

**THE EFFECT OF WATER CEMENT RATIO AND AGGREGATE-  
CEMENT RATIO ON THE 28 DAYS STRENGTH OF NORMAL  
CONCRETE**

**BY**

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**NAU/2017224014**

**A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF  
CIVIL ENGINEERING, FACULTY OF ENGINEERING NNAMDI  
AZIKIWE UNIVERSITY, AWKA**

**IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE  
AWARD OF BACHELOR OF ENGINEERING (B.ENG.) DEGREE IN  
CIVIL ENGINEERING**

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**MAY 2023.**

## CERTIFICATION

This project “The Effects of Water-cement ratio and Aggregates-cement ratio on the 28-days Strength of Normal Concrete” was conducted by Nwezeh Emmanuel Nnamdi under the supervision of Engr. Dr. B. O. Adinna and has not been used in part or full for the award of a degree in this University or other Institutions.

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## APPROVAL

This project work has been assessed and approved as a satisfactory project for the award of Bachelor of Engineering (B.ENG) Degree by the department of Civil Engineering, Faculty of Engineering, Nnamdi Azikiwe University, Awka , Anambra State.

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## **DEDICATION**

This work is dedicated to God Almighty, for his infinite provision, protection and direction throughout my study period and stay in Nnamdi Azikiwe University.

## **ACKNOWLEDGEMENTS**

First, I appreciate God for life and for the knowledge he gave me concerning this project and the period of work.

My profound gratitude goes to my supervisor, Engr. Dr. B. O. Adinna whose dedication, selfless and fatherly treatment brought me much encouragement and discipline to work hard to make this research a reality. Also my gratitude goes to my Head of Department, Engr., Prof. Ezeagu Akaolisa C. and all his Honourable lecturers in the persons of Engr. Prof. C.M.O Nwaiwu, Prof. (Mrs) N.E. Nwaiwu, Engr. Prof. C.H. Aginam, Engr. Rev. C. Nwakire, Engr. P.D. Onodagu, Engr. A. Nwajuaku, Engr. (Mrs) I. Nwajuaku, Engr. A.A. Ezenwamma, the Lab Technologists and all other staff and management of the Department of Civil Engineering for their role in my advancement of this academic pursuit.

I also appreciate my parents Mr and Mrs E .C. Nwezeh, whose love, backing and support has been very crucial to my life and has brought me this far.

I cannot forget all my friends whose encouragement and help has helped me so much even in the realization of this project work.

God bless you all. Amen.

## ABSTRACT

This project work investigated the effects of water cement ratio and aggregate-cement ratio on the 28 days strength of normal concrete. The investigation of this study was limited to the effect on the compressive strength and workability of concrete mix. Concrete cubes were prepared with a mix of 1:2:4,  $1:1\frac{1}{2}:3$ , 1:3:6 and water-cement ratio of 0.50, 0.55, 0.60. The concrete cubes were cured for 28 days. The results showed that the workability of freshly mixed concrete increases as the water-cement ratio increases. And also the compressive strength of the hardened concrete increases as the water-cement ratio is reduced. The test result showed that the compressive strength achieved at  $1:1\frac{1}{2}:3$  concrete mix with water-cement ratio of 0.55 is the highest.

A higher water-cement ratio should be employed when concrete with high workability is required, having in mind that the higher the water-cement ratio the lower the compressive strength of concrete.

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# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of the study

As a country, Nigeria can still be classified as a developing nation. That is to say that irrespective of the technology being used and infrastructures, when compared to first world countries, we still have a long way to go in terms of development and innovation. Civil engineering deals with the analysis, design, construction, demolition and reconstruction and maintenance of infrastructures. Building such infrastructure cannot be done without the use of concrete, no matter how minute.

Concrete is an essential part of any construction project. It is the most widely used construction material in the entire world. Rather than existing as an independent material, concrete is a mix of various materials. These materials include cement, fine aggregates (sand) and coarse aggregates (crushed stones or gravel), mixed with water. Since the invention of Portland cement in 1824, plenty of research works have proved that the 28-day strength of cement-based materials is determined by raw materials including cement, supplementary cementitious materials, aggregate etc., proportions including water-cement ratio, aggregate-cement ratio, cement content, etc., and curing conditions including ambient temperature, pressure, and humidity.

Strength and Workability are both dominating factors in the making of concrete. These factors affecting the strength of concrete are:

1. Water-cement ratio (w/c ratio)
2. Aggregate-cement ratio (a/c ratio)
3. Grading of aggregate

4. Shape and size of aggregate
5. Compaction
6. Curing

This study will be based on the effects of water-cement ratio and aggregate-cement ratio.

Water-cement ratio is the ratio of the volume/weight of water to the weight of cement used to form concrete. As per Abram's Law (1918), the strength of workable concrete mix entirely depends on the water-cement ratio. The higher the water-cement ratio, the greater the initial spacing between the cement grains and greater the volume of residual voids not filled by hydration products. Thus, the reduction in water-cement ratio leads to an increase in the strength of concrete; [therefore, the strength of concrete is inversely proportional to water-cement ratio]. Also for a given workability an increase in the proportion of cement in a mix has little effect on water demand and results in a reduction in water-cement ratio.

Aggregate plays an important role in concrete especially as they occupy 60-80% of concrete volume (Neville, 1995). Aggregate-cement ratio (A/C) is the ratio of weight of aggregate to the weight of cement. If this ratio is more, it implies aggregates are more and cement is less; there will be less cement paste available to coat aggregate surface and fill the voids which makes the concrete pervious and decreases its strength. And if this ratio is less, it implies that the weight of aggregate is less and weight of cement is more relatively; the concrete has more cement paste required to coat aggregates and fill the void between them. This more cement paste makes the concrete relatively easy to mix, place and compact as it reduces the friction between aggregates and allows its smooth movement. Thus, the workability and strength of concrete increases.

## **1.2 Statement of the Problem**

Every designed concrete structure has design strength which is in-built in the concrete mix proportion. Changing the water content of a mix causes noticeable change in the strength of the hardened concrete. Change in the cement content changes the yield and concrete strength and affect the cost of the project. The gradation of aggregate has the main role in establishing the workability of mixtures which affects the workability, strength, shrinkage and durability of hardened concrete.

In 28 days, the concrete's strength would have reached 99% and continues to gain strength in the future. However, the rate of gain advances at a much-reduced pace when compared to the first 28 days; so Engineers rely on the results of the compressive strength after 28 days and use this number in any design calculations.

## **1.3 Aim and Objectives**

### **1.3.1 Aim**

The main aim of this study is to determine the effect of water-cement ratio and aggregate-cement ratio on the 28 days strength of normal concrete using varying water-cement ratios and aggregate-cement ratios.

### **1.3.2 Objectives**

1. To perform sieve analysis for coarse aggregate with a view to determine its grading and suitability.
2. To prepare concrete mixes of a given concrete grade but with varying water-cement ratios (0.5, 0.55, 0.6) and varying aggregate-cement ratios in M-10, M-15, M-20 concrete grade.

3. To perform slump test (workability) on the freshly mixed concrete.
4. To determine the strength of concrete cubes with varying mix proportions(W/C ratio and A/C ratio) after 28 days curing.

#### **1.4 Scope of the Study**

This project research is concerned with the effect of aggregate-cement ratio and water-cement ratio on the strength of concrete. The study will be carried out using Portland cement (Dangote Cement), fine aggregate (sand), coarse aggregates (gravel  $\frac{3}{4}$  Inches) and water. The concrete is batched in ratios of 1:3:6, 1:2:4 and 1:1.5:3 (cement: sand: gravel); and water-cement ratio of 0.5, 0.55 and 0.6 was employed in this research.

This study will be limited to the effects of W/C ratio and A/C ratio on the strength and workability of concrete. Workability, strength and durability are three basic properties of concrete. The amount of useful internal work necessary to overcome the internal friction to produce full compaction or the ability of concrete to flow is termed as workability. The slump cone test would be used for checking the workability of fresh concrete mix. Strength is the property of concrete that enables it to withstand stresses within the permissible factor of safety in expected exposure conditions. The cube test would be used in testing for the compressive strength of hardened concrete.

#### **1.5 Significance of Study**

The significance of this study is as follows:

1. It will help in adequate quality control of concrete works and site supervision
2. To establish a relationship between A/C and W/C with the 28 days strength of normal concrete for research purposes.

3. To aid civil engineers, builders and other profession that make use of concrete in solving the problem of proportioning of concrete constituents such as cement, aggregate (fine and coarse) and water in order to get desirable concrete properties such as strength, workability and durability.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Concrete Constituents

Concrete is a composite material composed of coarse granular material (aggregate or filler) embedded in a hard matrix of a binder (cement) that fills the space between the aggregates particles and glues them together. Concrete can also be considered as a composite material that consists of a binding medium within which particle or fragments of aggregates are embedded in. According to Neville (2008), concrete can be defined as any product or mass made by use of cementing medium. Usually this medium is a product of reaction between hydraulic cement and water. Shetty (2005) defines concrete as a freshly mixed material which can be mould into any shape. The relative quantity of water, cement and aggregate in a concrete control its properties (workability) in wet and hardened state.

