 4.9 Aggregate Impact Value (AIV) Test for 19.50 mm aggregates

Details	Test 1	Test 2
Wt of mould + Aggregates (W1)g	3,394.00	3,348.00
Wt of mould (W2)g	2,632.00	2,632.00
Wt of Aggregates (W1-W2)g	762.00	676.00
Wt passing sieve 2.3mm (W3)g	115.30	100.40
AIV = $W3/(W1-W2) \times 100\%$	15.13	14.85
Therefore Average AIV = 14.99%	14.99%	

Table 4.10 Concrete compaction Factor Test - using 19.50 mm aggregates

0.40 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	11.72
Wt of fully compacted sample + cylinder (W2)kg	14.08
Compaction factor $CF = W1/W2$	0.83
0.42 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	12.36
Wt of fully compacted sample + cylinder (W2)kg	14.18
Compaction factor $CF = W1/W2$	0.87
0.44 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	12.48
Wt of fully compacted sample + cylinder (W2)kg	14.30
Compaction factor $CF = W1/W2$	0.87
0.46 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	12.90
Wt of fully compacted sample + cylinder (W2)kg	14.28
Compaction factor $CF = W1/W2$	0.90
0.48 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	12.74
Wt of fully compacted sample + cylinder (W2)kg	14.11
Compaction factor $CF = W1/W2$	0.90

0.50 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	12.95
Wt of fully compacted sample + cylinder (W2)kg	14.16
Compaction factor CF = W1/W2	0.91
0.52 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	13.00
Wt of fully compacted sample + cylinder (W2)kg	14.20
Compaction factor CF = W1/W2	0.92
0.54 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	13.20
Wt of fully compacted sample + cylinder (W2)kg	14.25
Compaction factor CF = W1/W2	0.93
0.56 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	13.30
Wt of fully compacted sample + cylinder (W2)kg	14.27
Compaction factor CF = W1/W2	0.93
0.58 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	13.35
Wt of fully compacted sample + cylinder (W2)kg	14.20
Compaction factor CF = W1/W2	0.94
0.60 Water/Cement ratio	
Wt of partially compacted Sample + cylinder (W1)kg	13.40
Wt of fully compacted sample + cylinder (W2)kg	14.25
Compaction factor CF = W1/W2	0.95

Table 4.11 results of Slump Test on Concrete using 19.50 mm aggregates

Water cement ratio	Slump (cm)
0.40	0.00
0.42	0.00
0.44	0.50
0.46	1.00
0.48	1.50
0.50	2.00
0.52	2.30
0.54	2.70
0.56	3.20
0.58	3.80
0.60	4.50

