# PRODUCTION OF LIGHWEIGHT CONCRETE THROUGH UTILIZATION OF PALM KERNEL SHELL AND RICE HUSK

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**SUBMITTED TO**

**THE DEPARTMENT OF CIVIL ENGINEERING**

**FACULTY OF ENGINEERING**

**NNAMDI AZIKIWE UNIVERSITY AWKA.**

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

**MAY, 2023**

## CERTIFICATION

This is to certify that this project topic titled “ Production of Light Weight Concrete Through Utilization of Palm Kernel Shell and Rice” was undertaken by Peter…. with registration number (NAU/2017224) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State.

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**APPROVAL PAGE**

This research work " Production of Light Weight Concrete Through Utilization of Palm Kernel Shell and Rice" has been assessed and approved by department of civil engineering Nnamdi Azikiwe University.

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# DEDICATION

This work is dedicated to Almighty God for the gift of life and also for guiding me through school. I also want to dedicate this work to my lovely mother Mrs------- who served as a real source of inspiration toward my academic pursuit.

**ACKNOWLEDGEMENT**

Special thanks go to Almighty God for giving me the strength to complete this work and also for His guidance and protection throughout my stay in Nnamdi Azikiwe University.

Also I will like to express my profound gratitude to my mum; Mrs ----- for her moral support, constant prayers throughout my stay in school, special thanks goes also to my siblings---------- for their encouragement during trying times of my academic pursuit.

I want to thank in a very special way, my project supervisor in the person of Engr. Dr. Boniface Adinna for his time and guidance in the accomplishment of this project. May the lord rain blessing from heaven for him and his family and may he also protect your family.

Special thanks go to the Head of Department of Civil Engineering in the person of Engr. Prof. C. A. Ezeagu. He has been more like a father to us all and I appreciate him so much.

I will also like to extend my heartfelt appreciation to all the staff (academic and non-academic) of the Department of Civil Engineering for their invaluable tutorship and professional guidance.

Finally, I will like to appreciate everyone who has in one way or the other contributed to making me a better person, may the Lord Almighty reward you all greatly

**ABSTRACT**

The study was carried out to evaluate the effect of palm kernel shell and rice husk on the mechanical properties of light weight concrete. Granite was partially replaced with sand in an in an increasing order of 10% to 40% by weight of granite while sand was partially replaced with rice husk in an increasing order of 5% to 20% by weight of sand. Laboratory test was conducted to evaluate the effect of utilization of palm kernel shell and rice husk in concrete production. This test includes: sieve analysis test, workability test, water absorption test, specific gravity test and compressive strength test. Results obtained from sieve analysis test revealed that sand granite and palm kernel shell were classified as A-2-4 and A-1-b a according to AASHTO Soil Classification System, SC and GM according to Unified Soil Classification System, the specific gravity of granite sand and palm kernel shell were 2.66, 2.69 and 2.17 respectively. Slump test results showed that the slump of the concrete decreased on consistent addition of palm kernel shell and rice husk to the concrete, the hardened density and compressive strength was found to decrease on consistent addition of palm kernel shell and rice husk to the concrete. This study therefore discourage the use of palm kernel shell and rice husk as constituents in concrete production as the density and compressive strength was undermined.

## TABLE OF CONTENT

**Contents** **Page No**

## CHAPTER TWO: Literature Review

2.1 Overview

2.2 Concrete Production Process

2.2.1 Batching

2.2.2 Mixing

2.2.3 Transportation

2.2.4 Placing

2.2.5 Compaction

2.2.6 Curing

2.2.7 Formwork

2.2.8 Inspection and Testing

2.3 Constituents of Concrete

2.3.1 Cement

2.3.1.1 Chemical Composition of Portland Cement

2.3.1.2 Properties of Cement

2.3.2 Aggregate

2.3.3 Water

2.3.4 Admixture

2.3.4.1 Normal Water-Reducing Admixtures

2.3.4.2 Accelerating Water-Reducing Admixtures

2.3.4.3 Retarding Water – Reducing Admixture

2.3.4.4 Air Entraining Admixtures

2.4 Properties of Fresh Concrete

2.4.1 Workability

2.4.2 Plastic Cracking

2.4.3 Early Thermal Cracking

2.5 Properties of Hardened Concrete

2.5.1 Tensile Strength

## APPENDICES

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF PLATE

## LIST OF SYMBOL & ABBREVIATION

$G_S$ – Specific Gravity

AASHTO – American Association of State Highway and Transportation Officials

USCS – Unified Soil Classification System

ASTM – American Society for Testing and Material

BSL – British Standard Light

BSH – British Standard Heavy

$D_{10}$ – Particle Size such that 10% is finer than the Size

$D_{30}$- Particle Size such that 30% is finer than the Size

$D_{60}$- Particle Size such that 60% is finer than the Size

$C_U$ – Coefficient of Uniformity

$C_C$ – Coefficient of Curvature

SC – Clayey Sand

SM – Silty Sand

GM – Silty Gravel

GC—Clayey Gravel

GW—Well Graded Gravel

GP—Poorly Graded Gravel

SP—Poorly Graded Sand

SW—Well Graded Sand

CL – Inorganic Clay of Low Plasticity (lean clay)

CH—Inorganic Clay of High Plasticity (fat clay)

ML- Silt of low Plasticity

MH – Silt of High Plasticity

**LIST OF APPENDICES**

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of Study

Conventional materials utilized in the production of concrete like cement, sand, granite and water are essential prerequisite in the construction industry, of which concrete is one of the widely used materials for construction of civil engineering structures like building, roads, bridge, tunnel, embankment and others (Bheel, et al., 2018). Since is far more in demand and is largely utilized industrially, its versatile nature, inevitable dependence and economic viability have placed it at the top of the mot building material (Sourav, et al., 2015: Nguyen, et al., 2018: Meghevar, et al., 2016). Aggregate used in concrete production account for 60 -80 percent of the total volume of concrete depending on the mix design (Ezekiel, 2018). Coarse aggregate are produced during quarrying of limestone. Extraction and crushing of limestone involves stripping, drilling, blasting and impact crushing (Ezekiel, 2018). These processes constitute severe noise pollution; affect natural air quality and generally environmental instability (Ezekiel, 2018).

Fine aggregate (natural river sand) on the other hand are obtained during dredging, excavation and mining of natural river sand (Subramanian and Kannan, 2013). This activity constitutes severe negative effect on the natural environment such as erosion and failure of river banks, lowering of river beds and damage of structures situated closer to the rivers, saline water intrusion into the land and coastal erosion (Subramanian and Kannan, 2013). Also, during the last decade, concrete production cost have risen due to rising cost of fine and coarse aggregate which contribute significantly to the entire volume of concrete. These developments have necessitated an intensified research into ways in which the production cost of concrete and environmental problems caused by quarrying and excavation of both coarse and fine aggregate can be reduced and the use of palm kernel shell and rice husk forms a viable alternative. Palm kernel shell and rice husk are agricultural by-products and their utilization as an alternative material in concrete production have advantages over conventional materials in low cost construction (Abdullah, 1997).The use of this waste materials in construction contribute to conservation of natural resources and the protection of the environment.  (Ramezanianpour, et al., 2009).

Many agricultural such as palm kernel shell, rice husk, coconut shell recognized as potential replacement of conventional aggregate in concrete are light weight aggregate Uchechi, et al., (2017). Advantages of light weight aggregate concrete over conventional concrete include decreased dead load, lower rate of depletion of natural resources, lower thermal conductivity, and reduced construction costs. There is a continuing trend towards the use of more lightweight concrete in applications such as pre-stressed concrete and high-rise buildings (Neville and Brooks, 2010).

In other to reduce the negative environmental effect caused by aggregate production and also increase in concrete production cost resulting from increasing cost of both fine and coarse aggregate respectively, this study will therefore investigate the production of light weight concrete by utilization of palm kernel shell and rice husk.

## 1.2 Statement of Problem

During the last decade, there is a growing urge to explore the use of alternative material in the production of concrete Uchechi, et al., (2017). This need is due to environmental and economic consideration Uchechi, et al., (2017). Concrete production cost have risen significantly due to increasing cost of both fine and coarse aggregate used in it production. Moreover, there are severe environmental consequence associated with the mode of production and collection of both coarse and fine aggregate respectively. Production of coarse aggregate involves stripping, drilling, blasting and impact crushing (Ezekiel, 2018). These processes constitute severe noise pollution; affect natural air quality and generally environmental instability (Ezekiel, 2018).

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### 1.3 Aim and Objectives of Study

The aim of the study is to assess the effect of partial replacement of fine and coarse aggregate with rice husk and palm kernel shell on mechanical properties of concrete while the objectives includes:

1 Separate the palm kernel shell from oil palm fruit and determine its index properties.
2 Determine the index properties of properties of fine and coarse aggregate used in the experimental study.
3 Ascertain the efficacy and feasibility of rice husk and palm kernel shell as an alternative for partial replacement of both fine and coarse aggregate respectively.
4 To partially replace coarse aggregate with palm kernel shell and evaluate its effect on fresh and hardened properties of concrete with that of corresponding normal (plain) concrete.
5 To partially replace fine aggregate with rice husk and evaluate its effect on fresh and hardened properties of concrete with that of corresponding normal (plain) concrete.
6 To determine the change in weight of palm kernel and rice husk concrete with that of corresponding normal concrete.
7 Draw conclusion and make relevant recommendations based on key findings.

## 1.4 Scope of Study

The scope of the study is focused entirely on light weight concrete produced with partial replacement of coarse and fine aggregate with palm kernel shell and rice husk respectively. Concrete grade 1: 2: 4 will be adopted for the experimental study. The coarse aggregate will be partially replaced with palm kernel shell in a stepped increase of 10 to 30% by dry weight of coarse aggregate while the fine aggregate will be partially replaced with rice husk in a stepped increase of 5% to 25% by dry weight of fine aggregate. Concrete produced with rice husk and palm kernel shell will be subjected to various laboratory investigations. These tests includes: Sieve analysis test, Specific gravity test, Water absorption test, Slump (workability) test, and Compressive strength test. The curing of the concrete is entirely by outer immersion other method of curing will not be used. Results obtained from density and compressive strength test will be used as bases for making conclusion and recommendation.

## 1.5 Significance of Study

Key findings obtained from the experimental study on effect of partial replacement of coarse and fine aggregate with palm kernel shell and rice husk on properties of light weight concrete will be significant in the following ways:

1. Foster economy in concrete production process by reduction in cost of procurement and transportation of both coarse and fine aggregate respectively.
2. Ensure rational use of earth resources in the production of concrete.
3. Reduce adverse effect resulting from production and collection of both fine and coarse aggregate.
4. Facilitate high rate of construction work.
5. Serve as waste treatment process by reducing the volume of agricultural waste generated and disposed.

# CHAPTER TWO

## LITERATURE REVIEW

### 2.1 Overview

Concrete is the most versatile heterogeneous construction material and the most valuable construction material for infrastructural development of any nation. Concrete is a structural material composed of crushed rock, or gravel, and sand, bound together with a hardened paste of cement and water (Reynolds and Steedman, 2008). A large range of cements and aggregates, chemical admixtures and additions, can be used to produce a range of concretes having the required properties in both the fresh and hardened states (Reynolds and Steedman, 2008). Civil engineering practice and construction works around the world depend to a very large extent on concrete. Concrete is a synthetic construction material made by mixing cement, fine aggregates, coarse aggregates and water in the proper proportions. Aggregates serve as inert filler materials while at the same time improving concrete workability, volume stability and durability. Recent studies (Alengaram et al., 2013; Yap et al., 2013; Williams et al., 2014; Itam et al., 2016) have shown the suitability of palm kernel (PK) in concrete production as coarse aggregate replacement. Concrete may be defined as a composite material consisting of a binding material, water, fine and coarse aggregates, and in some instances, the incorporation of admixtures all in definite proportions to achieve a desired property. The binding material in most instances is the Ordinary Portland Cement (OPC) although other binding materials are also in used. Concrete is an artificial material comparable in appearance and properties to some natural lime stone rock. It is a man-made composite, the major constituent being natural aggregate such as gravel, or crushed rock, sand and fine particles of cement powder all mixed with water. The concrete as time goes on through a process of hydration of the cement paste, producing a required strength to endure the load (Maninder and Manpreet, 2012).