Concrete can simply be represented according to the type of binder used. For instance, Portland cement concrete, asphalt concrete, and epoxy concrete. In concrete construction, the Portland cement concrete is utilized the most. Thus in this course of study, the term concrete usually refers to Portland cement concrete and its composition can be represented as follows;

Cement + water + Admixtures (optional) = cement paste.

Cement paste + fine aggregate (sand) =mortar.

Mortar + coarse aggregate (stone) = concrete.

Admixtures are materials other than aggregates (fine or coarse), water, fibre and cement, which are added into concrete mix immediately before or during mixing in order to influence the

properties of the wet or hardened concrete mix. These admixtures are commonly used in modern day practice and thus it has become an essential component of modern day concrete. Admixtures include:

1. Chemical admixtures: they are used to modify the setting and hardening characteristics of cement paste by influencing the rate of cement hydration.
2. Water reducing cement: they are used in reducing the surface tension of water.
3. Air entraining admixtures: they help to improve the durability of concrete and mineral admixtures such as pozzolans.

## **2.2 Cement**

Cement in general sense, can be described as a material with adhesive and cohesive properties that when mixed with water, a chemical reaction (hydration) takes place which in time, produces a very hard and strong binding medium for the aggregate particles. The cement of interest in the making concrete have the property of setting and hardening under water by virtue of a chemical reaction with it and are, therefore called hydraulic cements according to (Neville, 2008).

### **2.2.1 Types of Cement**

The use of additives, changing chemical composition and use of different raw materials have resulted in the availability of many types of cement to cater the needs of the construction industries. The various types of cement are listed below

#### **A. Rapid Hardening Cement**

1. When form work is to be removed early for reuse.
2. When sufficient strength for further construction is wanted.
3. Emergency repair work.

### **B. Portland Pozzolana Cement**

1. It can be used in mass construction work.
2. It can be used for low cost housing project.
3. For construction of water tanks and water retaining structures.
4. It can be used in hot weather region.

### **C. Portland Blast Furnace Slag Cement**

1. It can be used in mass construction work.
2. It is used for construction of marine structures.
3. It is used for areas with high sulphate content in ground water.
4. For manufacturing of sewage pipes

### **D. Sulphate Resisting Cement**

1. It is used for construction work near seashore or where sulphate content is higher in ground water.
2. For construction of marine structures.

### **E. Low Heat Cement**

1. It is used in hot weather regions.
2. For mass concreting works such as gravity dam and thick retaining wall.

### **F. White Cement**

1. For joining marbles and ceramic tiles.
2. For preparing joints of sanitary wares.
3. For architectural work.
4. It is used in manufacturing of mosaic tiles.

## **2.2.2 Specialized Type of Cement**

Over the years, specialized cements have been manufactured which have specialized characteristics. This has been achieved by the use of admixtures. Admixtures additives to concrete other than the usual cement, water and aggregates. The admixtures are added before, during or after the mix. The chief purpose of the admixtures is to reduce the cost of concrete and the other purposes include:

1. To modify the properties of hardened concrete.
2. To ensure the quality of concrete during mixing, transportation, placing and curing.iii.
3. To overcome emergent situations during concrete operations.

### **2.3 Aggregates**

Aggregates are also one of the most mined materials known, since it consist of approximately three-quarter the volume of concrete, which is common in building materials. They influence the characteristics of concrete like improving the structural stability and performance of the concrete and also constitute its solid mass which helps in reducing shrinkage. In recent research aggregates are now known to be chemically active. According to Sidney and Young (1981) aggregates should be hard, strong and free of undesirable impurities. Other 25% include cementing materials like cement, sand and synthetic admixtures.

The quality and quantity of concrete constituent materials controls its strength (Chudley and Greeno, 1999) which has also been found to be one of the causes of building collapse all over the world (Ayedun et al, 2011; Ngugi et al, 2014). For this reason attention must be given to the factors which affect the strength of concrete (Olanitori, 2006; Savitha, 2012).

Among this factors are aggregates ( Fine and coarse), which constitute between two –third and one-quarter of the total volume of concrete and the careful selection and proportioning of

aggregate greatly affect all the important properties of both plastic and hardened concretes. The use of aggregates also improves several of the properties of the hardened concrete such as volume stability and durability of concrete (Nevils, 1983).

Aggregates are used in road bases as Asphalt aggregates, with ordinary Portland cement (OPC) as normal aggregates, as fills in foundation and as aggregates accordingly to project specific studies.

When the fines content in sand are excessive, there is the need to add more water to concrete mix in order to improve the workability. That is fine particles such as clay and cement interact with water in a physiochemical state which leads to more absorption of water than that of fine and coarse aggregates. Research has shown that higher amount of sand in concrete results in poor workability. This eventually leads to the addition of water to the concrete mix before or even during the unloading process to improve workability.

### **2.3.1 Classification of Aggregates**

- 1. In Accordance with size:** Course Aggregates: Retained on the No.4 (4.75mm) sieve.  
Fine aggregates: aggregate passing No.4 sieve and predominantly retained on the No.200um sieve.
- 2. In Accordance with source:** Natural Aggregates: Aggregate is taken from natural deposit. Some examples are sand, crushed limestone, dolomite and gravels. Manufactured aggregates: Man-made materials produced as a main product or an industrial by-product. Some examples are blast furnace slag, lightweight aggregates and heavy weight aggregates.
- 3. In accordance with weight:** Light weight aggregate: Their unit weight is less than  $1120\text{kg/m}^3$  and bulk density less than  $1800\text{kg/m}^3$ . Examples are cinder, blast furnace

slag, volcanic pumice. Normal weight Aggregates: Their unit weight is 1520-1680kg/m<sup>3</sup> and bulk density of 2300-2400kg/m<sup>3</sup>. Heavy weight aggregate: their unit weight is greater than 2100kg/m<sup>3</sup> and the bulk density is greater than 3200kg/m<sup>3</sup>. A typical example is magnetite limonite, a heavy iron ore.

### 2.3.2 Types of Aggregates

1. **Granite aggregates:** Granite aggregates are crushed hard rock of granular structure, being the most common on Earth. It is the best aggregate for high-grade concrete Gravel aggregates. Gravel aggregates are aggregates acquired as the result of examining mined rock and by crushing natural stone rock. Gravel aggregates are used for foundation and concretes.
2. **Limestone aggregates:** Limestone is one of the main types of aggregates that besides the gravel and the granite types used in road construction and in production of reinforced concrete objects.
3. **Secondary aggregates:** Secondary aggregate comes from crushing construction waste-concrete, bricks, and asphalt. These aggregates are used as large-scale filler for concretes and in road construction as filler for roads and ramps.
4. **Slag aggregates:** Slag aggregates are obtained by crushing of smelter slag. The cost of products from slag concrete is 20-30% lower than traditional ones.

### 2.3.3 Properties of Aggregates

1. Strength.
2. Hardness.
3. Toughness.

4. Durability.
5. Shape of aggregate.
6. Specific gravity.
7. Absorption, porosity, permeability.

**Strength:** The aggregates should be sufficiently strong to bear the subjected load due to traffic wheel load, wear and tear, crushing, and structure load.

**Hardness:** Hardness is the measure of resistance to crushing and abrasion of aggregate. Aggregate are subjected to crushing and abrasive wear during production, placing, compaction and also subjected to abrasion under traffic load.

**Toughness:** Toughness is the ability of aggregates to resist impact forces. Aggregates which lack adequate toughness and abrasion resistance may cause construction and performance problems.

**Durability:** Aggregates must be resistant to breakdown, and disintegration from weathering or they may break apart. Durability and soundness are terms physically given to

**Specific Gravity:** the ratio of the mass of unit volume of material at a stated temperature to the mass of same volume of gas-free distilled water at a stated temperature. Higher value of specific gravity indicates better aggregates, but the other properties should be necessary.

**Absorption, Porosity, Permeability:** the size number and continuity of pores through the aggregate particles may affect the strength of aggregates, abrasion resistance, surface texture, specific gravity, bonding capability and resistance to freeze and thaw action. Aggregates with low specific gravity and high water absorption are generally considered unsuitable unless they have

**Shape of Aggregates:** Particle shape and surface texture are important for proper compaction, deformation resistance and workability. In hard mix Asphalt (HMA), since aggregates are relied upon to provide stiffness and strength by interlocking with one another, cubic angular-shaped particles with a rough surface are best.

#### **2.3.4 Test on Aggregates**

1. Specific gravity and water absorption test.
2. Los Angeles abrasion test on coarse aggregates.
3. Soundness test.
4. Shape test or flakiness index.

#### **2.4 Water**

Water is a relevant ingredient of concrete as it is engaged in the chemical reaction with cement. The water content in a concrete plays an important role in both workability and strength of concrete. In practice, attentions are focus mainly on the use of cements and aggregates while that of water mix is neglected, the quality and quantity of the water content in concrete has an effect on said concrete. In terms of quality concrete with water of PH value between 6-8 is recommended since it is free from organic matter. Basically, the best way to determine the proper water to be used is by casting cubes for testing with different source of water and cured, compare their strength after 28 days and if 90% of the compressive strength is reached then the water used is of good concrete. Waters used in construction should also have their chemical properties known, because water with considerable amount of carbonates and bi-carbonates of sodium and potassium affects setting time of cement.