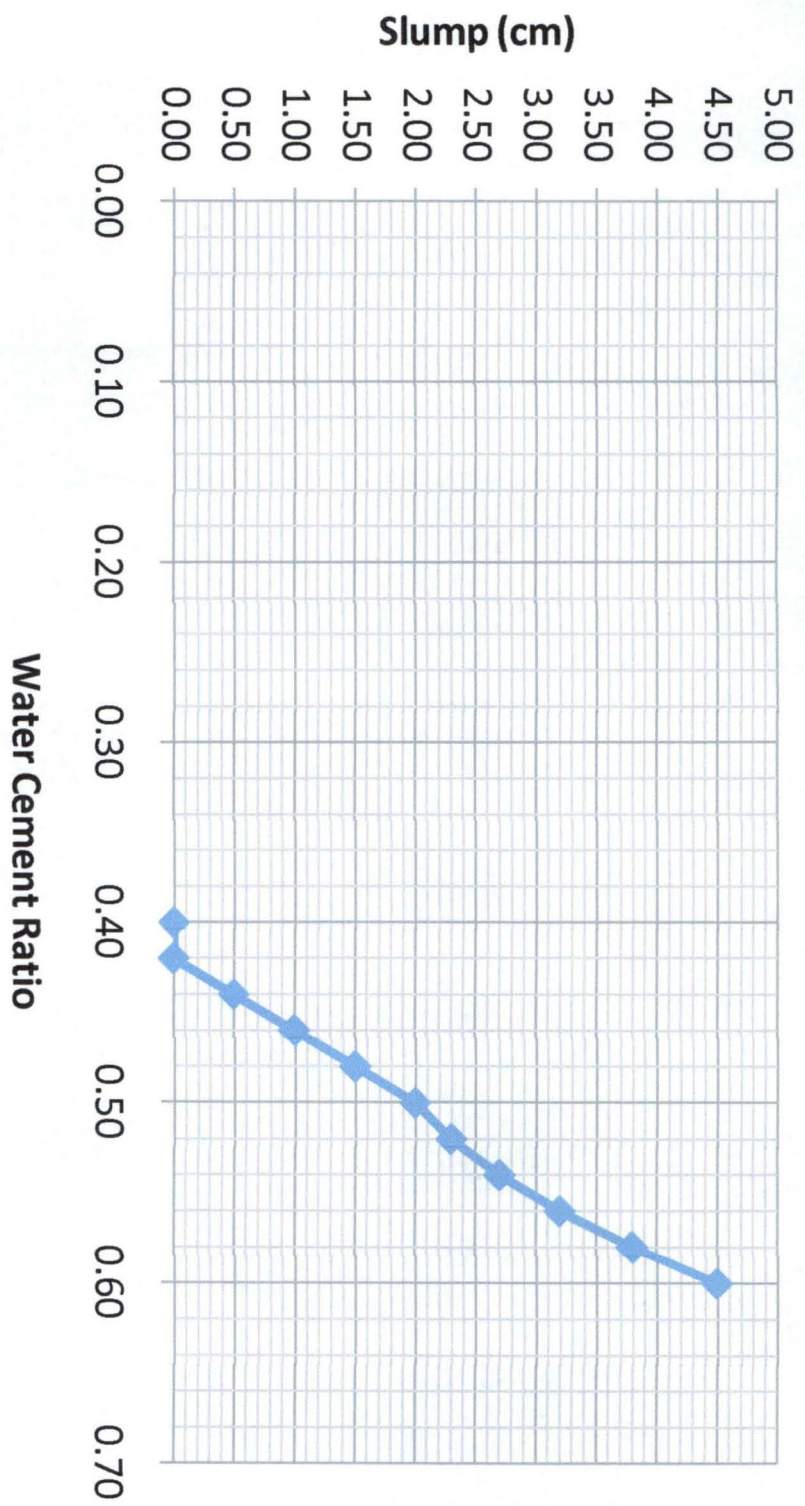


Table 4.12 Summary of Density of Concrete using 19.50 mm aggregates as computed in Appendix I

Water cement ratio	Average Density (kg/m ³)
0.40	2358
0.42	2364
0.44	2385
0.46	2400
0.48	2410
0.50	2421
0.52	2409
0.54	2385
0.56	2372
0.58	2362
0.60	2356