The density and compressive strength of concrete are one of the most useful properties of concrete. In most structural applications, concrete is employed primarily to resist compressive strength stresses. In case where strength in tension or in shear is of primary importance, the compressive strength is frequently used as a measure of these properties. Therefore the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength. Compressive strength is also used in a qualitative measure for other properties of a hardened concrete. The compressive strength is determined by testing cubes or cylinders in the laboratory. The strength of a concrete is it resistance to rupture. It can be measured in a number of ways: strength compression in tension, in shear or in flexures. The cohesion and internal friction developed by concrete in resisting failure is related to the water-cement ratio, the design constituents, the mixing, placement and curing methods employed. There is a need to explore alternative material for concrete production in such a way that the concrete mechanical properties especially the compressive strength is not undermined.

This section will review literatures relevant to the utilization of palm kernel shell and rice husk as a partial substitute for production of light weight concrete, mode of variation of additives and findings obtained from addition of such additives.

## 2.2 Concrete Production Process

### 2.2.1 Batching

The correct measurement of the various materials used in the concrete mix is called batching. Errors in batching are partly responsible for the variation in the quality of concrete. Concrete can be batched in two ways:

a) By volume batching and
b) By mass (weight) batching

Weigh-batching of materials is always preferred than volume batching. When weigh-batching is not possible and the aggregates are batched by volume, such volume measures to be regularly checked for the weight-volume ratio.

### 2.2.2 Mixing

This is the practical means of producing fresh concrete and placing it in the form so that it can harden into the structural or building material referred to as concrete‘. The sequence of operation is that the correct quantities of cement, aggregates and water, possibly also admixture are batched and mixed in a concrete mixer which produces fresh concrete. This is transported from the mixer to its final location. The fresh concrete is then placed in the forms, and compacted so as to achieve a dense mass which is allowed and helped, to harden. The objective of mixing of concrete is to coat the surface of all aggregate particles with cement paste and to blend all ingredients of concrete into a uniform mass. Mixing of concrete is done either by hand or by machine. Mixers performances shall be checked for conformity to the requirements of the relevant standards. Concrete shall be mixed for the required time; both under-mixing and over-mixing shall be avoided.

### 2.2.3 Transportation

After mixing, concrete shall be transported and placed at site as quickly as possible without segregation, drying, etc. as soon as concrete is discharged from the mixer, internal as well as external forces starts acting to separate the dissimilar constituents (Shetty, 2005). If over-weight concrete is confined in restricting forms, the coarser and heavier particles tend to settle and finer and lighter materials tend to rise. If concrete is to be transported for some distance over rough ground the runs shall be kept as short as possible since vibrations of this nature can cause segregation of the materials in the mix (Shetty, 2005). For the same reason concrete should not be dropped from a height of more than 1m. If this is unavoidable a chute shall be used. The green concrete shall be handled, transported and placed in such a manner that it does not get segregated. The time interval between mixing and placing the concrete shall be reduced to the minimum possible.

### 2.2.4 Placing

The formwork and position of reinforcement shall be checked before placing concrete to make sure that they are clean and free of any detritus, such as ends of tying wire (Shetty, 2005). The fresh concrete shall be deposited as close as possible to its ultimate position. Care need to be taken when discharging concrete from skips to avoid dislodging the reinforcement or over filling the formwork. When filling columns and walls, care shall be taken that the concrete does not strike the face of the formwork, which might affect the surface finish of the hardened concrete. For deep sections the concrete shall be placed in uniform layers, typically not more than about 500 mm thick, each layer being fully compacted.

### 2.2.5 Compaction

Compaction of concrete is the process adopted for expelling the entrapped air form the concrete. In the process of placing and mixing of concrete, air is likely to get entrapped in the concrete. If this air is not detrained out fully, the concrete losses strength considerably. Anticipated targets of strength, impermeability and durability of concrete can be achieved only by thorough and adequate compaction. One per cent of the air voids left in concrete due to incomplete compaction can lower the compressive strength by nearly five percent (Gambhir, 2004).

### 2.2.6 Curing

Curing of concrete is the process of maintaining satisfactory moisture content and a favorable temperature in concrete during the period immediately after the placement of concrete so that hydration of cement may continue till the desired properties are developed sufficiently to meet the requirements of service. The reasons for curing concrete are to keep the concrete saturated or as nearly saturated as possible, until the originally water filled space in the fresh cement paste has been filled to the desired extent by the product of hydration of cement, to prevent the loss of water by evaporation and to maintain the process of hydration, to reduce the shrinkage of concrete and to preserve the properties of concrete. Concrete derives its strength by the hydration of cement particles. The hydration of cement is of momentary action but a process continuing for a long time. The rate of hydration is fast to start with but continues over a long time at a decreasing rate. Curing is usually requires for at least 7 days after the day the concrete is placed, this may vary in certain special circumstances (Onwuka and Omerekpe, 2003). Adequate curing is essential for the handling and development of strength of concrete. The curing period depends upon the shape and size of member, ambient temperature and humidity conditions, type of cement, and the mix proportions. Nevertheless, the first week or ten days arc the most critical, as any drying out during this young age can cause irreparable loss in the quality of concrete. Generally, the long-term compressive strength of concrete moist cured for only 3 days or 7 days will be about 60 per cent and 80 per cent, respectively, of the one moist cured for 28 days or more (Gambhir, 2004).

### 2.2.7 Formwork

Formwork is a structure, usually temporary, used to contain poured concrete and to mould it to the required dimensions and support until it is able to support itself. It consists primarily of the face contact material and the bearers that directly support the face contact material. Proper removal of formwork is an important factor to achieve good quality of concrete during the service life.

### 2.2.8 Inspection and Testing

Inspection and testing play a vital role in the overall quality control process. Inspection could be of two types, quality control inspection and acceptance inspection. For repeated operations early inspection is vital, and once the plant has stabilized, occasional checks may be sufficient to ensure continued satisfactory results. The operations which are not of repetitive type would require, on the other hand, more constant scrutiny. Apart from the tests on concrete materials, concrete can be tested both in the fresh and hardened states. The tests on fresh concrete offer some opportunity for necessary corrective actions to be taken before it is finally placed. These include tests on workability, unit weight or air content (if air-entrained concrete is used).

## 2.3 Constituents of Concrete

Chudley and Greeno, (2006) assert that the proportions of each of concrete materials control the strength and quality of the resultant concrete. Fresh concrete is a plastic mass, which can be moulded into any desired shape. This is its main advantage as a construction material (Gupta and Gupta, 2004). They further assert that aggregate, coarse and fine combined occupy about 70% space in a given mass of concrete and the rest 30% space is filled by water, cement and air voids. Bert-Okonkwor, (2012) in his definition described concrete as a mixture of Portland cement, fine aggregate coarse aggregate, air and water. Sharma, (2008) concludes in stating that concrete is a heterogeneous mix consisting of the following materials: cement, aggregate (coarse and fine), water and admixture (when necessary). Below are descriptions of some of these components of concrete.

### 2.3.1 Cement

Cement is a binder material, a substance made of burned lime and clay which after mixing with water, set and harden independently and can bind other materials together Ezeokonkwo, (2014). According to (Onwuka and Omerekpe, 2003), cement as a hydraulic binders react exothermically with water to form hard strong masses with extremely low solubility. They consist of chemical compounds such as calcium silicate and calcium aluminates. Cement is a cementitious material which has adhesive and cohesive properties necessary to bound inert aggregates into a solid mass of adequate strength and durability. Neville, (1993) also adds that cement is the binding material constituent of concrete which reacts chemically with water and aggregate to form a hardened mass on hydrating. Iheama, (2010) further defines it as a finely pulverized product resulting from calcination of natural argillaceous limestone at a temperature below the fusion. In addition to this Ivor, (1995), defines cement as a mixture of compounds, consisting mainly of silicates and aluminates of calcium, formed out of calcium oxide, silica, aluminium oxide and iron oxide. Hydraulic cements are of four types: Portland cement, Blended Portland Cement, and Portland cement with addictives and High Alumina Cement. Cement varying chemical composition and physical characteristics exhibit different properties on hydration. The cement of desired properties can be produced by selecting suitable mixture of raw materials. Portland cements are made from limestone and clay, or other chemically similar suitable raw materials, which are burned together in a rotary kiln to form a clinker rich in calcium silicates (Reynolds and Steadman, 2008). This clinker is ground to a fine powder with a small proportion of gypsum (calcium sulphate), which regulates the rate of setting when the cement is mixed with water. Over the years several types of Portland cement have been developed. The various types of Portland cement used in the construction industry are: Ordinary Portland Cement(OPC), Rapid Hardening Portland Cement(RHPC), Sulphate resisting Portland Cement(SRPC), Low Heat Portland Cement(LHPC), Blast Furnace Portland Cement BFPC), Portland Pozzolana Cement(PPC), Modified Portland Slag Cement (MPC).

Many authors (Ezeokonkwo, 2014: Anosike, 2010: Gupta and Gupta, 2004: Iheama, 2010) agreed to the fact that on the addition of water to cement, hydration takes place, liberating a large quantity of heat. On hydration of cement, the gel is formed which binds the aggregate particles together and provides strength and water tightness to concrete on hardening. Thus cement has the property of setting and hardening underwater by a chemical reaction with it. Portland cement is a substance which binds together the particles of aggregates (usually sand and gravel) to form a mass of high compressive strength concrete. It is a combination of limestone or chalk with clay mixed in a proportion depending on the type of cement desired. Portland cement is the most common type of cement generally used around the world because it is a basic ingredient of concrete, mortar and stucco. It is a fine powder produced by grinding Portland cement clinker more than 90%, and a limited amount of calcium sulphate which controls the set time. Portland cement clinker is a hydraulic material which consist at least two-thirds by mass of calcium silicates ($3CaO.SiO2$ and $2CaO.SiO2$).

Okereke, (2003), Portland cement is manufactured by firing a controlled mixture of chalk or limestone ($CaCO_3$) and substances containing silica and alumina such as shale in a kiln at 1500°c temperature. They are heated to clinker and grounded to a fine powder with a small proportion of gypsum (calcium sulphate) which regulates the rate of setting when the cement is mixed with water. Anosike, (2010) also states that the manufacture of PC consists of the following three distinct processes: Mixing, Burning and Grinding. Mixing can be done by dry-process or wet-process. The wet process is the most common. The main difference between the wet and dry production process is the larger amount of water expelled from the kiln during the production process.

**2.3.1.1 Chemical Composition of Portland Cement**

Anosike, (2010), the ordinary and rapid hardening PC can be tested by the methods given in I.S. 4032. The results of the tests should comply with the following chemical requirements:

a) The ratio of the percentage of lime to the percentage of silica, alumina and ironoxide when calculated by the following formula:

$$\frac{\mathbf{CaO-0.7SO3}}{\mathbf{SiO2+1.2AL2O3\ 0.65\ Fe2O3}}$$

It should be between 0.66 and 1.02.

b) The Ratio of the percentage of alumina to iron oxide should not be less than 0.66.

c) Weight of insoluble residue should not be more than 2%.

d) Weight of magnesia should not exceed 6%.

e) Total sulphur content calculated as sulphuric anhydride (SO3) should not exceed 2.75 or 3.0%.

f) Total loss of ignition should not be more than 2%.

According to Shetty, (2005), the raw materials used in the manufacture of Portland cement consist mainly of lime (Cao), silica (SiO2), alumina (Al2O3) and iron oxide (Fe2O3). The four compounds are usually regarded as the major constituents of cement. They are described in abbreviated form by cement chemists as follows: CaO = C; SiO2 = S; Al2O3 = A; and Fe2O3 = F. Likewise, H2O in hydrated cement is denoted by H, and SO3 by S. In addition to the main compounds listed above, there exist minor compounds, such as MgO, TiO2, Mn2O3, K2O and $Na_2O$; they usually amount to not more than a few per cent of the mass of cement. Two of the minor compounds are of particular interest: the oxides of sodium and potassium, $Na_2O$ and $K_2O$, known as the alkalis. They have been found to react with some aggregates, the products of the reaction causing disintegration of the concrete, and have also been observed to affect the rate of the gain of strength of cement (Neville, 2005). The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding. Table 2.0 shows the approximate oxide composition limits of ordinary Portland cement.