Meanwhile, research have also shown that an increase in water/cement ratio result to decrease in the compressive strength of concrete. Additionally, the increase in sand fines content has also been found to decrease the compressive and tensile strength of concrete. Inadequate sand fines content also have adverse effect of the strength of concrete due to poor adhesion.

## **2.5 Mix Design**

Mix design is defined as the process of selecting suitable ingredients of concrete and determining their relative proportion with the object of producing concrete of certain minimum strength and durability as economically as possible. A mix design was conducted as per IS 10262-1982 to arrive at M20 mix concrete. This was the process by which the proportions of various constituents of concrete were determined with the objective of producing concrete with the required fresh and hardened properties.

### **2.5.1 Factors Influencing the Choice of Mix Design**

1. Compressive workability
2. Workability
3. Type and grading of aggregates.
4. Maximum size of aggregates.
5. Durability requirement.

## **2.6 Mixing of concrete**

The coarse aggregates and fine aggregate were weighed and the concrete mixture was prepared by hand mixing on a water tight platform. On the water tight platform cement and fine aggregates are mixed thoroughly until a uniform color is obtained, to this mixture coarse aggregates was added and mixed thoroughly. Then water is added carefully making sure no water is lost during mixing. While adding water care should be taken to add it in stages so as to prevent bleeding which may affect the strength formation of concrete rising of water required for hydration to the surface. Clean and oiled mould for each category was then placed on the

vibrating table respectively and filled in three layers. Vibrations were stopped as soon as the cement slurry appeared on the top surface of the mould.

## **2.7 Casting and Curing**

These specimens were allowed to remain in the steel mould for the first 24 hours at ambient condition. After that these were de-moulded with care so that no edges were broken and were placed in the tank at the ambient temperature for curing. After de-moulding the specimen by loosening the screws of the steel mould, the cubes were placed in water for 7-28 days.

## **2.8 Setting time of Concrete**

Setting time of concrete differs widely from setting time of cement. Setting time of concrete does not coincide with the setting time of cement with which the concrete is made. The setting time of concrete depends upon the w/c ratio, temperature condition, type of cement used, use of material admixture, and use of plasticizers in particular retarding plasticizers

## **2.9 Process of Manufacture of Concrete**

Production of quality concrete requires meticulous care exercised at every stage of manufacture of concrete. It is interesting to note that the ingredient of good concrete and bad concrete are the same. If meticulous care is not exercised and good rules are not observed, the resultant concrete is going to be a bad quality.

With the same material of intense care taken to exercise control at every stage, it will result in good concrete. The various stages of manufacturing of concrete are;

1. Batching.
2. Mixing.

3. Transporting.
4. Placing.
5. Compacting.
6. Finishing.
7. Curing

### 2.10.0 Workability

Workability is an indication of the ease at which a fresh mix of concrete or mortar can be handled and shaped. Methods involved in the determination of the workability of concrete include: slump, compacting factor, and flow

**Table 2.1: Tolerance of workability test for concrete**

Method	Workability	Allowable tolerance
Slump	Medium-high	Greater of +25mm of 1/3 of required
Compacting factor	Low-high	+0.03 required value > 0.90 =0.04 for required value > 0.80 and < 0.90 +0.05 for required value < 0.80
Flow	Very low	+50mm about the required value

(Neville, 2010)

### 2.10.1 Factors Affecting Workability of Concrete

1. Cement content of concrete.
2. Water content of concrete.
3. Mix proportion of concrete.
4. Surface texture of aggregates.
5. Grading of aggregates.
6. Size of aggregates.
7. Shape of aggregates.
8. Use of admixtures in concrete.

**1. Cement content of concrete:** cement content affects the workability of concrete in good measure. More the quality of cement, the more will be the paste available to coat the surface of aggregates and fill the voids between them. This will help to reduce the friction between aggregates and smooth movements of aggregates during mixing, transporting, placing and compacting of concrete.

Also, for a given water-cement ratio, the increase in the cement content will also increase the water content per unit volume of concrete increasing the workability of concrete. Thus increase in cement content of concrete also increases the workability of concrete.

**2. Water content of concrete:** Water/cement ratio is one of the most important factors which influence the concrete workability. Generally, a water cement ratio of 0.45 to 0.6 is used for good workable concrete without the use of any admixture. Higher the water/cement ratio, higher will be the water content per volume of concrete and concrete will be more workable.

Higher water/cement ratio is generally used for manual concrete mixing to make the mixing process easier. For machine mixing, the water/cement ratio can be reduced. This generalized method of using water content per volume of concrete is used only for nominal mixes.

For designed mix concrete, the strength and durability of concrete is of utmost importance and hence water cement ratio is mentioned with the design. Generally designed concrete uses low water/cement ratio so that desired strength and durability of concrete can be achieved.

**3. Mix proportion of concrete:** mix proportion of concrete tells us the ratio of fine aggregates and coarse aggregates with respect to cement quality. This can also be called as the aggregates cement ratio of concrete. The more cement is used, concrete becomes richer and aggregates will have proper lubrication for easy mobility or flow of aggregates.

The low quality of cement with respect to aggregates will make the less paste available for aggregates and mobility of aggregates is restrained.

**4. Surface texture of aggregates:** surface texture such as rough surface and smooth surface of aggregates affect the workability of concrete in the same way as the shape of aggregates.

With rough texture of aggregates, the surface area is more than the aggregates of same volume with smooth texture. Thus concrete with smooth surface are more workable than with rough textured aggregates.

**5. Grading of aggregates:** Grading of aggregates have the maximum effect on the workability of concrete. A well graded aggregate have all sizes in required percentages. This helps in reducing the voids in a given volume of aggregates.

The less volume of voids makes the cement paste available for aggregate surfaces to provide better lubrication to the aggregates.

With less volume of voids, the aggregate particle slides past each other and less compacting effort is required for proper consolidation of aggregates. Thus low water cement ratio is sufficient for properly graded aggregates.

**6. Size of aggregates:** surface area of aggregates depends on the size of aggregates. For a unit volume of aggregates with large size, the surface area is less compared to same volume of aggregates with small sizes.

When the surface area increases, the requirement of cement quantity also increases to cover up the entire surface of aggregates with paste. This will make more use of water to lubricate each aggregate.

Hence, lower sizes of aggregates with same water content are less workable than the large size aggregates.

**7. Shape of aggregates:** The shape of aggregate affects the workability of concrete. It is easy to understand that rounded aggregates will be easy to mix than elongated, angular and flaky aggregates due to less frictional resistance.

Other than that, the round aggregates also have less surface area compared to elongated or irregular shaped aggregates. This will make less requirement of water for some workability of concrete. This is why river sands are commonly preferred for concrete as they are rounded in shape.

**8. Use of admixture in concrete:** There are many types of admixtures used in concrete for enhancing its properties. There are some workability enhancer admixture such as plasticizers and super-plasticizer which increase the workability of concrete even with low water/cement ratio.

They are also called as water reducing concrete admixtures. They reduce the quantity of water required for some value of slump.

### **2.11 Hardening of Concrete**

A fully cured hardened concrete must be strong enough to bear the structural and service loads will be applied to it and also be durable enough to resist the environmental pressure for which it is designed. Fresh concrete is only relevant in the first few hours of its mixing but hardened concrete acquires an importance which is obtained for the remaining life of the concrete.

Strength of the concrete is defined as the maximum load or stress it can withstand. The compressive strength of concrete is taken to be the maximum compressive load it can withstand per unit area while its tensile strength is of a great importance in the design of road. Factors like durability and shrinkage play a vital role in the life span of hardened concrete. The durability of hardened concrete is its resistance to deterioration processes that may occur as a consequence of interaction with its environment which may include damage or corrosion of the embedded reinforcement while shrinkage in concrete is changes in volume induced or not. Change in the volume of concrete caused by shrinkage is due to loss of moisture content at different stages and will affect concrete long term strength and durability.

### **2.12 The compressive strength**

The compressive strength of concrete is taken as maximum compressive load it can carry per unit area. Concrete strength can be achieved by selective use of the types of cement, mix proportions, method of compaction and curing.

Factor affecting concrete strength is the water content used which in some cases are increased to improve workability (Reynolds et al, 2008; Cemex 2013). Meanwhile, research have also shown that an increase in water/cement ratio result to a decrease in the compressive strength of concrete (Olusola et al, 2012; Apebo, 2013). There have been various researches on the effect of water cement ratio on the workability and compressive strength of concrete which shows that there is an optimum amount of water that will produce a concrete of maximum strength from a particular mix of fine and coarse aggregates and cement (Lafe, 1986). The use of than the optimum amount of water may make setting difficult and reduce workability. On the other hand, greater shrinkage and a reduction in strength will occur when more water than the optimum amount is used. The best water-cement ratio, therefore, depends on the particular concrete mix.

The problem in the proportioning of concrete using mixture of cement, fine, and coarse aggregate along with applied water cement ratio is how to get desirable concrete properties such as strength, durability and due economy for the intended structure. Researchers have therefore developed various models for predicting the effect of fine/coarse aggregate ratio and water/cement ratio on the strength of concrete.

The compressive strength of concrete is generally determined by testing cubes made in laboratory or field or core drilled from hardened concrete at site or from the non-destructive testing of the specimen or actual structures. Vibrations must be applied uniformly to the entire concrete mass as otherwise some parts of it would not fully compacted while others might be segregated due to over-vibration.