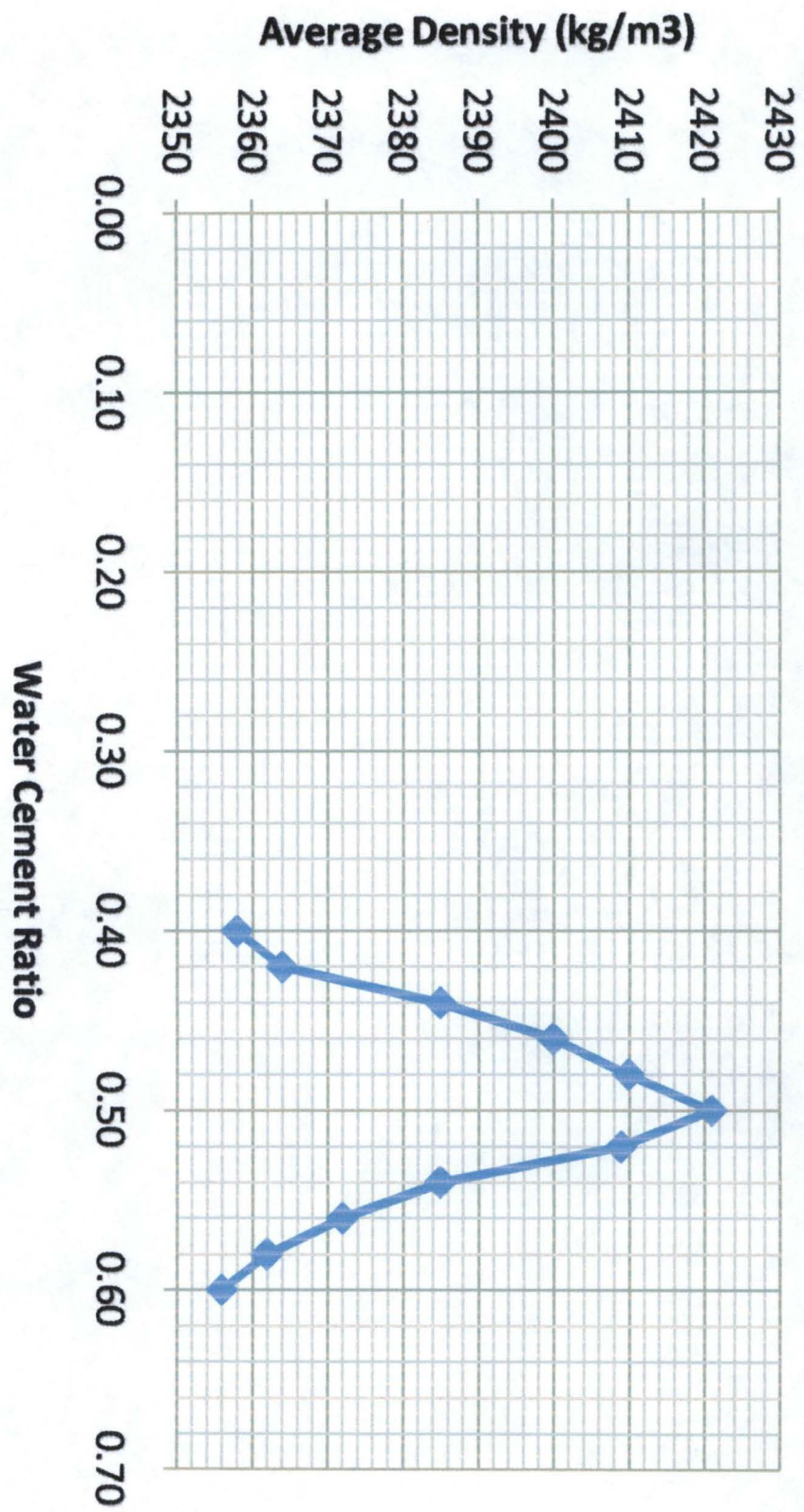
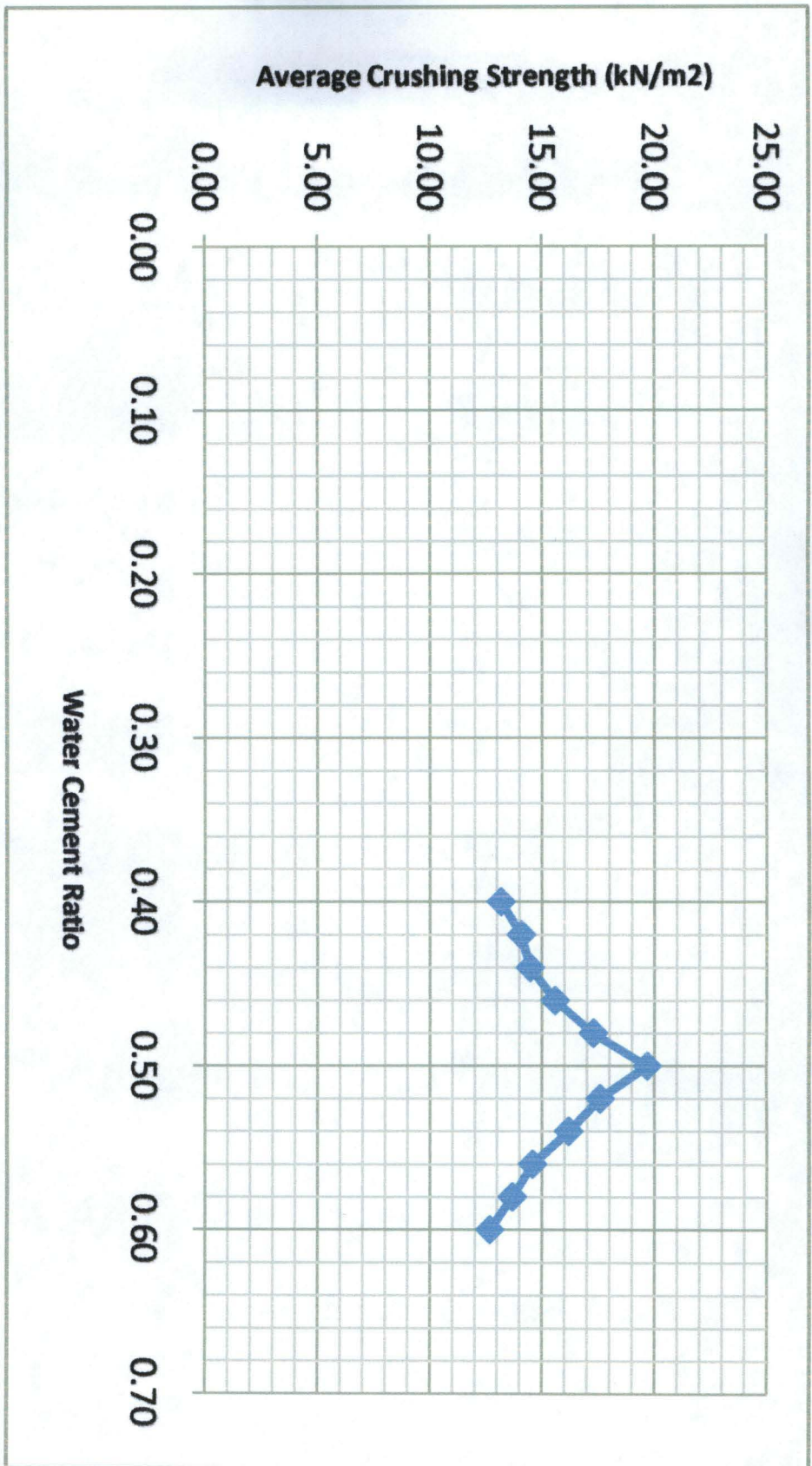