**Table 2.0 Oxide Composition Limit of Ordinary Portland cement (OPC) (Shetty, 2005).**

| Oxide | Approximate Percentages |
|---|---|
| CaO | 60-67 |
| SiO2 | 17-25 |
| AL2O3 | 3.0-8.0 |
| Fe2O3 | 0.5-6.0 |
| MgO | 0.1-4.0 |
| Alkalis( K2O, N2O) | 0.4-1.3 |
| SO3 | 1.3-3.0 |

The oxides present in the raw materials when subjected to high clinkering temperature combine with each other to form complex compounds. The identification of the major compounds is largely based on R.H. Bogue’s work and hence it is called ―Bogue’s Compounds. The four compounds usually regarded as major compounds are tricalcium silicate (C3S), dicalcium silicate (C2S), tricalcium aluminate (C3A) and tetracalciumalumino ferrite (C4AF). Shetty, (2005).The Bogue’s formula used in calculating the percentage of the various compounds is given as follow:

$$\mathrm{C3S} = 4.07\,(\mathrm{CaO}) - 7.60\,(\mathrm{SiO2}) - 6.72\,(\mathrm{Al2O3}) - 1.43\,(\mathrm{Fe2O3}) - 2.85\,(\mathrm{SO3})\ \mathrm{C2S}$$
$$= 2.87\,(\mathrm{SiO2}) - 0.754\,(\mathrm{3CaO.SiO2})\ \mathrm{C3A}$$
$$= 2.65\,(\mathrm{Al2O3}) - 1.69\,(\mathrm{Fe2O3})\ \mathrm{C4AF} = 3.04\,(\mathrm{Fe2O3}$$

### 2.3.1.2 Properties of Cement

**a) Fineness of Cement**

Fineness is a vital property of cement which influences the rate of reaction of cement with water (hydration). The fineness of the cement affects the rate of hydration. It also affects its place ability, workability and water content of a concrete mix much like the amount of cement used in concrete. For a given weight of a finely ground cement, the surface area of the particles is greater than for a coarsely ground cement. The advantages of finer cement include:

a) Increases the rate of hydration
b) More rapid and greater strength development,
c) Reduced bleeding rate of concrete
d) Improving the workability of concrete

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence fastens the development of strength. Fineness of cement is determined by permeability. For example in the blaine air permeability method, a known volume of air is passed through cement. The time is recorded and the specific surface is calculated by a formula. Fineness is expressed in terms of specific surface of the cement ($Cm^2/gr$). For OPC specific surface area is 2600-3000 $Cm^2/gr$. This test is conducted as per BS EN196-6:1995.
Neville and Brooks, (2004), three methods of determining the fineness of cement are by sieve analysis, by specific surface area method and by LEA and nurse method.

**b) Soundness of Cement**

Soundness is referred to as the volume stability of cement paste. The cement paste should not undergo large changes in volume after it has set. Free CaO and MgO may result in unsound cement (Chanadan. 2019). Upon hydration, C and M (calcium and magnesium) will form CH and MH with volume increase thus cracking. (Gartener, et al. 1989), since unsoundness is not apparent until several months or years, it is necessary to provide an accelerated method for its determination which includes:

a) Lechatelier Method where only free CaO can be determined.
b) Autoclave Method where both free CaO and MgO can be determined.

In the soundness test a specimen of hardened cement paste is boiled for a fixed time so that any tendency to expand is sped up and can be detected. Soundness means the ability to resist volume expansion. For ordinary Portland cement, BS-EN 197 part1 (2000) has specified a maximum expansion of 10mm. The work of Chowdhury et al., (2015) indicated that the soundness of cement was improved with the addition of saw dust ash as partial replacement. In the research, cement was replaced by the ash within the range of 5% to 30% and the soundness was found to increase with an increase in the ash content.

**c) Setting Time of Cement**

Setting time refers to a change from liquid state to solid state. During setting time, cement paste acquire some strength (Gartener, et al. 1989). The water content has a marked effect on time of setting. In acceptance test for cement, the water content is regulated by bringing the paste to a standard condition of wetness and this is referred to as "normal consistency". Normal consistency of OPC ranges from 20-30% by weight of concrete. Vicat apparatus is used to determine normal consistency. Normal consistency is that condition for which the penetration of a standard weighed plunger into the paste is 10mm in 30sec. In practice, the terms initial set and final set are used to describe arbitrary chosen time of setting. Initial set indicates the beginning of a noticeable stiffening and final set may be regarded as the start of hardening (or complete loss of plasticity). It is the also the period between the time water is added to cement and time at which 1 mm square section needle fails to penetrate the cement paste, placed in the Vicat'smould 5 mm to 7 mm from the bottom of the mould. Final setting time is that time period between the time water is added to cement and the time at which 1 mm needle makes an impression on the paste in the mould but 5 mm attachment does not make any impression. The setting time test is carried out using the Vicat apparatus as per BS-EN 196 part3 (1995). The results of the test should comply with the requirements of BS-EN 197 part1 (2000), which recommend a minimum of 60 minutes and a maximum of 10 hours as the initial and final setting times of ordinary Portland cement respectively. (Gartener, et al. 1989) summarized the factors affecting setting time as:

a) Temperature and Humidity.
b) Amount of water
c) Chemical composition of cement
d) Fineness of cement (the finer the cement, the faster the setting)

Marthong, (2012), investigated that the addition of saw dust ash in OPC grade 42.5 had increased the initial and final setting times. This was attributed to the low rate of hydration in the paste containing the saw dust ash.

### 2.3.2 Aggregate

Ezeokonkwo, (2014), the term aggregate includes the natural sand, gravels and crushed stone used in making concrete. Bert-Okonkwor, (2012) describes the term aggregate, as inert materials like gravel, crushed stones, broken bottles which are mixed with cement and water to make concrete. (Merritt, 1983: Rangwala, 2005), in their contribution describe aggregates as inert or chemically inactive materials which form the bulk of concrete and are bound together using cement as a binder. In any concrete, aggregates (fine and coarse) usually occupies about 70-75% (Gupta and Gupta, 2004: Neville and Brooks, 2004). The aggregates have to be graded so the whole mass of concrete acts as a relatively solid, homogeneous, dense combination with the smallest particles acting as inert filler for the voids that exist between the larger particles (Nawy, 2002). This statement gives us the suggestion that the selection and proportioning of aggregates should be given due attention as it not only affects the strength but the durability and structural performance of the concrete also.

Aggregates are considered clean if they are free of excess clay, silt, mica, organic matter, chemical salts and coated grains Ezeokonkwo, (2014). In addition to that, (Merritt, 1983: Rangawala, 2005: Neville, 1993), support the idea that an aggregate should be physically sound if it retains dimensional stability under temperature or moisture change and resists weathering without decomposition. Ezeokonkwo, (2014) concludes that for an aggregate to be considered adequate in strength, aggregate should be able to develop the full strength of the cementing matrix. Anosike, (2010), aggregates provide better strength, stability and durability to the structure made out of cement concrete than cement paste alone.

Aggregate is not truly inert because its physical, thermal and chemical properties influence the performance of concrete. While selecting aggregate for a particular concrete, the economy of the mixture, the strength of the hardened mass and durability of the structure must first be considered (Gupta and Gupta, 2004).

### 2.3.3 Water

Water used in the concrete reacts with cement and causes it to set and harden. It also facilitates mixing, placing and compacting of fresh concrete. Abruckle, (2007), states that mixing water for concrete is required to be fit for drinking or to be taken from an approved source. Findings in previous works (Ezeokokwo, 2014: Bert-Okonkwo, 2012: Neil and Ravrinda, 1996) suggest that, to achieve the required workability and strength of concrete in both its fresh and hardened state, the water used for mixing and curing needs to be of appropriate quality, that is, it should be free from impurities such as suspended solids, organic matter and salts which may adversely affect the setting, hardening, strength and durability of the concrete.

Water is used in the production of concrete, washing of aggregates, mortar and bricks formation. Water is also used for construction operations like casting, painting, terrazzo finishing, plastering and other operations. After casting of concrete, water is poured on the concrete to give it strength in a process known as curing. After completion of the building, water is used for cleaning the building in readiness for inspection, handing-over and occupancy. As a result of these facts, it is obvious that water is very important in building construction and related activities. Neil and Ravindra, (1996) further define water to cement ratio (w/c) as the weight of water divided by the weight of cement.

According to (BS8110: Part 1, 1997), the amount of water required in a concrete mix is the minimum for complete hydration of cement. If such concrete is fully compacted without segregation, it would develop the maximum attainable strength at a given age. The BS8110, (1997) further states that the water-cement ratio of approximately 0.25 weights is required for full hydration of cement. Omuvwie and Mosaku, (2010) suggest that if the water is not properly managed, it can turn around to inflict serious structural damage to the building over time and that such damage can lead to structural failure of the building and eventual collapse aside of the economic drain on client, safety risks as well as aesthetic devaluation.

### 2.3.4 Admixture

Admixtures are not a primary constituent of concrete. They are added to concrete if necessary and not all the time. Brantley and Brantley, (2004) admixtures are those chemicals that can be added to the concrete mix to achieve special purposes or meet certain construction conditions. An admixture is a material, usually a liquid, which is added to a batch of concrete during mixing to modify the properties of the fresh or the hardened concrete in some way (Reynolds and Steadman, 2008). Most admixtures benefit concrete by reducing the amount of free water needed for a given level of consistence, often in addition to some other specific improvement (Reynolds and Steadman, 2008). Admixtures are mixed into the concrete to change or alter its properties. The use of admixtures should offer improvement in the properties of concrete by adjusting the proportions of cement and aggregates. However, it should not affect adversely any property of concrete. An admixture should be used only after assessing its effect on the concrete to be used under an intended situation. It should also be known that admixtures are no substitute for good workmanship i.e. the effect of bad workmanship cannot be improved by the use of admixtures.

Gupta and Gupta, (2004) and Anosike, (2010) suggest that admixtures perform the following functions:

a) Accelerate the initial setting and hardening of concrete.
b) Retard the initial setting of concrete
c) Increase the strength of concrete
d) Improve the workability of fresh concrete
e) Improve the durability of concrete
f) Reduce the heat of evaluation
g) Control the alkali-aggregate expansion
h) Aid in the curing of concrete
i) Improve wear resistance to concrete
j) Reduce shrinkage during the setting of concrete.

Reynolds and Steadman, (2008) classified admixtures into different types. Below are descriptions of the different types of admixture utilized in concrete production.

#### 2.3.4.1 Normal Water-Reducing Admixtures

Commonly known as plasticizers or workability aids, these act by reducing the inter-particle attraction within the cement, to produce a more uniform dispersion of the cement grains (Reynolds and Steadman, 2008). The cement paste is better lubricated and hence the amount of water needed to obtain a given consistency can be reduced. The use of these admixtures can be beneficial in one of three ways:

a) When added to a normal concrete at normal dosage, they produce an increase in slump of about 50 mm. This can be useful in high-strength concrete, rich in cement, which would otherwise be too stiff to place.
b) The water content can be reduced while maintaining the same cement content and consistence class: the reduction in water/ cement ratio (about 10%) results in increased strength and improved durability. This can also be useful for reducing bleeding in concrete prone to this problem; and for increasing the cohesion and thereby reducing segregation in concrete of high consistence, or in harsh mixes that sometimes arise with angular aggregates, or low sand contents, or when the sand is deficient in fines.
c) The cement content can be reduced while maintaining the same strength and consistence class. The water/cement ratio is kept constant, and the water and cement contents are reduced accordingly. This approach should never be used if, thereby, the cement content would be reduced below the minimum specified amount. Much dosage of admixture may result in retardation and/or a degree of air-entrainment, without necessarily increasing workability, and therefore may be of no benefit in the fresh concrete (Reynolds and Steadman, 2008).

#### 2.3.4.2 Accelerating Water-Reducing Admixtures

Accelerators act by increasing the initial rate of chemical reaction between the cement and the water so that the concrete stiffens, hardens and develops strength more quickly (Reynolds and Steadman, 2008). They have a negligible effect on consistence, and the 28-day strengths are seldom affected. Accelerating admixtures have been used mainly during cold weather, when the slowing down of the chemical reaction between cement and water at low temperature could be offset by the increased speed of reaction resulting from the accelerator (Reynolds and Steadman, 2008). The most widely used accelerator used to be calcium chloride but, because the presence of chlorides, even in small amounts, increases the risk of corrosion, modern standards prohibit the use of admixtures containing chlorides in all concrete containing embedded metal. Accelerators are sometimes marketed under other names such as hardeners or anti-freezers, but no accelerator is a true anti-freeze, and the use of an accelerator does not avoid the need to protect the concrete in cold weather by keeping it warm (with insulation) after it has been placed.