### **2.12.1 Factors that Affect the Strength of Concrete**

Several factors which affect the strength of concrete are as follows:

1. The water/cement ratio
2. The aggregate/cement ratio
3. The gel/space ratio
4. Porosity
5. Effective water in the mix
6. Effect of the maximum size of aggregate

### **2.13 The Relationship between Compressive Strength and Tensile Strength**

The compressive strength of concrete is its property commonly considered in structural design but for some purpose the tensile strength is of interest. In reinforced concrete construction the concrete in compression is only taken into account, the tensile strength of concrete is generally not taken into account. The design of concrete pavement slabs is often based on the flexural strength of concrete. Therefore, it is necessary to assess the flexural strength of concrete either from compressive strength or independently.

### **2.14 Testing of Concrete**

Properties of concrete are a function of time and ambient humidity, and this is why in order to be valued, tests on concrete have to be performed under specified or known conditions, test can be made of different purposes but main two objectives of testing are quality control and compliance with specification.

### **2.15 Compressive Strength Test**

Of all the test on hardened concrete, compressive strength test is the most common one not only because it is easy to perform, many though not all, of the desirable characteristics of concrete are qualitatively related to its strength of concrete in structural design. Study shows that test result is affected by variation in type of test specimen, specimen size, type of mould, curing, preparation of end surface, rigidity of testing machine and rate of application of stress. It is usually determined using 150mm by 150mm by 150mm cubes.

### **2.16 Flexural Test**

Concrete we know is relatively strong in compression and weak in tension. In reinforced concrete members, little dependence is placed on the tensile strength of concrete since steel reinforced bars provided to resist all tensile forces. However, tensile stress is likely to develop in concrete due to drying shrinkage, temperature gradient and other reasons, therefore, the knowledge of tensile strength of concrete is important.

## **CHAPTER THREE**

### **MATERIALS AND METHODOLOGY**

#### **3.1 Description of study area**

This project was carried out in the concrete laboratory, Department of Civil Engineering, Nnamdi Azikiwe University Awka, Anambra State.

#### **3.2 Materials and Source**

The materials used for this experiment are:

1. Coarse aggregate
2. Fine aggregate
3. Portland cement
4. Water

##### **Coarse Aggregate**

The coarse aggregate used in the experiment was 19mm ( $\frac{3}{4}$  inch) in size and were obtained from Agu-Awka in Anambra State

##### **Fine Aggregate**

The fine aggregate used were river sand with a maximum size of 2mm, free from all organic substance and it was obtained from one river source in Amansea.

##### **Portland Cement**

The cement used for this experiment was ordinary Portland cement, precisely 3X Grade 42.5R Dangote Portland cement was used. The cement was purchased from a cement dealer at Ifite, Anambra State.

## **Water**

The water used in this research was drinkable water. The same water was used for mixing and for curing of concrete cubes. Water quality is of great importance in concrete, as impure water can cause: corrosion of steel used in reinforcement, staining of concrete surface, alteration of the cement setting time.

### **3.3 Equipments and apparatus**

The equipments and apparatus used in this research work are as follows:

1. Shovel
2. Hand trowel
3. Cement/head pan
4. Slump cone
5. Casting cubes
6. A pocket tape
7. Plumb or Spirit level
8. Set of sieves
9. Mechanical sieve shaker
10. Weighing balance
11. Tamping rod
12. Wire brush
13. Measuring cylinder

### **3.4 METHODOLOGY**

The following experiments were carried out during the research work.

- i. Sieve analysis test of fine and coarse aggregate

- ii. Slump test
- iii. Curing of concrete
- iv. Compressive strength test
- v. Specific Gravity Test

### **3.4.1 Sieve analysis**

This test is used to determine the particulate sizes of aggregates.

#### **Apparatus**

- i. B.S test sieves
- ii. Weighing balance
- iii. Wire brush
- iv. Electric weighing balance
- v. Mechanical sieve shaker

#### **Procedure**

- i. The sieves were properly cleaned using a wire brush and the weight of each sieve and receiving pan recorded.
- ii. The specimen was air dried (sun dried) and its weight recorded.
- iii. The sieves were arranged in descending order, as smaller openings sieve to the last and the large openings to the top
- iv. The sample was poured into the top sieve and the complete sieve stack was placed on a mechanical sieve shaker.
- v. The mechanical sieve shaker was turned on to shake the sample for 10 minutes.
- vi. After 10minutes, the sieve stack was removed from the shaker and weight of each sieve containing particles of sample and receiving pan recorded.

- vii. The particles of the specimen whose diameter was smaller than the mesh openings passes through the sieves. The weight of sample of each sieve was then divided by the total weight to give the percentage retained in each sieve. The result of this test was used to define the sizes of the sample.

### **3.4.2 Slump Test**

This test was used to ascertain the workability of the freshly mixed concrete. The mold of slump test is a frustum of a cone, 30.5mm in height and with a base of 20.3mm in diameter.

#### **Apparatus**

- i. Meter rule and plumb/spirit level
- ii. Tamping rod
- iii. Hand trowel
- iv. Slump cone

#### **Procedure**

- i. Inside of the slump cone was thoroughly cleaned
- ii. The slump cone was placed on a smooth, horizontal, non-water absorbable surface with its smaller opening at the top
- iii. One layer of the freshly mixed concrete was poured into the cone, that is the mixed concrete occupying one-third of the entire cone
- iv. After pouring of the first layer, a tamping rod was used to tamp the fresh concrete in the cone 25 times. The second layer was also poured ( $\frac{2}{3}$  of the entire cone) followed by third layer
- v. Each of the three layers were tamped or stroked for 25times

- vi. Once the tamping of the third layer is completed, the top of the cone was leveled off with a trowel
- vii. After the leveling, the cone was removed from the fresh concrete immediately by carefully raising it
- viii. The cone was placed by the side of freshly mixed and tamped concrete, and both heights measured. The difference in height between the top of the cone and the top of the fresh concrete is the slump. If no difference, that means zero slump(no slump)

### **3.4.3 Curing of Concrete**

Curing involves removing the concrete cube from the mold and promoting the hydration of cement in concrete. In order for quality concrete, the placing of an appropriate mix must be followed by curing in suitable environment during the early stage.

The curing process used for the purpose of this project is by placing the concrete cubes in hydration tank full of water to the brim, so as to keep the concrete cube at a constant saturated condition during the testing period. Basically, curing helps to maximize cracking, to reduce permeability and in turn increase the durability of concrete.

The concrete cubes were removed from the mold after 24 hours of casting and transferred to the water tank for a period of 28 days.

### **3.4.4 Compressive Strength Test**

The compressive strength of concrete is its resistance to failure under the action of compressive force or load. Compressive strength is measured by breaking cube or cylindrical concrete

specimens in a compression-testing machine. Compressive strength is calculated from the failure load by dividing failure load by cross-sectional area resisting the load.

### **Procedure**

- i. The cubes after curing are dried for testing and brought to the machine.
- ii. The part of the testing machine bearing the load was cleaned and a cube placed on it, as the test was done one after the other for each of the concrete cubes.
- iii. The cube was centered on the base plate of the machine, and another metal plate was placed resting on the concrete, vertically opposite the base plate.
- iv. Pressure (load) was gradually applied on the second plate without shock at the rate of 140kg/cm/minute till the specimen (concrete cubes) fails. At failure the clock like hand showing the reading, instead of moving to higher compressive strength, starts decreasing and the evidence of this failures are mostly shown as cracks in the concrete cubes.
- v. The maximum load was recorded as failure before the decreasing of the reading, and the load at failure divided by the area of the specimen (concrete cubes) gives the compressive strength of the concrete.
- vi.  $Compressive\ Strength = \frac{Crushing\ load}{Area} (N/mm^2)$

### **3.4.5 Specific Gravity Test**

The specific gravity of solid particles is the ratio of mass of given volume of solids to the mass of an equal volume of water at 4<sup>0</sup>C; it is represented by “G”

### **Apparatus**

- i. Density bottle
- ii. Electric balance of accuracy 0.001g
- iii. Oven

- iv. Vacuum desiccator
- v. Two soft absorbent cloth

### **Procedure**

- i. The density bottle was cleaned and put in an oven at temperature of 100<sup>0</sup>C to 105<sup>0</sup>C for drying. After drying, it was put in the desiccator to cool down.
- ii. The density bottle along with stopper was weighed using weighing balance to an accuracy of 0.001g; this was recorded as “M1”
- iii. 5 to 10g of oven dried sample was poured into the density bottle along with stopper and dry sample recorded as “M2”
- iv. De-aired distilled water was added to the soil in the density bottle up to the soil level and shake gently to mix soil and water
- v. The stopper of the density bottle was removed and the density bottle placed in vacuum desiccator and vacuum pump connected. The air entrapped in the soil is expelled by applying vacuum pressure.
- vi. After that, the lid was removed and soil stirred using spatula. The soil adhere to the spatula was washed into the bottle with air free distilled water.
- vii. The bottle was removed from the desiccator and more distilled water added until the bottle was full. The stopper was then inserted. To attain constant temperature through the bottle, the bottle was immersed into a water bath for one hour; the bottle was brought out from the water bath after attaining constant temperature, its outside was cleaned and dried using smooth cloth