Table 4.13 Summary of compressive strength for each water-cement ratio as computed in Appendix II

Water cement ratio	Average compressive strength (KN/m ²)
0.40	13.20
0.42	14.10
0.44	14.50
0.46	15.60
0.48	17.30
0.50	19.70
0.52	17.60
0.54	16.20
0.56	14.60
0.58	13.70
0.60	12.70



4.2 Discussion of Results

The analysis of the results above led to the following observed facts: That the water cement ratio of concrete affect a) The workability and consequently, the slump of fresh concrete, b) The density of compacted concrete and c), The strength of the hardened concrete among other parameters like void ratio, porosity, bleeding, segregation of concrete etc.

- 1) Workability: Increase in water-cement ratio increases slump and also workability, but enhancement of workability is not the very essence of concrete production. Concrete is a structural material renowned for its compressive strength, hence any factor that negates this norm is working against the very essence of the product.
- 2) Density: The density of compacted concrete is observed to increase as the water-cement ratio is increased up to a point after which a further increase in the water-cement ratio results in the continuous decline of the concrete density. This can be attributed to the fact that water is required for the hydration of cement and also for the lubrication of the surfaces of the aggregates for a more effective packing and filling the interspaces with smaller particles (Neville 1995). Any extra water added after that required for the hydration of cement and lubrication is left as free water. This free water only swells the concrete leading to a reduction of density – mass per unit volume. The mass of concrete being constant while the volume continues to increase.
- 3) Strength: It is a clear fact that anything or process that increases the density of concrete will ultimately also increase its strength and vice versa. Concrete needs water for hydration which aids the development of strength of the hardened concrete. Water added over and above that required for the hydration of cement and the lubrication of the aggregates does not contribute positively to the strength of concrete. In the test under review, it is observed that the strength of hardened concrete increased as the water-cement ration is increased from 0.4 to about 0.5 after which a decline sets in. It means therefore that cement hydration and