#### 2.3.4.3 Retarding Water – Reducing Admixture

These slow down the initial reaction between cement and water by reducing the rate of water penetration to the cement. By slowing down the growth of the hydration products, the concrete stays workable longer than it otherwise would. The length of time during which concrete remains workable depends on its temperature, consistence class, and water/cement ratio, and on the amount of retarder used. Although the occasions justifying the use of retarders in the United Kingdom are limited, these admixtures can be helpful when one or more of the following conditions apply.

a) When there is a delay of more than 30 minutes between mixing and placing – for example, when ready-mixed concrete is being used over long-haul distances or there are risks of traffic delays. This can be seriously aggravated during hot weather, especially if the cement content is high.
b) When a large concrete pour, which will take several hours to complete must be constructed so that concrete already placed does not harden before the subsequent concrete can be merged with it (i.e. without a cold joint).
c) When the complexity of a slip-forming operation requires a slow rate of rise.

#### 2.3.4.4 Air Entraining Admixtures

These may be organic resins or synthetic surfactants that entrain a controlled amount of air in concrete in the form of small air bubbles. The bubbles need to be about 50 microns in diameter and well dispersed. The main reason for using an air-entraining admixture is that the presence of tiny bubbles in the hardened concrete increases its resistance to the action of freezing and thawing, especially when this is aggravated by the application of deicing salts and fluids (Reynolds and Steadman, 2008). Saturated concrete will be seriously affected by the freezing of water in the capillary voids. If the concrete is air-entrained, the air bubbles, which intersect the capillaries, stay unfilled with water even when the concrete is saturated. Thus, the bubbles act as pressure relief valves and cushion the expansive effect by providing voids into which the water can expand as it freezes, without disrupting the concrete. When the ice melts, surface tension effects draw the water back out of the bubbles.

Air-entrainment also affects the properties of the fresh concrete (Reynolds and Steadman, 2008). The minute air bubbles act like ball bearings and have a plasticizing effect, resulting in a higher consistence (Reynolds and Steadman, 2008). Concrete that is lacking in cohesion, or harsh, or which tends to bleed excessively, is greatly improved by air-entrainment. The risk of plastic settlement and plastic-shrinkage cracking is also reduced. There is also evidence that colour uniformity is improved and surface blemishes reduced. One factor that has to be taken into account when using air-entrainment is that the strength of the concrete is reduced, by about 5% for every 1% of air entrained (Reynolds and Steadman, 2008). However, the plasticizing effect of the admixture means that the water content of the concrete can be reduced, which will offset most of the strength loss that would otherwise occur, but even so some increase in the cement content is likely to be required.

## 2.4 Properties of Fresh Concrete

### 2.4.1 Workability

It is vital that the workability of concrete is matched to the requirements of the construction process (Reynolds and Steadman, 2008). The ease or difficulty of placing concrete in sections of various sizes and shapes, the type of compaction equipment needed the complexity of the reinforcement, the size and skills of the workforce are amongst the items to be considered (Reynolds and Steadman, 2008). In general, the more difficult it is to work the concrete; the higher should be the level of workability. But the concrete must also have sufficient cohesiveness in order to resist segregation and bleeding (Shetty, 2005). Concrete needs to be particularly cohesive if it is to be pumped, or allowed to fall from a considerable height.

### 2.4.2 Plastic Cracking

There are two basic types of plastic cracks, plastic settlement cracks, which can develop in deep sections and, often follow the pattern of the reinforcement and plastic shrinkage cracks which are most likely to develop in concrete slabs (Reynolds and Steadman, 2008). Both types form while the concrete is still in its plastic state, before it has set or hardened and, depending on the weather conditions, within about one to six hours after the concrete has been placed and compacted (Reynolds and Steadman, 2008). They are often not noticed until the following day. Both types of crack are related to the extent to which the fresh concrete bleeds.

Fresh concrete is a suspension of solids in water and, after it has been compacted, there is a tendency for the solids (both aggregates and cement) to settle. The sedimentation process displaces water, which is pushed upwards and, if excessive, appears as a layer on the surface. This bleed water may not always be seen, since it can evaporate on hot or windy days faster than it rises to the surface. Bleeding can generally be reduced, by increasing the cohesiveness of the concrete (Reynolds and Steadman, 2008). This is usually achieved by one or more of the following means: increasing the cement content, increasing the sand content, using finer sand, using less water, air-entrainment, using rounded natural sand rather than an angular crushed one. The rate of bleeding will be influenced by the drying conditions, especially wind, and bleeding will take place for longer on cold days. Similarly, concrete containing a retarder tends to bleed for a longer period of time, due to the slower stiffening rate of the concrete, and the use of retarders will, in general, increase the risk of plastic cracking.

Plastic settlement cracks, caused by differential settlement, are directly related to the amount of bleeding (Reynolds and Steadman, 2008). They tend to occur in deep sections, particularly deep beams, but they may also develop in columns and walls. This is because the deeper the section, the greater the sedimentation or settlement that can occur. However, cracks will form only where something prevents the concrete 'solids' from settling freely. The main danger from plastic cracking is the possibility of moisture ingress leading to corrosion of any reinforcement (Reynolds and Steadman, 2008). If the affected surface is to be covered subsequently, by either more concrete or a screed, no treatment is usually necessary. In other cases, often the best repair is to brush dry cement (dampened down later) or wet grout into the cracks the day after they form, and while they are still clean; this encourages natural or autogenous healing.

### 2.4.3 Early Thermal Cracking

The reaction of cement with water, or hydration, is a chemical reaction that produces heat (Reynolds and Steadman, 2008). If this heat development exceeds the rate of heat loss, the concrete temperature will rise. Subsequently the concrete will cool and contract. If the contraction of the concrete were unrestrained, there would be no cracking at this stage. However, in practice there is nearly always some form of restraint inducing tension, and hence a risk of cracks forming. The restraint can occur due to both external and internal influences. Concrete is externally restrained when, for example, it is cast onto a previously cast base, such as a wall kicker, or between two already hardened sections, such as in infill bay in a wall or slab, without the provision of a contraction joint. Internal restraint occurs, for example, because the surfaces of an element will cool faster than the core, producing a temperature differential. When this differential is large, such as in thick sections, surface cracks may form at an early stage. Subsequently, as the core of the section cools, these surface cracks will tend to close in the absence of any external restraints. Otherwise, the cracks will penetrate into the core, and link up to form continuous cracks through the whole section.

The main factors affecting the temperature rise in concrete are the dimensions of the section, the cement content and type, the initial temperature of the concrete and the ambient temperature, the type of formwork and the use of admixtures (Reynolds and Steadman, 2008). Thicker sections retain more heat, giving rise to higher peak temperatures, and cool down more slowly.

## 2.5 Properties of Hardened Concrete

### 2.5.1 Tensile Strength

The direct tensile strength of concrete, as a proportion of the cube strength, varies from about one-tenth for low-strength concretes to one-twentieth for high-strength concretes (Reynolds and Steadman, 2008). The proportion is affected by the aggregate used, and the compressive strength is therefore only a very general guide to the tensile strength (Reynolds and Steadman, 2008). For specific design purposes, in regard to cracking and shear strength, analytical relationships between the tensile strength and the specified cylinder/cube strength are provided in codes of practice. The indirect tensile strength (or cylinder splitting strength) is seldom specified nowadays. Flexural testing of specimens may be used on some airfield runway contracts, where the method of design is based on the modulus of rupture, and for some precast concrete products such as flags and kerbs.

### 2.5.2 Shrinkage

Withdrawal of water from hardened concrete kept in unsaturated air causes drying shrinkage (Reynolds and Steadman, 2008). If concrete that has been left to dry in air of a given relative humidity is subsequently placed in water (or a higher relative humidity), it will swell due to absorption of water by the cement paste. However, not all of the initial drying shrinkage is recovered even after prolonged storage in water. For the usual range of concretes, the reversible moisture movement represents about 40%–70% of the drying shrinkage. A pattern of alternate wetting and drying will occur in normal outdoor conditions. The magnitude of the cyclic movement clearly depends upon the duration of the wetting and drying periods, but drying is much slower than wetting. The consequence of prolonged dry weather can be reversed by a short period of rain. More stable conditions exist indoors (dry) and in the ground or in contact with water (e.g. reservoirs and tanks).

Shrinkage of hardened concrete under drying conditions is influenced by several factors in a similar manner to creep (Reynolds and Steadman, 2008). The intrinsic shrinkage of the cement paste increases with the water/cement ratio so that, for a given aggregate proportion, concrete shrinkage is also a function of water/cement ratio. The relative humidity of the air surrounding the member greatly affects the magnitude of concrete shrinkage according to the volume/surface area ratio of the member (Reynolds and Steadman, 2008). The lower shrinkage value of large members is due to the fact that drying is restricted to the outer parts of the concrete.

### 2.5.3 Creep

The increase in strain beyond the initial elastic value that occurs in concrete under a sustained constant stress, after taking into account other time-dependent deformations not associated with stress, is defined as creep (Reynolds and Steadman, 2008). If the stress is removed after some time, the strain decreases immediately by an amount that is less than the original elastic value because of the increase in the modulus of elasticity with age (Reynolds and Steadman, 2008). This is followed by a further gradual decrease in strain. The creep recovery is always less than the preceding creep, so that there is always a residual deformation.

The creep source in normal-weight concrete is the hardened cement paste. The aggregate restrains the creep in the paste, so that the stiffer the aggregate and the higher its volumetric proportion, the lower is the creep of the concrete. Creep is also affected by the water/cement ratio, as is the porosity and strength of the concrete (Shetty, 2005). For constant cement paste content, creep is reduced by a decrease in the water/cement ratio. The most important external factor influencing creep is the relative humidity of the air surrounding the concrete. For a specimen that is cured at a relative humidity of 100%, then loaded and exposed to different environments, the lower the relative humidity, the higher is the creep. The values are much reduced in the case of specimens that have been allowed to dry prior to the application of load. The influence of relative humidity on creep is dependent on the size of the member. When drying occurs at constant relative humidity, the larger the specimen, the smaller is the creep. This size effect is expressed in terms of the volume/surface area ratio of the member. If no drying occurs, as in mass concrete, the creep is independent of size.

Creep is inversely proportional to concrete strength at the age of loading over a wide range of concrete mixes (Reynolds and Steadman, 2008). Thus, for a given type of cement, the creep decreases as the age and consequently the strength of the concrete at application of the load increases. The type of cement, temperature and curing conditions all influence the development of strength with age.

### 2.5.4 Compressive Strength

The strength of concrete is specified as a strength class or grade, namely the 28-day characteristic compressive strength of specimens made from fresh concrete under standardized conditions (Reynolds and Steadman, 2008). The results of strength tests are used routinely for control of production and contractual conformity purposes. The characteristic strength is defined as that level of strength below which 5% of all valid test results is expected to fall.

In principle, compressive strengths can be determined from cores cut from the hardened concrete. Core tests are normally made only when there is some doubt about the quality of concrete placed (e.g. if the cube results are unsatisfactory), or to assist in determining the strength and quality of an existing structure for which records are not available. Great care is necessary in the interpretation of the results of core tests, and samples drilled from in situ concrete are expected to be lower in strength than cubes made, cured and tested under standard laboratory conditions.

## 2.6 Durability of Concrete

Concrete has to be durable in natural environments ranging from mild to extremely aggressive, and resistant to factors such as weathering, freeze/thaw attack, chemical attack and abrasion (Reynolds and Steadman, 2008). In addition, for concrete containing reinforcement, the surface concrete must provide adequate protection against the ingress of moisture and air, which would eventually cause corrosion of the embedded steel.

Strength alone is not necessarily a reliable guide to concrete durability; many other factors have to be taken into account, the most important being the degree of impermeability (Reynolds and Steadman, 2008). This is dependent mainly on the constituents of the concrete, in particular the free water/cement ratio, and in the provision of full compaction to eliminate air voids, and effective curing to ensure continuing hydration (Shetty, 2005). Concrete has a tendency to be permeable as a result of the capillary voids in the cement paste matrix. In order for the concrete to be sufficiently workable, it is common to use far more water than is actually necessary for the hydration of the cement. When the concrete dries out, the space previously occupied by the excess water forms capillary voids (Reynolds and Steadman, 2008). Provided the concrete has been fully compacted and properly cured, the voids are extremely small, the number and the size of the voids decreasing as the free water/cement ratio are reduced. The more open the structure of the cement paste, the easier it is for air, moisture and harmful chemicals to penetrate.