- viii. Weight of the bottle, which is the total mass of bottle, soil and water was recorded as “M3”. The bottle was emptied, washed and refilled with distilled water. It was also placed in water bath for one hour to maintain same temperature during experiment.
- ix. The weight of the bottle full of distilled water along with stopper was recorded as “M4”. The same procedure was repeated for two or three times and an average reading taken as final result
- x. Specific gravity is the calculated using the formula:

$$G.S = \frac{M2 - M1}{(M4 - M1) - (M3 - M2)}$$

**Table 3.1: Range of Specific Gravity value of different Soils**

SOIL TYPE	SPECIFIC GRAVITY
Gravel	2.65 – 2.68
Sand	2.65 – 2.68
Silty sand	2.66 – 2.70
Silt	2.66 – 2.70
Inorganic soil	2.68 – 2.80
Organic soil	<2.00

## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 RESULTS

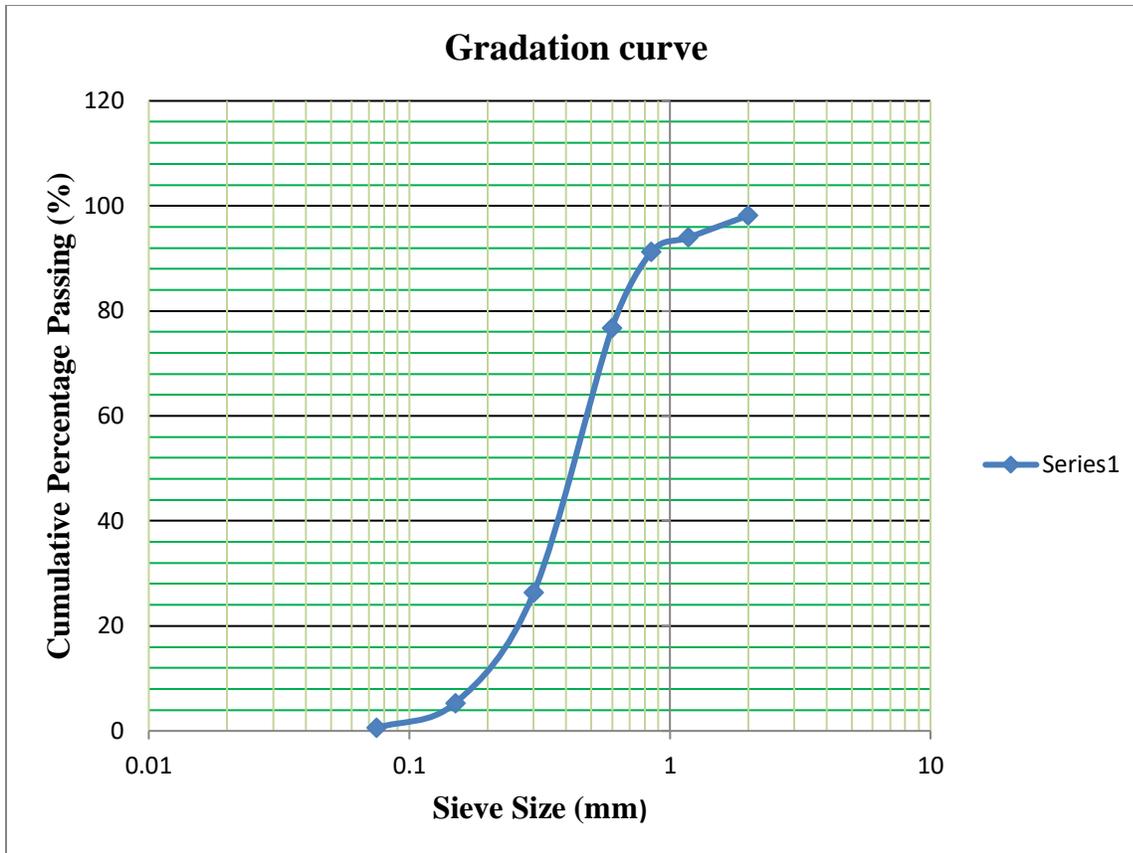
##### 4.1.1 Sieve Analysis of Fine Aggregate

Table 4.1.1 presents the results of sieve analysis for fine aggregates.

The total weight of fine aggregate sample was 400g.

**Table 4.1.1: Result of sieve analysis for fine aggregates.**

<b>Sieve Size (mm)</b>	<b>Mass Retained (g)</b>	<b>Percentage Retained (%)</b>	<b>Cumulative Percentage Retained (%)</b>	<b>Cumulative Percentage Passing (%)</b>
2.0	7.25	1.82	1.82	98.17
1.18	16.79	4.1	6.01	93.99
0.850	10.93	2.74	8.76	91.24
0.60	57.75	14.47	23.22	76.78
0.30	197.89	49.37	72.58	26.31
0.150	93.05	23.18	95.79	5.32
0.075	14.53	3.65	99.43	0.58
Tray	2.31	0.58	100	0
	399.54			



**Figure 4.1 Graph of Cumulative Percentage Passing against Sieve Size**

From figure 4.1 the uniformity coefficient ( $C_u$ ) of the aggregate can be determined using the expression below.

$$C_u = \frac{D_{60}}{D_{10}}$$

Where  $D_{60} = 0.50$

$$D_{10} = 0.20$$

$$\text{Therefore } C_u = \frac{0.50}{0.20} = 2.5$$

The coefficient of Curvature ( $C_c$ ) of the aggregate is given as;

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$$

Where  $D_{30} = 0.35$

$$C_c = \frac{(0.35)^2}{(0.50) \times (0.20)} = 1.225$$

From the result obtained:  $C_u = 2.5$  shows that the fine aggregate is well graded and  $C_c = 1.225$  shows that the sand is well graded.

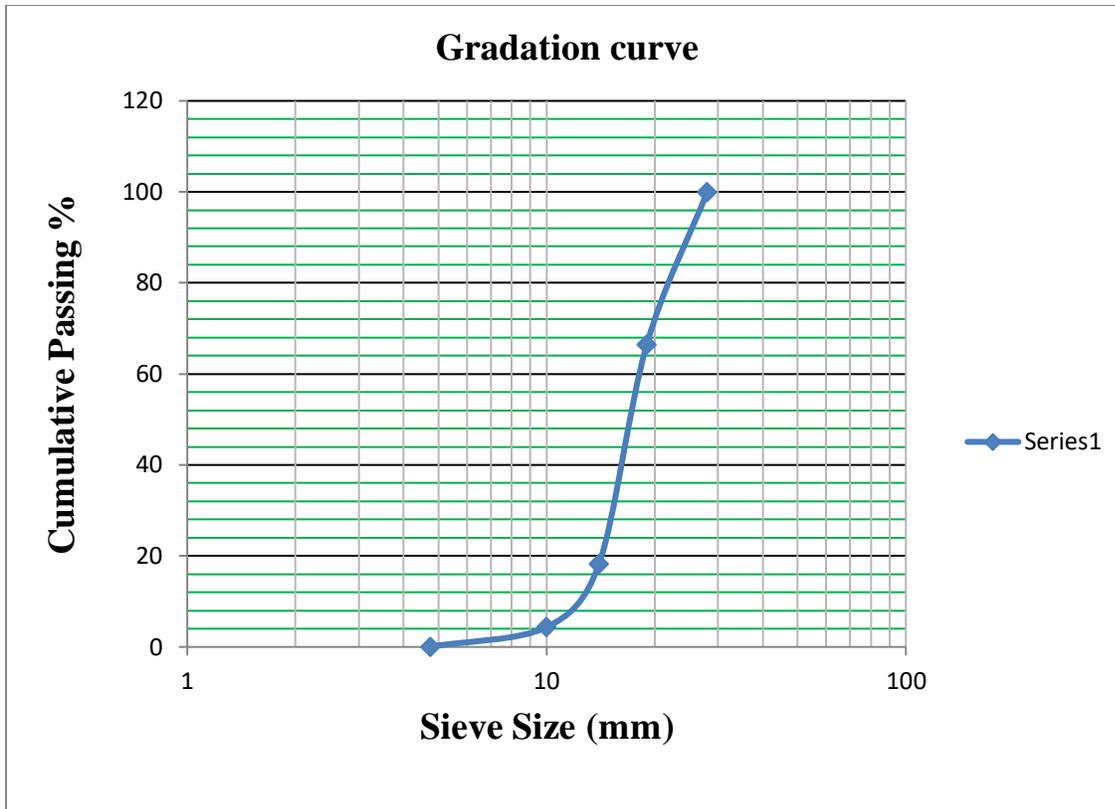
#### 4.1.2 Sieve Analysis of Coarse Aggregate

Table 4.1.2 presents the results of sieve analysis for coarse aggregates.

The total weight of coarse aggregate sample was 1000g.