effective concrete workability requires water-cement ratio of between 0.45 - 0.50 to be completed. Beyond this point, there exists excess water which evaporates from the fresh concrete. This leaves pore spaces in the concrete and pore spaces crack easily on application of load thereby leading to a reduction in strength.

Other areas where water-cement ratio has effect in concrete are as follows:-

- a) Void ratio: When the water-cement ratio goes above the water needed for cement hydration, the excess water remains as free water and rather swells the concrete. After concrete curing, the water dries up leaving air voids, hence high void ratio, which leads to a reduction in concrete strength.
- b) Porosity: When the air voids are connected to one another, the concrete becomes porous and water and other liquids seeps through with ease. This in turn negatively affects the strength and durability of the concrete.
- c) Bleeding: With too much water in the concrete being batched, the cement paste in the concrete leaks through any little openings in the form work leaving behind, only the aggregates. This results in weak concrete by all standards.
- d) Segregation: With high and excess water-cement ratio, the tendency of separation of the aggregates from the cement paste (known as segregation) during transportation is very high. This means non homogenous concrete being batched with the attendant poor concrete work out put.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the research carried out, the following conclusions can be reached:

- (i) For normal concrete, the higher the water-cement ratio the higher the workability of the fresh concrete.
- (ii) The water-cement ratio needed to be increased up to the volume that will be enough for hydration and compaction thereafter there will be a reduction in the strength of the hardened concrete due to various reasons like increased porosity, void ratio etc.
- (iii) As the water-cement ratio increased, the density of the concrete start to increase up to a maximum point and then a decline will set in.

5.2 Recommendation

The following recommendations are made based on the research work done on the normal concrete:

- (i) From the study of the graph of the water-cement ratio against the crushing strength at the age of 28 days, it is recommended that the water-cement ratio of normal concrete be in the range of 0.46-0.54 for maximum strength and effective workability.
- (ii) It is recommended that where high amount of water is needed for any other reason, a richer mix should be adopted by increasing the amount of cement in the mix like using 1:1.5:3 mix instead of the 1:2:4 mix.

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Appendix I - Computations for Density of compacted concrete (19.50 mm aggregates)

For water cement ratio of 0.40; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{ m}^3$

Sample	Mass, M (Kg)	Density, P = M/V	Density, P (Kg/m ³)
A	7.95	$7.95/0.003375$	2356
B	7.96	$7.96/0.003375$	2359
C	7.96	$7.96/0.003375$	2359
Average			2358

For water cement ratio of 0.42; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{ m}^3$

Sample	Mass, M (Kg)	Density, P = M/V	Density, P (Kg/m ³)
A	7.99	$7.99/0.003375$	2367
B	7.98	$7.98/0.003375$	2364
C	7.97	$7.97/0.003375$	2361
Average			2364

For water cement ratio of 0.44; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{ m}^3$

Sample	Mass, M (Kg)	Density, P = M/V	Density, P (Kg/m ³)
A	8.00	$8.00/0.003375$	2370
B	8.05	$8.05/0.003375$	2385
C	8.10	$8.10/0.003375$	2400
Average			2385

For water cement ratio of 0.46; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{ m}^3$

Sample	Mass, M (Kg)	Density, P = M/V	Density, P (Kg/m ³)
A	8.10	$8.10/0.003375$	2400
B	8.10	$8.10/0.003375$	2400
C	8.10	$8.10/0.003375$	2400
Average			2400

For water cement ratio of 0.48; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{m}^3$

Sample	Mass, M (Kg)	Density, $P = M/V$	Density, P (Kg/m ³)
A	8.15	$8.15/0.003375$	2415
B	8.10	$8.10/0.003375$	2400
C	8.15	$8.15/0.003375$	2415
Average			2410