## 2.7 Palm Kernel Shell (PKS)

Palm kernel shells (PKS) also known as Oil Palm Shells (Ezekiel, 2018). They are by-product of palm oil and palm kernel oil production, and are fractions of shells that result from the cracking of the nuts. PKS is obtained as crushed pieces, the sizes of which vary from fine aggregates to coarse aggregates, after the crushing of palm kernel to remove the seed, which is used in the production of palm kernel oil (Olutoge, 2010). Palm kernel shells are hard, flaky and of irregular shape (Oti and Kinuthia, 2015). There is no single type of shape that can be used to describe the palm kernel shell. The shape depends on the pattern of breaking during the nut cracking. It is usually composed of many shapes among which are roughly parabolic or semi-circular shapes, flaky shapes and other irregular shapes (Okafor, 1988). PKS are hard in nature and do not deteriorate easily when used for concrete and therefore, do not contaminate or leach to produce toxic substances (Basri et al., 1999). PKS may consist of about 65 to 70% of medium size particles in the range of 5 to 10 mm based on the method of cracking the nut (Alengaram et al., 2010).

PKS physical and mechanical properties make it suitable for so many applications. It can be used as an aggregate for concrete production (Okafor, 1988; Okpala, 1990; Osei and Jackson, 2012). Okoroigwe et al. (2014) used PKS as a sorbent material for industrial water treatment and stated that the physical and chemical properties of the material make it suitable for the purpose. PKS can also be used in road construction. However, for heavily trafficked roads, PKS replacement for aggregate of stone dust and bitumen in 10% blend with asphalt is recommended (Ndoke, 2006). PKS is also used in the preparation of pozzolana, a cement substitute material that has been developed by the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana (FAO Rome, 2002). Also, Oti and Kinuthia (2015) used PKS ash to produce concrete and stated that the potential to replace up to 50% Portland cement with PKS ash burnt at oven temperature of 750$^{o}$C is more feasible. Also, a recent study has shown that PKS can be used as a partial replacement for sand in sandcrete block production. Blocks produced from PKS aggregates are heavier, denser and stronger than the traditional sandcrete blocks when the PKS aggregate content do not exceed 10% (Dadzie and Yankah, 2015).

Palm kernel shell has both physical and mechanical properties suitable for use as coarse aggregate in concrete. According to Okoroigwe et al. (2014), the material physical and chemical properties determined using standard methods showed that it can fill useful applications in light weight construction as material filler and as sorbent material for industrial water treatment. The shell has a 24 hours water absorption capacity range of 21 – 33% (Shafigh et al., 2010). Okpala (1990) stated that the indirect compressive strength of PKS aggregate was 12.1 MPa with a standard deviation of about 2 MPa. The material bulk density ranges from 572 to 620 kg/m$^3$ (Itam et al., 2016; Okafor, 1988; Alengaram et al., 2010). The material has been found to have a specific gravity of 1.34 (Williams et al., 2014). Properties of PKS given by researchers summarized in Table 2.0, show that the material possesses desired characteristics that rendered it necessary to be used as coarse aggregate for concrete production.

**Table 2.0: Physical Properties of Palm Kernel Shell (Ezekiel, 2018).**

| Researchers | Specific Gravity | Bulk Density | Shell Thickness | Water Absorption | Fineness Modulus | Aggregate Impact |
|---|---|---|---|---|---|---|

| | | (kg/m$^3$) | (mm) | for 24hrs (%) | | Value (%) |
|---|---|---|---|---|---|---|
| Okafor, (1988) | 1.37 | 589 | - | 27.3 | - | 6.0 |
| Okpala, (1990) | 1.14 | 595 | - | 21.3 | - | - |
| Alengram, et al., (2010) | 1.27 | 620 | 3 | 25.0 | 6.2 | 3.91 |
| Shafigh, et al,, (2010) | 1.22 | - | - | 18.73 | 5.72 | - |
| Item, et al., (2016) | 1.21 | 572 | - | 25.64 | - | 6.65 |

**2.8 Palm Kernel Shell Concrete (PKSC)**

Palm Kernel Shell concrete (PKSC) is a concrete produce by substituting coarse aggregate either partially or fully with PKS. Depending on the mix design, it can be classified as either Structural Light Weight Concrete (SLWC) or an Insulating Light Weight Concrete when the 28-day compressive strength is below 17 MPa. According to the American Concrete Institute (ACI), Structural Light Weight Concrete is defined as a concrete made with low density aggregate that has an air-dry density of not more than 115 lb/ft3 (1840 kg/m3) and a 28 day compressive strength of more than 2,500 psi/17 MPa (ACI 116R, 2000). BS 5328 (1997), defined SLWC as hardened concrete having an oven dried density not greater than 2000 kg/m3. Okafor (1988) suggested that the use PKS as a full replacement of coarse aggregate cannot produce concrete with compressive strength above 30 MPa and that PKS is suitable for concrete grade 25 and below compared to conventional coarse aggregates. However, in latter researches, Alengaram et al. (2010) increased the 28-days compressive strength to 36-38 MPa by incorporating silica fume while Shafigh et al. (2011) developed a new method to produce high strength PKS concrete of 28-days compressive strength of 53MPa by using crushed PKS. Osei and Jackson (2012), studied PKS as Coarse Aggregates in Concrete and ascertained the possibility to replace coarse aggregate up to 100 percent but recommended that batching by volume should be used for better results. The mechanical and structural properties of PKSC have been compared with normal weight concrete (NWC) by many researchers to show the effectiveness of PKSC (Alengaram et al., 2013).

### 2.8.1Fresh and Hardened Properties of Palm Kernel Shell Concrete

Mechanical properties of palm kernel shell concrete are the same as that of normal weight concrete (Ezekiel, 2018). The fresh and hardened properties are workability, density, water absorption, split tensile strength and compressive strength test (Ezekiel, 2018).

#### 2.8.1.1 Workability

The most important property of fresh concrete is its workability defined as the ease with which concrete is mixed, transported, placed, compacted, and finished without segregation. Slump test is a standard test for determining the workability of concrete. It is used to calculate the variation in the uniformity of mix of a given proportion and also to measure the consistency of the concrete. Workability of PKSC is dependent on the water to cement ratio and also the content of PKS. As can be seen in Figure 2-2, Danashmand and Saadatian (2011) performed a slump test on PKSC for different percentages of PKS (Oil Palm Shell-OPS-as on the figure) content as a partial replacement for coarse aggregate with a constant water cement ratio of 0.5 and showed that with increase in PKS content, the workability of the concrete reduces.

Also, according to Alengaram et al. (2008), higher PKS content in the mix combined with the irregular and angular shapes of the PKS result in poor workability. This poor workability might be due to the friction between the angular surfaces of the PKS particles and lower fine content. A reduction in PKS content and a subsequent increase in fine aggregate content increases workability as can be seen from reports by different researchers summarized in Table 2.1.

**Table 2.1: Findings for Slump of PKSC by Past Researchers**

| Researchers | Water to Cement Ratio | Mix Proportion | Slump (mm) |
|---|---|---|---|
| Abdullah, (1984) | 0.6<br>0.4 | 1: 1.5: 0.5<br>1: 2: 0.6 | 200<br>260 |

| | | | |
|---|---|---|---|
| Okafor, (1988) | 0.48<br>0.65 | 1: 1.7: 2.08<br>1: 2.1: 1.12 | 8<br>50 |
| Okpala, (1990) | 0.5<br>0.6<br>0.7<br>0.5<br>0.6<br>0.7 | 1:1:2<br>1: 1: 2<br>1: 1: 2<br>1: 2: 4<br>1: 2: 4<br>1: 2: 4 | 30<br>63<br>Collapse<br>3<br>28<br>55 |
| Mahumed, et al., (2009) | 0.35 | 1: 1: 0.8 | 160 |

**2.8.1.2 Density**

For structural applications of Light Weight Concrete (LWC), the density is often more important than the strength (Rossignolo et al., 2003). The density of concrete is study in terms of bulk density, fresh density, and dry density. According to Okafor (1988), the fresh density of PKSC is in the range of 1753 – 1763 kg/m3 depending on the mix proportion, water to cement ratio, and also the use of sand. Mannan and Ganapathy (2001), based on the mix proportion also reported the fresh density of PKSC in the range of 1910 – 1958 kg/$m^3$. Alengaram et al., 2008, reported the fresh density of PKSC to be approximately 1880 kg/m3 by incorporating 10% silica fume and 5% fly ash by weight with a cement : sand : aggregate : water ratio of 1:1.2:0.8:0.35. Usually the fresh density of PKSC is about 100 – 120 kg/m3 lower than the saturated density of LWC (Alengaram et al., 2013). As shown on Figure 2-3, Osei and Jackson (2015) showed that the dried density of PKSC reduces with an increase in PKS content but increases with curing time.

**2.8.1.3 Water Absorption**

According to Basheer et al. (2001), water absorption is the transport of liquids in porous solids caused by surface tension acting in the capillaries. Water absorption for light weight concrete such as expanded polystyrene concrete and pumice aggregate concrete is in the range of 3 – 6% according to Babu and Babu (2003), and 14 – 22% according to Guduz and Ugur (2005) respectively. For PKSC, Teo et al. (2007) showed that the water absorption is 11.23% and

10.64% for air dry curing and full water curing respectively. This high water absorption for PKSC can be explained by the analysis of the PKS structure. Alengaram et al. (2011) examined the structure of the PKS using a scanning electron microscope and it was observed that tiny pores in the range of 16 - 24μm exist on the convex surface of the PKS as shown in Figure 2-4, which are responsible for the high water absorption of PKSC.

#### 2.8.1.4 Compressive Strength

The compressive strength is the most commonly used parameter to describe the quality of concrete in practice (Weigrink et al., 1996). All other mechanical parameters such as flexural strength, splitting tensile strength and modulus of elasticity directly depend on the compressive strength of the concrete (Alengaram et al., 2013). Ikponmwosa et al., (2014), Daneshmand and Saadatian (2011), and Olutoge et al. (2012), all reported that the compressive strength of PKSC is dependent on the amount of PKS aggregate in the concrete and that the strength increases with curing age.

Depending on the mix design, percentage of PKS aggregate, and method of curing, different grades of PKSC have been reported by researchers. Table 2.2 shows the compression strength of PKSC by various researchers. Okpala (1990) reported a 28 – day compressive strength of 22.2 MPa using water to cement ratio of 0.5 and a mix design of 1: 1: 2 (cement: sand: aggregate). Shafigh et al. (2011), incorporated steel fibers using a water to cement ratio of 0.38 and a design mix of 1: 1.736: 0.72 (cement: sand: aggregate) and reported a 28 – day compressive strength in a range of 39.34 – 44.95 MPa.

**Table 2.2: Compressive Strength of PKSC at 28 days of Curing (Ezekiel, 2018).**

| Researchers | Water to Cement Ratio | Mix Proportion | Compressive Strength at 28 days of Curing |
|---|---|---|---|
| Okafor, (1988) | 0.48 | 1: 1.7: 2.08 | 23 |
| Okpala, (1990) | 0.5 | 1: 1: 2 | 22.2 |
| Alengram, et al., (2010) | 0.35 | 1: 1.2: 0.8 | 37.41 |

| | | | |
|---|---|---|---|
| Shafigh, et al., (2011) | 0.38 | 1: 1.736: 0.32 | 39.34 |

### 2.8.1.5 Split Tensile Strength

The tensile strength of concrete is one of the basic and important properties (Ezekiel, 2018). Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. Since concrete is very weak in tension due to its brittle nature, it is not expected to resist the direct tension. According to Mannan and Ganapathy (2001), splitting tensile strength of PKSC depends on the curing condition and the physical strength of the PKS. Okafor (1988) showed that the splitting tensile strength of PKSC varied in the range of 2.0 – 2.4 by varying water to cement ratio from 0.48 – 0.65. Shafigh et al. (2011) obtained the splitting tensile strength of 5.55 by incorporating steel fibers. Table 2.4 shows a summary of splitting tensile strength reported by different researchers.

**Table 2.4: Split Tensile Strength of PKSC by Different Researchers (Ezekiel, 2018).**

| Researchers | Water to Cement Ratio | Mix Proportion | Split Tensile Strength (MPa) |
|---|---|---|---|
| Okafor, (1988) | 0.4<br>0.65 | 1: 1.7: 2.08<br>1: 2.1: 1.12 | 2.4<br>2.0 |
| Teo and Liew, (2006) | 0.41 | 1: 1.12: 0.8 | 2.24 |
| Mahmud, et al., (2009) | 0.35 | 1: 1: 0.8 | 1.98 |
| Shafigh, et al., (2011) | 0.38 | 1: 1.736: 0.72 | 5.55 |

## 2.9 Suitability of Palm Kernel Shell Concrete

PKS has been experimented in research as light weight aggregate to produce light weight and low cost concrete since 1984 (Alengaram et al., 2013). According to Shafigh et al. (2010), research over the last two decades has shown that PKS can be used as a lightweight aggregate for producing low cost and structural lightweight concrete. Also, it has been reported by Yap et al. (2013), that PKS is a suitable replacement for coarse aggregate to produce high strength LWC with 28 days compressive strength up to 53 MPa.