**Table 4.1.2: Result of sieve analysis for coarse aggregates.**

<b>Sieve Size (mm)</b>	<b>Mass Retained (g)</b>	<b>Percentage Retained (%)</b>	<b>Cumulative Percentage Retained (%)</b>	<b>Cumulative Percentage Passing (%)</b>
28	0	0	0	100
19	335.80	335.80	33.58	66.42
14	481.70	817.50	81.75	18.25
10	139.00	956.50	95.65	4.35
4.75	43.00	999.50	99.95	0.05
Tray	0.42	1000	100	0



**Fig 4.2 Graph of Cumulative percentage passing against sieve size**

From the graph:  $D_{60} = 19.5$ ;  $D_{30} = 16.5$ ;  $D_{10} = 15$

$$\text{Uniformity Coefficient (Cu)} = \frac{D_{60}}{D_{10}} = \frac{19.5}{16.5} = 1.30$$

$$\text{Coefficient of Curvature (Cc)} = \frac{D_{30}^2}{(D_{60} \times D_{10})} = \frac{16.5^2}{19.5 \times 15} = 0.93$$

## 4.2 Specific Gravity Test Result

Table 4.2.1 presents the specific gravity of fine aggregates

Number of Trials	1	2
Weight of density bottle + lid $M_1$ (g)	26.20	26.41
Weight of bottle + dry soil $M_2$ (g)	36.20	36.41
Weight of bottle + soil + water $M_3$ (g)	78.41	82.52
Weight of bottle + water $M_4$ (g)	72.21	76.35
Weight of sample $M_2 - M_1$ (g)	10	10
Weight of water $M_4 - M_1$ (g)	46.01	49.94
Weight of water added to dry sample $M_3 - M_2$ (g)	42.21	46.11
Specific Gravity	2.63	2.61

$$\text{Specific Gravity} = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$$

$$\text{For first Trial} = \frac{36.20 - 26.20}{(72.21 - 26.20) - (78.41 - 36.20)} = 2.63$$

$$\text{For second Trial} = \frac{36.41 - 26.41}{(76.35 - 26.41) - (82.52 - 36.41)} = 2.61$$

$$\text{Average Specific Gravity} = \frac{2.63 + 2.61}{2} = 2.62$$

**Table 4.2.2 presents the specific gravity for coarse aggregates**

Number of Trials	1	2
Weight of bottle + lid $M_1$ (g)	664.6	664.5
Weight of bottle + dry sample $M_2$ (g)	1397.9	1349.4
Weight of bottle + sample + water $M_3$ (g)	2146.3	2118.7
Weight of bottle + water $M_4$ (g)	1688.5	1684.4
Weight of sample $M_2 - M_1$ (g)	733.3	684.9
Weight of water $M_4 - M_1$ (g)	1023.9	1019.9
Weight of water added to dry sample $M_3 - M_2$ (g)	748.4	769.3
Specific Gravity	2.69	2.73

$$\text{Specific Gravity} = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$$

$$\text{For first Trial} = \frac{1397.9 - 664.6}{(1688.5 - 664.6) - (2146.3 - 1397.9)} = 2.69$$

$$\text{For second Trial} = \frac{1349.4 - 664.5}{(1684.4 - 664.5) - (2118.7 - 1349.4)} = 2.73$$

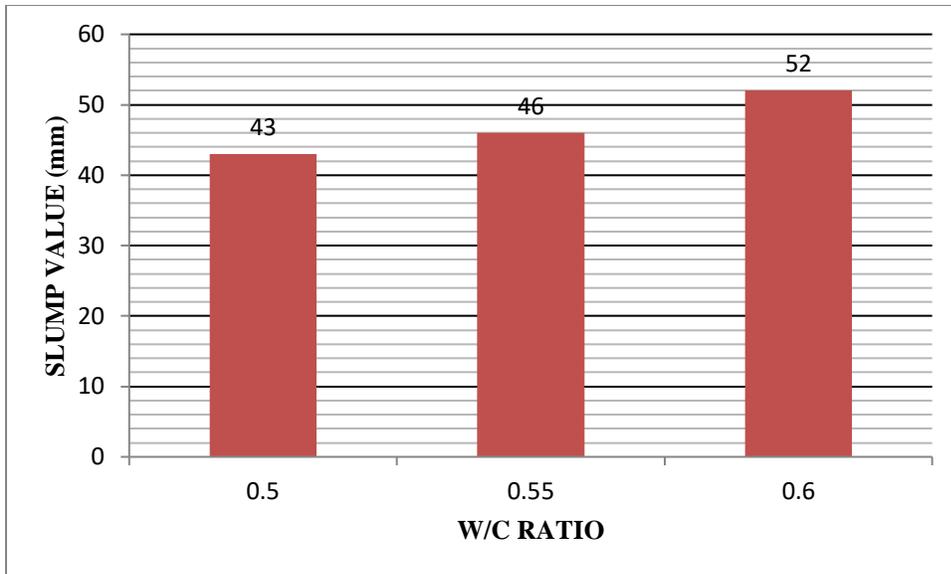
$$\text{Average Specific Gravity} = \frac{2.69 + 2.73}{2} = 2.71$$

### 4.3 Slump Test

The workability results are shown in the tables below:

**Table 4.3.1 slump test values for 1:2:4 concrete mix**

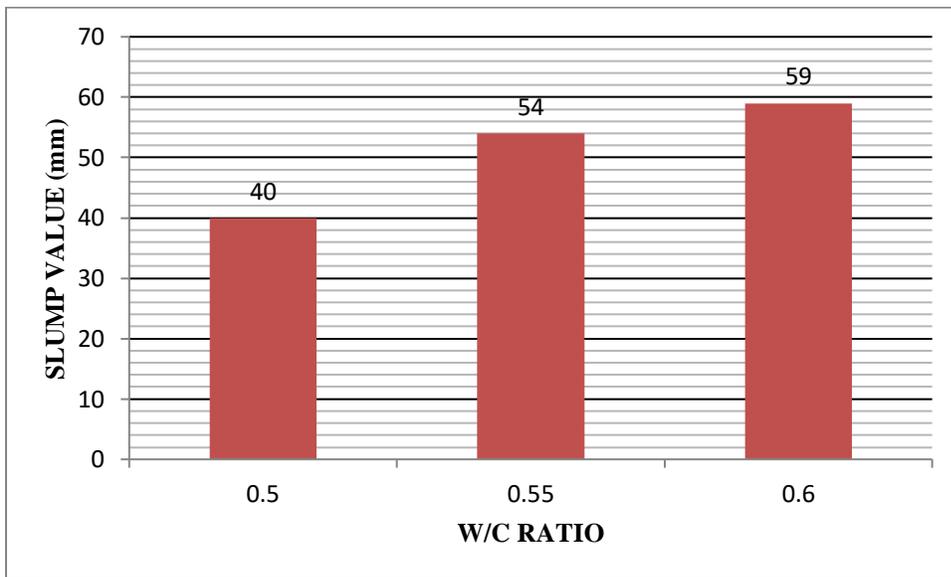
Water-cement ratio	Slump value (mm)
0.50	43
0.55	46
0.60	52



**Fig 4.3 Slump value variation with water-cement ratio (1:2:4)**

**Table 4.3.2 slump test values for 1:3:6 concrete mix**

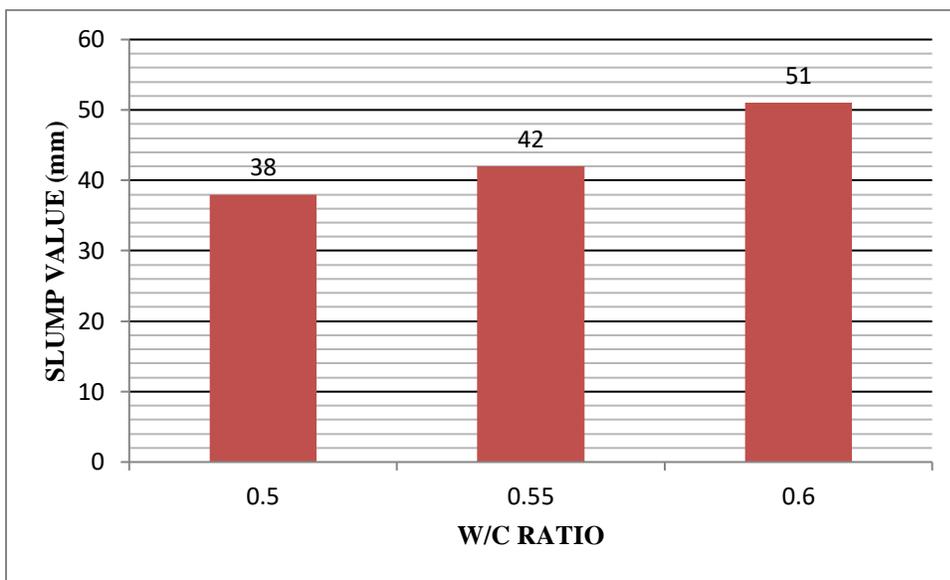
Water-cement ratio	Slump value (mm)
0.50	40
0.55	54
0.60	59



**Fig 4.4 Slump value variation with water-cement ratio (1:3:6)**

**Table 4.3.3 slump test values for 1:1½:3 concrete mix**

Water-cement ratio	Slump value (mm)
0.50	38
0.55	42
0.60	51



**Fig 4.5 Slump value variation with water-cement ratio (1:1½:3)**

#### 4.4 Compressive Strength Test

$$\text{Volume of cube} = (150 \times 150 \times 150)\text{mm} = (0.15\text{m})^3 = 0.003375\text{m}^3$$

$$\text{Area of cube} = 150 \times 150 = 22500\text{mm}^2$$

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{\text{Crushing Load (KN)} \times 10^3}{22500}$$