For water cement ratio of 0.50; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{m}^3$

Sample	Mass, M (Kg)	Density, $P = M/V$	Density, P (Kg/m ³)
A	8.17	$8.17/0.003375$	2421
B	8.16	$8.16/0.003375$	2418
C	8.18	$8.18/0.003375$	2424
Average			2421

For water cement ratio of 0.52; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{m}^3$

Sample	Mass, M (Kg)	Density, $P = M/V$	Density, P (Kg/m ³)
A	8.12	$8.12/0.003375$	2406
B	8.13	$8.13/0.003375$	2409
C	8.14	$8.14/0.003375$	2412
Average			2409

For water cement ratio of 0.54; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{m}^3$

Sample	Mass, M (Kg)	Density, P = M/V	Density, P (Kg/m ³)
A	8.05	8.05/0.003375	2385
B	8.10	8.10/0.003375	2400
C	8.00	8.00/0.003375	2370
Average			2385

For water cement ratio of 0.56; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{m}^3$

Sample	Mass, M (Kg)	Density, P = M/V	Density, P (Kg/m ³)
A	7.99	7.99/0.003375	2367
B	8.05	8.05/0.003375	2385
C	7.98	7.98/0.003375	2364
Average			2372

For water cement ratio of 0.58; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{m}^3$

Sample	Mass, M (Kg)	Density, P = M/V	Density, P (Kg/m ³)
A	7.98	7.98/0.003375	2364
B	7.98	7.98/0.003375	2364
C	7.96	7.96/0.003375	2359
Average			2362

For water cement ratio of 0.60; vol. of cube (V) = $0.15 \times 0.15 \times 0.15 = 0.003375 \text{m}^3$

Sample	Mass, M (Kg)	Density, P = M/V	Density, P (Kg/m ³)
A	7.95	7.95/0.003375	2356
B	7.94	7.94/0.003375	2353
C	7.96	7.96/0.003375	2359
Average			2356

Appendix 2 - Computations for compressive crushing strength test for the concrete

For water cement ratio of 0.40; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	300	300/0.0225	13.30
B	296	296/0.0225	13.20
C	298	298/0.0225	13.20
Average			13.20

For water cement ratio of 0.42; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	318	318/0.0225	14.10
B	322	322/0.0225	14.30
C	316	316/0.0225	14.00
Average			14.10

For water cement ratio of 0.44; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	332	332/0.0225	14.80
B	326	326/0.0225	14.50
C	318	318/0.0225	14.10
Average			14.50

For water cement ratio of 0.46; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	350	350/0.0225	15.60
B	345	345/0.0225	15.30
C	355	355/0.0225	15.80
Average			15.60

For water cement ratio of 0.48; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	394	$394/0.0225$	17.50
B	389	$389/0.0225$	17.30
C	386	$386/0.0225$	17.20
Average			17.30

For water cement ratio of 0.50; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	420	$420/0.0225$	18.70
B	460	$460/0.0225$	20.40
C	453	$453/0.0225$	20.10
Average			19.70

For water cement ratio of 0.52; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	403	$403/0.0225$	17.90
B	399	$399/0.0225$	17.70
C	387	$387/0.0225$	17.30
Average			17.60

For water cement ratio of 0.54; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	367	$367/0.0225$	16.30
B	362	$362/0.0225$	16.01
C	365	$365/0.0225$	16.20
Average			16.20

For water cement ratio of 0.56; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	333	333/0.0225	14.80
B	328	328/0.0225	14.60
C	325	325/0.0225	14.40
Average			14.60

For water cement ratio of 0.58; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	306	306/0.0225	13.60
B	301	301/0.0225	13.40
C	315	315/0.0225	14.00
Average			13.70

For water cement ratio of 0.60; area of cube (A) = $0.15 \times 0.15 = 0.0225\text{m}^2$

Sample	Force, F (KN)	Stress = F/A	Stress (KN/m ²)
A	292	292/0.0225	13.00
B	289	289/0.0225	12.80
C	276	276/0.0225	12.30
Average			12.70