Okafor (1988) tested the physical properties of the shell, the compressive, flexural, and tensile splitting strength of the PKS concrete. Three mixes of widely different water to cement ratio were used with 100% coarse aggregate replacement with PKS. The properties tested were compared with those of similar concrete specimens made with crushed granite as coarse aggregate. The results showed that the material is suitable to produce concrete grade 25 and below. Similarly, Williams et al. (2014), produced a concrete with 100% replacement of coarse aggregate using PKS at a mix design of 1:2:4 (cement: sand: coarse aggregate) and a water to cement ratio of 0.65. The results showed that the compressive and flexural strength improved with age of curing, though the compressive and flexural strength of PKSC were low as compared to that of normal weight concrete. They concluded that PKS can be used for concrete production as lightweight aggregate and therefore can be used to produce light weight concrete. The properties of PKS fresh concrete are however excellent, very workable, consistent and easily placed.

Therefore, with the aforementioned information, it is evident that the PKS is suitable for the production of low structural concrete by replacing coarse aggregate.

## 2.10 Rice Husk

The rice husk, also called rice hull, is the coating on a seed or grain of rice. It is a major agricultural by-product produced during the de-husking process of paddy rice (Ezekiel, 2018). It is formed from hard materials, including silica and lignin, to protect the seed during the growing season. During rice milling, about 78% of weight is received as rice, broken rice and bran, and the rest 22% of weight of paddy is received as husk (Rao et al., 2014). It is separated from the brown rice grain as part of the milling process, after which the rice is polished. Rice husk in its loose form is mostly used for energy production, such as combustion and gasification (Ezekiel, 2018). Rice husk was long considered a waste from the rice milling process and was often dumped and/or burned. But because it can be easily collected and is cheap, some amount of rice husk has always been used as an energy source for small applications, such as for brick production, for steam engines and gasifiers used to power rice mills, and for generating heat for rice dryers.

### 2.11 Rice Husk Concrete

Concrete produced from rice husk has unique characteristics similar to normal weight concrete (Ezekiel, 2018). Researchers have reported that the properties of concrete made from rice husk greatly depend on the quantity of rice husk in the concrete, the water cement ratio, and also the age of curing (Ezekiel, 2018). According to Ponmalar and Abraham (2015), replacement of 15% sand with rice husk brought about 11.4% improvement in the strength of concrete and also a significant reduction in chloride ion penetration. Similarly, Kartini (2011) reported that replacement of ordinary portland with grinded rice husk reduces the water permeability of the concrete, thus reduces coefficient of permeability, and hence improves the durability of the concrete. Also, Marthong (2012) studied the effect of grinded rice husk as partial replacement of cement on concrete properties by replacing cement at 10, 20, 30, and 40% with grinded rice husk. He stated that up to 20% replacement of ordinary Portland cement with grinded rice husk has the potential to be used as partial cement replacement, having good compressive strength and durability. However, as shown in Figures 2-7 and 2-8, Yap et al. (2013) reported that at 28 days of curing, there was a reduction in the compressive strength of the concrete with increase in rice husk ash content but a significant increase in the splitting tensile strength of the concrete at 5% replacement level.

#### 2.11.1 Suitability of Rice Husk Concrete

Researchers have ascertained that grinded rice husk can be used to replace portion of the cement used in concrete production. Substitution for ordinary Portland cement in concrete production brings about a significant reduction in the cost of concrete as OPC is the most costly constituent in concrete (Ezekiel, 2018). According to Kartini (2011), up to 30% replacement of OPC with grinded rice husk has the potential to be used as partial cement replacement, having good compressive strength and durability, and can therefore contribute to sustainable construction. However, he suggested that grinded rice husk can be used as partial replacement of cement up to a maximum of 10% by volume in all grades of cement.

# CHAPTER THREE

## MATERIALS AND METHODS

This section presents the materials and methods used to actualize the research goal. Relevant standards were employed to ascertain how the materials collected be analyzed and also the various laboratory tests to be conducted. All Tests such as sieve analysis test for fine, coarse aggregate, specific gravity of fine and coarse aggregate, water absorption test, bulk density test of fine aggregate, slump or workability test of fresh concrete and compressive strength of hardened concrete were carried out at Nnamdi Azikiwe University Civil Engineering Laboratory located inside the school campus.

### 3.1 Collection and Preparation of Materials

#### 3.1.1 Cement

Dangote cement designated as DT was used for the experimental study. The cement was purchased at Onitsha Market in Anambra State. Upon purchase, the cement was conveyed to school laboratory where it was kept in a cool dry place preparatory for various laboratory testing. The cement sample satisfy the requirement for use as one of the major component of concrete in that, it was not caked or baked through visual inspection and quick setting time.

#### 3.1.2 Water

Water sample used for the experimental study was collected within the school environment. The water sample passed all the necessary requirement for use as ingredient of concrete based on the fact that it is colourless, devoid of suspended solid particles, contains infinitesimal trace of dissolved solid particles with no trace of turbidity after being subjected to laboratory testing. The water was collected in two gallons.

#### 3.1.3 Fine Aggregate (Sand)

Sand sample used in producing the concrete was provided at a construction site at Nnamdi Azikiwe University Campus. The sand was Sieved through 5.0mm test sieve to remove larger particles and then air-dried to a saturated state of an aggregate. The sample passed the necessary requirement for use as ingredient of concrete based on the fact that it is gritty with particle sizes visible to the naked eyes, physical properties of the sand samples were determined prior to its incorporation into the concrete. Index properties of the sand sample were determined prior to its incorporation into the concrete. Sand used for this experimental study will be partially admixed with rice husk in a stepped increase of 5% to 25% by weight of sand.

### 3.1.4 Coarse Aggregate (Granite)

Granite samples designated as GT was procured from Infrastructure Development Company (popularly known as IDC) located along Enugu-Onitsha express way. After procurement, the granite samples were conveyed to the laboratory unit of Department of Civil Engineering Nnamdi Azikiwe University Awka Anambra State where the index properties of the aggregate were determined. The granite sample passed all the necessary physical test in that, it has high crushing strength, it is relatively large in size (within range of 4.75mm to 20mm) and is a representative of granite (chippings) in color. Palm kernel shell will be partially added to granite in a stepped increase of 10 to 30% by weight of granite.

### 3.1.5 Rice Husk

Rice husk used for the experimental study designated as RH was procured from a rice plantation at Aguleri in Anambra State. The rice husk was collected in two cement bags and conveyed to Civil Engineering Laboratory in Nnamdi Azikiwe University. The rice husk will be partially added to sand in a stepped increase of 5% to 25% by weight of sand.

**Plate 3.0: Sample of Rice Husk used for the Experimental Study**

### 3.1.6 Palm Kernel Shell

The palm kernel shell designated as PKS was obtained from palm kernel production site at Udi in Enugu State Nigeria. The palm kernel shell sizes ranges between 5mm to 14mm. The shells were flushed with hot water containing detergent to remove dust and other impurities that could be detrimental to concrete. It was collected in two empty cement bags and was conveyed to laboratory, but before use, they were sun-dried and packed in plastic sheets to prevent contact with water, after sun-drying, the shell were taken to a crushing site where it was crushed into finer particles. The palm kernel shell will be used to partially replace coarse aggregate in concrete

**Plate 3.1: Crushed Palm Kernel Shell used for the Experimental Study.**

### 3.2 Experimental Investigation

This section presents the experimental procedure and laboratory tests that were used to investigate the effect of variation of water to cement ratio and compaction pressure on wet and dry properties of concrete. The tests was conducted for all the constituents of concrete and this tests include: sieve analysis test for fine, coarse aggregate, specific gravity of fine and coarse aggregate, bulk density test of fine aggregate, slump or workability test of fresh concrete and compressive strength of hardened concrete. The above listed tests were carried out at Civil Engineering Laboratory located in Nnamdi Azikiwe University Awka Anambra State, Nigeria. Below is a description of test procedures and apparatus:

#### 3.2.1 Specific Gravity of Fine Aggregate

Specific gravity is the ratio of mass of unit volume of soil at a stated temperature to mass of equal volume of gas-free distilled water at the same temperature (Krishna, 2002). Also as defined by Braja, (2006), Specific gravity can be defined as the ratio of unit weight of a material to unit weight of water. The specific gravity of soil solids is often needed for various calculations in soil mechanics. It can be determined accurately in the soil laboratory.

Apparatus employed for this experiment includes:

1 Density bottle of 50ml capacity and a stopper.
2 Desiccator containing anhydrous silica gel.
3 Thermostatically controlled oven with temperature of about 80-110$^{O}$C.
4 Weighing balance of 0.01g sensitivity.
5 Mantle heater.
6 Plastic wash bottle.
7 Distilled water.
8 Funnel
9 Thin glass rod for stirring.
10 425um Sieve.
11 Dry piece of cloth for cleaning.
12 Masking tape for identification of sample.
13 Exercise book and pen for recording of result.

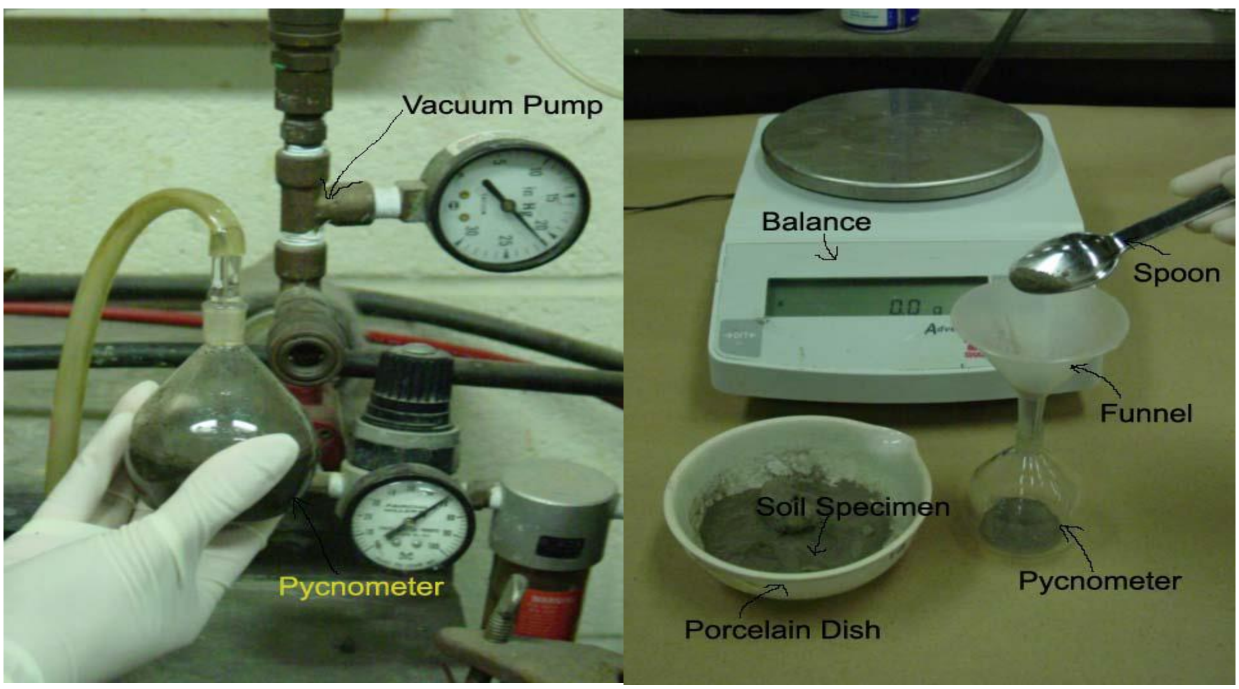


**Plate 3.2 Apparatus used for Specific Gravity Test (Source: Braja, 2006)**

### Test Procedure

1 The density bottle properly cleaned and rinsed with distilled water, thereafter oven- dried and then cooled it in a desiccator so as to remove any moisture present.

2 The empty clean and dry density bottle was weighed and recorded as ($M_1$).

3 About 10-15g of soil passing through 425um sieve was placed inside the density bottle, weigh and the weight of density bottle +dry soil + stopper was recorded as ($M_2$).