**Table 4.4.1 result of compressive strength of 1:2:4 concrete cube. W/C Ratio 0.50**

Curing Days	Sample	Mass of cube (kg)	Crushing Load (KN)	Compressive Strength (N/mm <sup>2</sup> )	Average Compressive Strength (N/mm <sup>2</sup> )
28	A	8.6	522.80	23.23	23.73
	B	8.5	541.92	24.08	
	C	8.5	537.44	23.88	

**Table 4.4.2 result of compressive strength of 1:2:4 concrete cube. W/C Ratio 0.60**

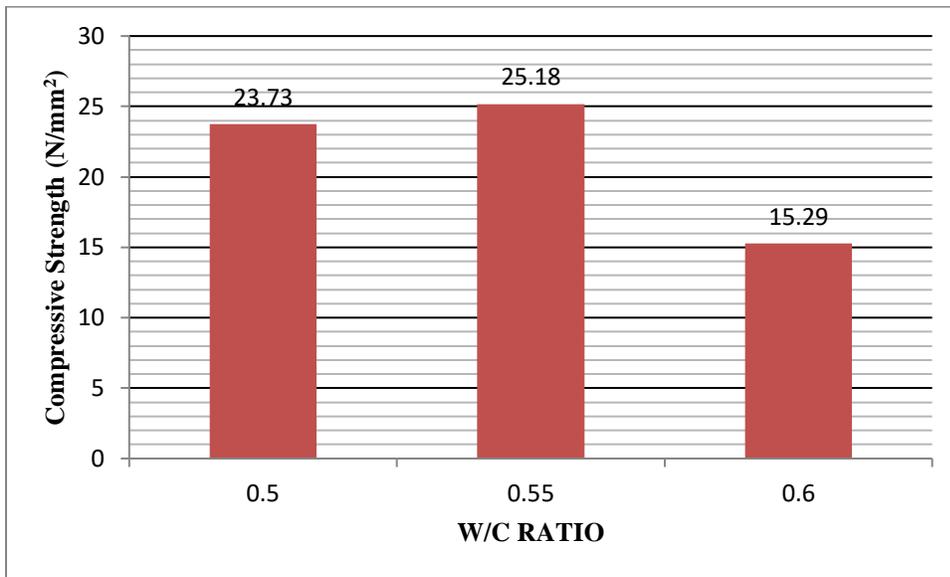
Curing Days	Sample	Mass of cube (kg)	Crushing Load (KN)	Compressive Strength (N/mm <sup>2</sup> )	Average Compressive Strength (N/mm <sup>2</sup> )
28	A	8.9	484.65	21.54	21.26
	B	8.5	467.33	20.77	
	C	8.6	483.53	21.49	

**Table 4.4.3 result of compressive strength of 1:1 $\frac{1}{2}$ :3 concrete cube. W/C Ratio 0.55**

Curing Days	Sample	Mass of cube (kg)	Crushing Load (KN)	Compressive Strength (N/mm <sup>2</sup> )	Average Compressive Strength (N/mm <sup>2</sup> )
28	A	8.9	563.40	25.04	25.18
	B	9.0	568.80	25.28	
	C	8.85	567.69	25.23	

**Table 4.4.4 result of compressive strength of 1:3:6 concrete cube. W/C Ratio 0.50**

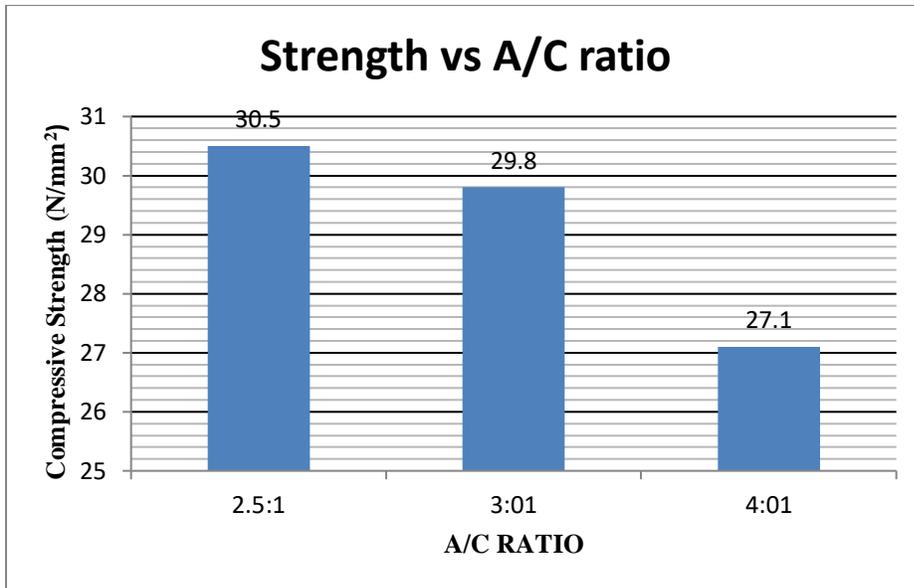
Curing Days	Sample	Mass of cube (kg)	Crushing Load (KN)	Compressive Strength (N/mm <sup>2</sup> )	Average Compressive Strength (N/mm <sup>2</sup> )
28	A	8.7	394.92	17.55	15.29
	B	8.5	321.75	14.30	
	C	8.6	315.45	14.02	



**Fig 4.6 a chart showing the variation of compressive strength for w/c ratio 0.50 of 1:2:4 mix, w/c ratio 0.55 of 1:1 $\frac{1}{2}$ :3 mix and w/c ratio 0.60 of 1:3:6 mix**

**Table 4.5: Compressive Strength variation with A/C Ratio**

Aggregate-cement ratio	Compressive strength (N/mm <sup>2</sup> )	Water-cement ratio	Slump (mm)
2.5:1	30.5	0.50	46
3:1	29.8	0.55	54
4:1	27.1	0.60	57