4 Distilled water was added to fill about half to three-fourth of the density bottle, and then the sample was soaked for 24hrs (The time stated is to enable complete settlement of the soil particle which is evident when clear water appears above the submerged soil).

5 The density bottle was gently stirred using thin glass rod and thereafter connected to a mantle heater to de-air the sample, the sample was not allowed to boil over.

6 After agitation, the sample was allowed to cool at room temperature and then filled with distilled water up to the specified mark (at lower meniscus level), the exterior surface of the density bottle was cleaned with a clean dry cloth and the weight of the density bottle + stopper +soil filled with water was determined and recorded as ($M_3$).

7 The density bottle was emptied, cleaned and rinsed with distilled water, then filled with distilled water up to the same mark. The exterior surface of the density bottle was cleaned with a clean dry cloth and the weight of the density bottle filled with distilled water + stopper was determined and recorded as ($M_4$).

8 The test procedure was repeated for two more trials and the average specific gravity value was obtained from the total no of trial, the variation in the specific gravity result obtained for each trial must not exceed 2%, otherwise repeat the experiment.

The Procedure for Computation of result obtained are as follows:

Specific gravity ($G_S$) = $\frac{(M2-M1)}{(M2-M1)-(M3-M4)}$

Where $M_1$= weight of density bottle + stopper

$M_2$= Weight of density bottle + air-dried soil + stopper.

### 3.2.2 Specific Gravity of Coarse Aggregate

The specific gravity of aggregate is defined as the ratio of aggregate to the weight of equal volume of water (Braja, 2006). The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Aggregate having low specific gravity are generally weaker than those with high specific gravity (Braja, 2006). This property helps in general identification of aggregate.

**Apparatus Employed**

1. Wires mesh Bucket or perforated container of convenient sizes with thin wire hangers for suspending it from a balance.
2. Pycnometer of 1000ml.
3. Set up consisting of container for filling water and suspending the wire basket in it and airtight container of capacity similar to that of a bucket, a shallow tray, two dry absorbent clothes.

**Test Procedure**

1. About 2 kg of aggregate sample is taken, washed to remove fines and then placed in the wire basket. The wire basket is then immersed in water, which is at a temperature of $22^0$C to $32^0$C.
2. Immediately after immersion the entrapped air is removed from the sample by lifting the basket 2mm above the base of the tank and allowing it to drop, 25 times at a rate of about one drop per second.
3. The basket, with aggregate are kept completely immersed in water for a period of 24 ± 0.5 hour.
4. The basket and aggregate are weighed while suspended in water, which is at a temperature of $22^0$C to $32^0$C.
5. The basket and aggregates are removed from water and dried with dry absorbent cloth.
6. The surface dried aggregates are also weighed.
7. The aggregate is placed in a shallow tray and heated to about $110^0$C in the oven for 24 hours. Later, it is cooled in an airtight container and weighed.

### 3.2.3 Particle Size Distribution Test

Sieve analysis is a procedure used to assess the particle size distribution of a granular material Atkinson (2000). The size distribution is often of critical importance to the behaviour of the material during use. Sieve analysis can performed on any type of non-organic or organic granular material including sand, crushed rock, clay, granite, feldspar and a wide range of manufactured powders, grains and seed down to minimum size depending on the exact method. The standard grain size analysis test determines the relative proportion of different grain sizes as they are distributed among certain size ranges.

Soil possesses a number of physical characteristics which can be used as aid to identify it sizes in the field. A handful of soil rubbed through the finger can yield the following:

1. Sand and other coarser particle are visible to the naked eye.
2. Silt particle becomes dusty and are easily brushed off.
3. Clay particle are greasy and sticky when wet and hard when dry and have to be scrapped or washed off hand and boot

For a soil to be well graded the value of coefficient of uniformity (Cu) has to be greater than 4 and 6 for gravel and sand respectively, while the Coefficient of Curvature ($C_v$) should be in the range of 1 to 3.

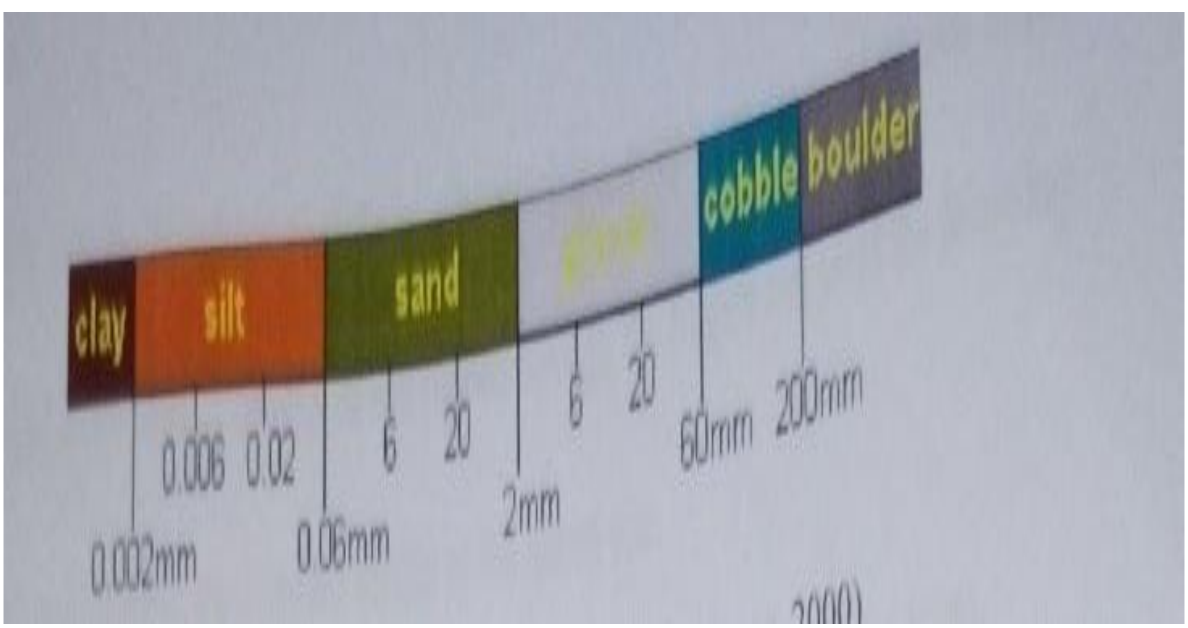


**Fig 3.0 Ranges for grain Sizes of different Soil type (Atkinson, 2000).**

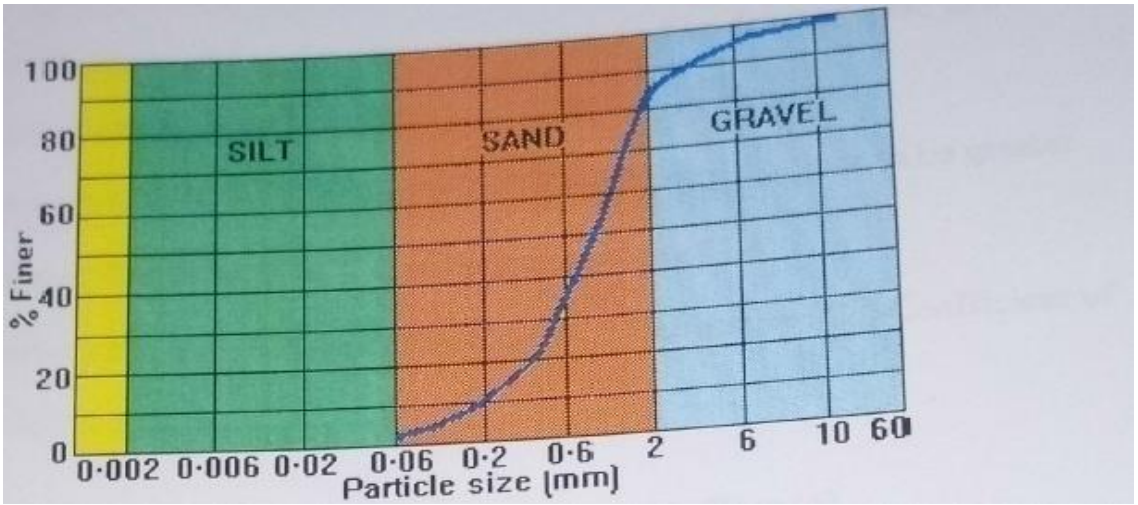


**Fig 3.1: Grading Curve Ranges for Different Soil Types (Atkinson, 2000).**

The apparatus needed for this experiment is listed below:

1. Stack of sieves including pan and cover.
2. Mechanical sieve shaker.
3. Weighing balance of 0.01g sensitivity.
4. Hand brush
5. Mortar and pestle (Used for crushing if the sample is conglomerated or lumped)
6. Thermostatically controlled Oven (With temperature of about 80$^{O}$C-110$^{O}$C).
7. Masking tape for identification of sample.
8. Exercise book and pen for recording of result.
9. The calculation for attaining Coefficient of uniformity and Coefficient of curvature are outlined below.

Percentage retained (%) $= \frac{\text{massofsoilretainedinthesieve(g)}}{\text{totalmassofsoilsample(g)}} \times 100$

Cumulative percentage retained = $\sum \text{Percentageretained}$ (%)

Cumulative Percentage Finer (%) = 100-Cummulative percentage retained.

Coefficient of Curvature $= \frac{D60}{D10}$

Coefficient of Uniformity $= \frac{(D30)2}{D10 \times D60}$

Where

D10= particle size such that 10% of the soil is finer than the size

D30= particle size such that 30% of the soil is finer than the size.

D60= particle size such that 60% of the soil is finer than the size**.**

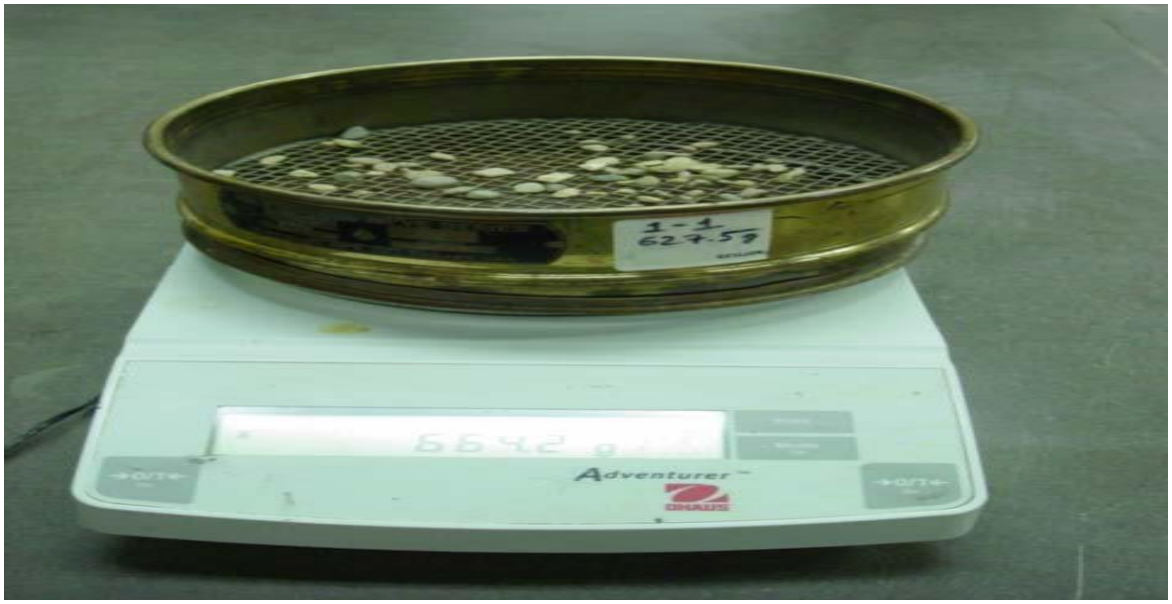


**Plate 3.3 Apparatus for Particle Size Distribution Test (Source: Braja, 2006).**


**Plate 3.4 Apparatus for Particle Size Distribution Test (Source: Braja, 2006).**

**Test Procedure**

1 The stack of sieves to be used for the experiment was properly cleaned using hand brush.

2 About 500g of air-dried soil sample was weighed with the aid of a weighing balance.

3 The weighed soil sample was poured into 75um sieve and wash under a steady supply of water until clear water start coming out from the sieve after passing through the soil sample.