**Fig 4.7 compressive strength variation with aggregate-cement ratio**

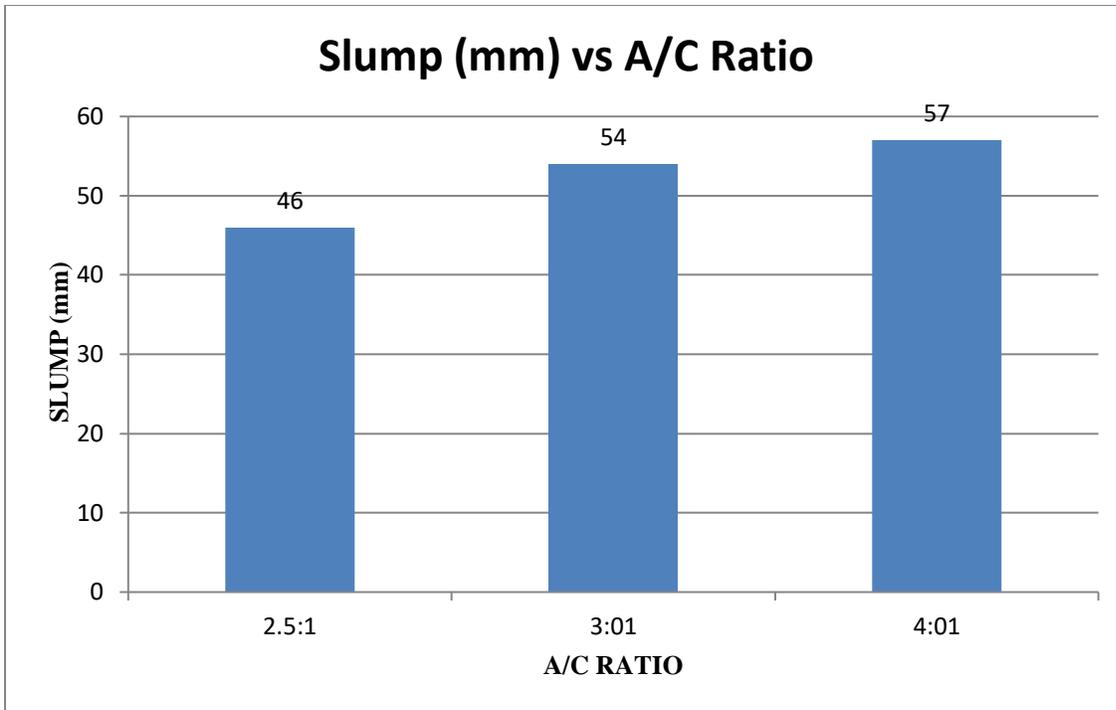


Fig 4.8 Slump variation with aggregate-cement ratio

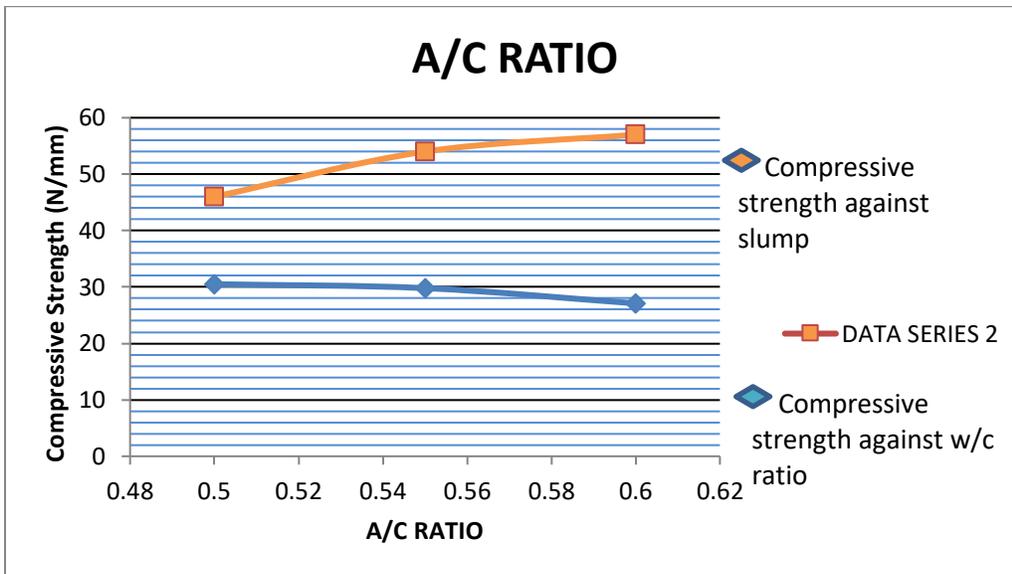


Fig 4.9 compressive strength variation with and a/c ratio

## 4.5 Discussion

1. From the result of sieve analysis of fine aggregate, the graph shows that the fine aggregates is uniformly graded with uniformity coefficient of 2.50 and the result of sieve analysis of coarse aggregate is well graded with  $C_u$  of 1.30. Hence, the fine and coarse aggregates are suitable for concrete production.
2. The specific gravity of fine and coarse aggregate is found to be 2.62 and 2.71 respectively. These figures are within the acceptable range of above 2.00 for the majority of natural occurring aggregates used in the production of normal weight concrete.
3. The slump test result shows that the workability of freshly mixed concrete increases with higher water-cement ratio. The highest workability was recorded at 1:3:6 mix with water-cement ratio of 0.6 which has a slump value of 59mm while the lowest workability was recorded at 1:1.5:3 mix with water-cement ratio of 0.50 which has slump value of 38mm.
4. The average compressive strength values at 28 days curing age varies with w/c ratio and the mean compressive strength recorded from w/c ratio of 0.5 is almost twice higher than the strengths gained from 0.60 w/c. That is higher strength concrete can be achieved with low water content.

## **CHAPTER FIVE**

### **CONCLUSION AND RECOMMENDATION**

#### **5.1 CONCLUSION**

From the comparative workability and strength analysis carried out on the concrete, the following conclusions were made based on the result obtained

1. The consistency or workability of concrete mixture which is indicated by slump; decreases with increasing aggregate-cement ratio for a constant water-cement ratio and increases with increasing water-cement ratio for a constant aggregate-cement ratio.
2. The compressive strength of concrete decreases with increasing water-cement ratio for a constant aggregate-cement ratio and increases slightly with increasing aggregate-cement ratio for a constant water-cement ratio. However, the compressive strength of concrete mixes increases with age.
3. The presence of larger aggregate sizes resulted in higher strength of concrete. This suggests that the larger the sizes of coarse aggregate present in a concrete mixture, the greater the compressive strength, this is in agreement with the finding of Vilane, B.R. and Sabelo, N. 2016.
4. It was concluded that the use of water-cement ratio above 0.60 should be discouraged since it produces concrete with compressive strength below  $21N/mm^2$  which is the minimum required compressive strength value by National Building Code.

#### **5.2 RECOMMENDATION**

1. The use of concrete mixture containing large amount of fine aggregates should be discouraged because the workability is poor and there is a lot of void that have adverse effect on the strength

2. A higher water-cement ratio should be employed when concrete with high workability is required, having in mind that the higher the water-cement ratio, the lower the compressive strength of the concrete.
3. Professionals should be involved in the production and supervision of concrete works so as to safeguard against quality control of mixes used on site.

### **5.3 DIFFICULTIES ENCOUNTERED**

1. Insufficient number of molds with which to cast the required number of cubes at a particular time.
2. Unavailability of constant and regular power supply makes the test results sometimes unreliable.

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**APPENDIX**  
**MIXTURE DESIGN**

Volume of cube  $150\text{mm} \times 150\text{mm} \times 150\text{mm} = (0.15\text{m})^3 = 0.003375\text{m}^3$

Mixed design by weight =  $\frac{\text{Ratio}}{\text{Total ratio}} \times \text{weight}(\text{kg})$

$$D = \frac{M}{V}$$

Where  $D = \text{Density}$

$M = \text{Mass}$

$V = \text{Volume}$

Therefore  $M = D \times V$

Assumed Density: Cement =  $1440\text{kg}/\text{m}^3$

Fine aggregate =  $2600\text{kg}/\text{m}^3$

Coarse aggregate =  $2400\text{kg}/\text{m}^3$

Density of concrete =  $2400\text{kg}/\text{m}^3$

$$\begin{aligned} \text{Mass} &= \text{Density} \times \text{Volume} \\ &= 2400\text{kg}/\text{m}^3 \times 0.003375\text{m}^3 \\ &= 8.1\text{kg} \end{aligned}$$

**1. W/C ratio 0.50**

**For 1: 2: 4 mixture**

$$1 + 2 + 4 = 7$$

$$\text{Cement} = \frac{1}{7} \times 8.1 = 1.16\text{kg}$$

$$\text{Fine aggregate} = \frac{2}{7} \times 8.1 = 2.31\text{kg}$$

$$\text{Coarse aggregate} = \frac{4}{7} \times 8.1 = 4.63\text{kg}$$

$$\frac{W}{C} = 0.5 \quad \text{where } W = \text{Water}$$

$$W = 0.5 \times C$$

$$W = 0.5 \times 1.16$$

$$= 0.58\text{kg} = 580\text{g}$$

$$580\text{g} = 580\text{ml} \quad [1\text{g} = 1\text{ml}]$$

2. **W/C ratio 0.55**

**For 1: 1  $\frac{1}{2}$ : 3 mixture**

$$1 + 1\frac{1}{2} + 3 = 5.5$$

$$\text{Cement} = \frac{1}{5.5} \times 8.1 = 1.47\text{kg}$$

$$\text{Fine aggregate} = \frac{1.5}{5.5} \times 8.1 = 2.21\text{kg}$$

$$\text{Coarse aggregate} = \frac{3}{5.5} \times 8.1 = 4.42\text{kg}$$

$$\begin{aligned}\text{Water} &= 0.55 \times C \\ &= 0.55 \times 1.47 \\ &= 0.8085\text{kg} = 808.5\text{g} \\ 808.5\text{g} &= 808.5\text{ml}\end{aligned}$$

3. **W/C ratio 0.60**

**For 1: 2: 4 mixture**

$$1 + 2 + 4 = 7$$

$$\text{Cement} = \frac{1}{7} \times 8.1 = 1.16\text{kg}$$

$$\text{Fine aggregate} = \frac{2}{7} \times 8.1 = 2.31\text{kg}$$

$$\text{Coarse aggregate} = \frac{4}{7} \times 8.1 = 4.63\text{kg}$$

$$\begin{aligned}\text{Water} &= 0.6 \times C \\ &= 0.6 \times 1.16 \\ &= 0.696\text{kg} = 696\text{g} \\ 696\text{g} &= 696\text{ml}\end{aligned}$$

**For 1: 3: 6 mixture**

$$1 + 3 + 6 = 10$$

$$\text{Cement} = \frac{1}{10} \times 8.1 = 0.81\text{kg}$$

$$\text{Fine aggregate} = \frac{3}{10} \times 8.1 = 2.43kg$$

$$\text{Coarse aggregate} = \frac{6}{10} \times 8.1 = 4.86kg$$

$$\begin{aligned}\text{Water} &= 0.6 \times C \\ &= 0.6 \times 0.81 \\ &= 0.486kg = 486g \\ 486g &= 486ml\end{aligned}$$

**For 1: 1  $\frac{1}{2}$ : 3 mixture**

$$1 + 1\frac{1}{2} + 3 = 5.5$$

$$\text{Cement} = \frac{1}{5.5} \times 8.1 = 1.47kg$$

$$\text{Fine aggregate} = \frac{1.5}{5.5} \times 8.1 = 2.21kg$$

$$\text{Coarse aggregate} = \frac{3}{5.5} \times 8.1 = 4.42kg$$

$$\begin{aligned}\text{Water} &= 0.6 \times C \\ &= 0.6 \times 1.47 \\ &= 0.882kg = 882g \\ 882g &= 882ml\end{aligned}$$

4. **W/C ratio 0.70**

**For 1: 2: 4 mixture**

$$1 + 2 + 4 = 7$$

$$\text{Cement} = \frac{1}{7} \times 8.1 = 1.16kg$$

$$\text{Fine aggregate} = \frac{2}{7} \times 8.1 = 2.31kg$$

$$\text{Coarse aggregate} = \frac{4}{7} \times 8.1 = 4.63kg$$

$$\begin{aligned}\text{Water} &= 0.7 \times C \\ &= 0.7 \times 1.16 \\ &= 0.812kg = 812g \\ 812g &= 812ml\end{aligned}$$