4 After washing pour the washed soil sample into a pre-weighed plate and dry it inside the thermostatically controlled oven at a controlled temperature of 80-110$^{O}$C for 16-24hrs.

5 The sample was removed from the oven and the weight was determine (net weight) by deducting the weight of plate from the weight of plate and soil.

6 The stacks of sieve was arranged in the ascending order, placed in a mechanical sieve shaker, and thereafter the sample was poured and connected to the shaker for about 10-15 minute.

7 The sieve shaker was disconnected and the mass retained on each of the sieve sizes was determined.

8 The percentage retained, Cumulative percentage retained and Cumulative percentage finer was determined.

9 The graph of sieve Cumulative percentage finer against sieve sizes was plotted.

10 D10, D30 and D60 were determined from the plotted graph.

11 The Coefficient of Curvature and Coefficient of Uniformity was determined and used to classify the soil adopting the American Association of State Highway and Transportation Official (AASHTO) and Unified Soil Classification System (USCS) respectively.

### 3.2.4 Slump (Workability) Test

Slump test is used to determine the workability or consistency of concrete mix prepared at the laboratory or the construction site during the progress of the work.

The procedures are as follows:

1. Clean the internal surface of the mold and apply oil.
2. Place the mold on a smooth horizontal non- porous base plate.
3. Fill the mold with the prepared concrete mix in 4 approximately equal layers.

4. Tamp each layer with 25 strokes of the rounded end of the tamping rod in a uniform manner over the cross section of the mold. For the subsequent layers, the tamping should penetrate into the underlying layer.
5. Remove the excess concrete and level the surface with a trowel.
6. Clean away the mortar or water leaked out between the mold and the base plate.
7. Raise the mold from the concrete immediately and slowly in vertical direction.
8. Measure the slump as the difference between the height of the mold and that of

height point of the specimen being tested.

Calculation

Slump = Height of the slump cone – Height of the unsupported concrete.

a) **True Slump** – True slump is the only slump that can be measured in the test. The measurement is taken between the top of the cone and the top of the concrete after the cone has been removed as shown above. In a true concrete just subsides shortly and more or less maintain the mould shape. This type of slump is most desirable and represents the reliable condition to get an idea about the workability of concrete.
b) **Zero Slump** – Zero slump is the indication of very low water-cement ratio, which results in dry mixes. This type of concrete is generally used for road construction. In this slump, the concrete maintains the actual shape of the mould as it is said to be stiff, consistent and almost non-workable.
c) **Collapsed Slump** – In the case, fresh concrete collapses completely. This is an indication that the water-cement ratio is too high, i.e. concrete mix is too wet or it is a high workability mix, for which a slump test is not appropriate.
d) **Shear Slump** – In this case, one-half of the cone slide down in an inclined plane, this slump indicates lack of cohesion in the concrete mix. Shear slump may occur in case of a harsh mix.

**Plate 3.5: Apparatus used for Slump Test**

### 3.2.5 Compressive Strength of Hardened Concrete Cubes

This is aimed at determining the compressive strength of concrete made with variation of water to cement ratio and compaction pressure. Compressive strength test is conducted by the application of compressive axial load to molded cubes at a rate which is within a prescribed range until failure occurs.

The Apparatus Used includes:

1. **Testing Machine -** The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load.
2. **Cube Moulds -** The mould shall be of 150 mm size conforming to IS: 10086-1982.
3. Weights and weighing device
4. Tools and containers for mixing,

5. Tamper (square in cross section)

**Preparation of Samples**

For this research concrete mix design of 1:2:4 with water/cement ratio of 0.55 was used. The materials used were batched by weight and mixing was carried out manually and separately for each of the Ordinary Portland Cement (OPC) under laboratory conditions. 150mm×150mm×150mm metallic moulds with oil smeared on the inside of the mould to avoiding sticking was used for casting the concrete specimen after obtaining a uniform and consistent mixture. Vibration to remove entrapped voids was done manually and the concrete specimens were left in the mould for 24hours after casting before they were removed from the mould.

**Test Procedure**

**1**. **Sampling of Materials -** Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.

**2**. **Proportioning -** The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.

**3. Weighing -** The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.

**4. Mixing Concrete -** The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

**5. Mould -** Test specimens cubical in shape shall be 15 × 15 × 15 cm. If the largest nominal size of the aggregate does not exceed 2 cm, 10 cm cubes may be used as an alternative. Cylindrical test specimens shall have a length equal to twice the diameter.

**6. Compacting -** The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.

**7. Curing -** The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27°± 2°C for 24 hours ± ½ hour from the time of addition of water to the dry ingredients.

**8. Placing the Specimen in the Testing Machine -** The bearing surfaces of the testing machine shall be wiped clean and any loose sand or other material removed from the surfaces of the specimen which are to be in contact with the compression plates.

9. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom

10. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and the steel platen of the testing machine.

11. The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained.

12**.** The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted.

The compressive strength of concrete cube is computed as follows:

Compressive Strength ($N/mm^2$) = $\frac{\text{Applied load (N)}}{\text{Area of Cube (mm×mm)}}$

Where applied load (N) = Force

Now conversion of applied load from Ton force to KN or N.

1 Ton force = 10kN or 10,000N.

For 220kN = 220× 1000 = 220,000N

Area of cube = 150mm×150mm = 22,500$mm^2$

Compressive Strength = $\frac{220{,}000\text{N}}{22{,}500\text{mm2}}$ = 9.78$N/mm^2$

**Plate 3.6: Universal Testing Machine for Compressive Strength Test**

### 3.2.6 Water Absorption Test

This is the rate at which a sample absorbs water. It is expressed in percentage. The oven-dried sample is weighted and then immersed in clean water for 24hours.

Water absorption is expressed as Wa = $\frac{(Ww-Wd)}{Wd}$ * 100%

**Apparatus**

1. Weighing balance
2. Water bath
3. Drying cloth
4. Oven

**Test Procedures**

1 Place the sample cube in oven at 105 to 115$°C$ for 18 to 24 hours

2 After removing from oven, measure the weight of the dry block

3 Place the block in water bath at 25 to 29$°C$ for 24hours

4 After 24hours, dry the surface of the block with drying cloth

5 Measure the weight of the wet concrete cube

# CHAPTER FOUR

# RESULTS AND DISCUSSION

During the experimentation phase of the study, certain results were obtained which was useful in evaluating the effect of palm kernel shell and rice husk on mechanical properties of concrete. These results are presented below:

## 4.1 Results

The experimental results which will be valuable in assessing the effect of palm kernel shell and rice husk on mechanical properties of concrete includes the following:

1 Sieve Analysis Test Results
2 Specific Gravity Test Results
3 Slump (Workability) Test Results
4 Water Absorption Test Results
5 Compressive Strength Test Results

Below is a detailed description of the test results:

### 4.1.1 Sieve Analysis Test

**Table 4.1: Sieve Analysis Test Result for Granite**

| Sieve Sizes | Mass Retained | Mass retained2 | Cum % Retained | Cum % finer |
|---|---|---|---|---|
| (mm) | | | | |
| 20 | 115.92 | 14.49 | 14.49 | 85.51 |
| 14 | 525.2 | 65.65 | 80.14 | 19.86 |
| 10 | 72.32 | 9.04 | 89.18 | 10.82 |
| 4.75 | 84.24 | 10.53 | 99.71 | 0.29 |
| Tray | 2.32 | 0.29 | 100.00 | 0.00 |
| Total | 800 | 100.00 | 200.00 | |

**Table 4.2: Sieve Analysis Test Results for Sand**

| Sieve Sizes | Mass Retained | Mass retained2 | Cum % Retained | Cum % finer |
|---|---|---|---|---|
| (mm) | 1.21 | 0.40 | 0.4 | 99.60 |
| 4.75 | 7.83 | 2.61 | 3.01 | 96.99 |
| 2 | 15.44 | 5.15 | 8.16 | 91.84 |
| 1.18 | 225.21 | 75.07 | 83.23 | 16.77 |
| 0.6 | 40.99 | 13.66 | 96.89 | 3.11 |
| 0.3 | 8.04 | 2.68 | 99.57 | 0.43 |
| 0.15 | 0.62 | 0.21 | 99.78 | 0.22 |
| 0.075 | 0.66 | 0.22 | 100.00 | 0.00 |
| Tray | 300g | | | |

**Table 4.3: Sieve Analysis Test Results for Sand**

| Sieve Sizes | Mass Retained | Mass retained2 | Cum % Retained | Cum % finer |
|---|---|---|---|---|
| (mm) | | | | |
| 14 | 25 | 8.33 | 14.49 | 91.67 |
| 12.5 | 95 | 31.67 | 46.16 | 60.00 |
| 10 | 60 | 20.00 | 66.16 | 40.00 |
| 9.5 | 105 | 35.00 | 101.16 | 5.00 |
| 4.75 | 10 | 3.33 | 104.49 | 1.67 |
| Tray | 5 | 1.67 | 106.16 | 0.00 |
| Total | 300 | 37.50 | | |

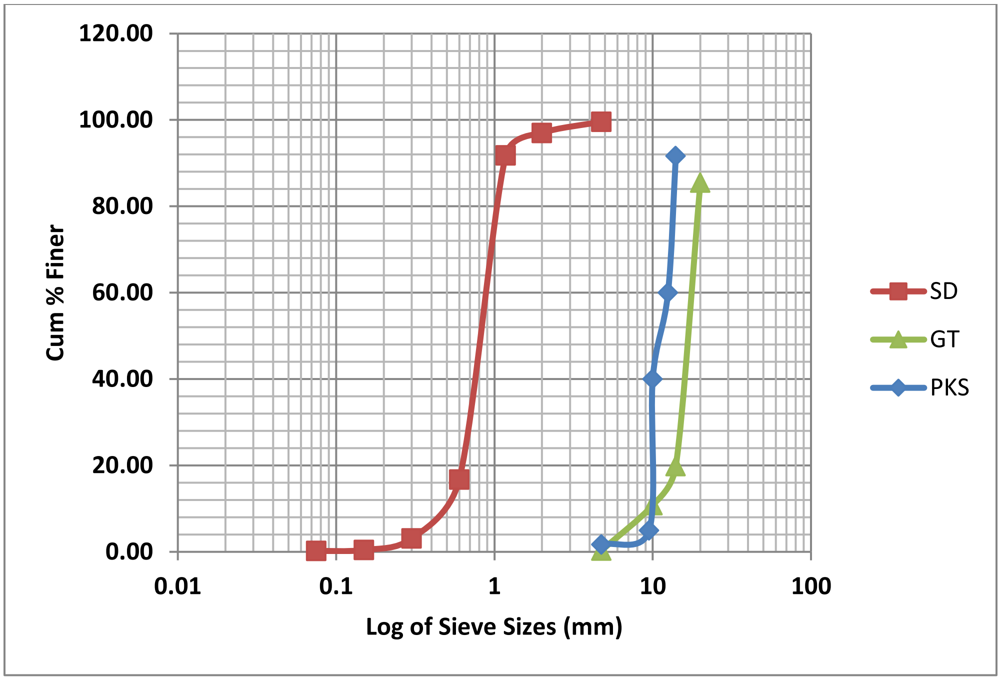


**Figure 4.1: Particle Size Distribution Curve for Sand, Granite and Palm Kernel Shell**

Figure 4.1 is the semi logarithmic plot of the particle size distribution of the GT, SD and PKS. Result recorded shows that for GT, the percentage passing through 4.75mm is 0.29 and according to AASHTO, it is classified as A-1-b and the constituent material constitutes an excellent sub-grade material. According to USCS, it is classified as GM (Gravel mixed with clay). The percentage passing through sieve size 0.075mm and 4.75mm for SD are 99.6 and 0.0033 respectively and according to AASHTO Classification system, it is classified as A-2-4 and SC (clayey sand) according to USCS Classification system. This material constitutes a good sub-grade material for road construction. While the percentage passing sieve size 4.75mm for the additive (PKS) is 1.67 and according to AASHTO, it is categorized as A-1-b and GM (gravel mixed with silt). The gradation of GT, SD and PKS obtained from their respective shape parameters (Cu and Cc) shows that they are poorly graded.

### 4.1.2 Specific Gravity Test

**Table 4.4: Specific Gravity Result for Sand**

| Determinants | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|

| | | | |
|---|---|---|---|
| **Wt of density bottle, $W_1$ (g).** | **24.76** | **25.64** | **25.90** |
| **Wt of bottle + dry soil, $W_2$ (g).** | **34.74** | **35.63** | **35.90** |
| **Wt of bottle + soil + water, $W_3$ (g).** | **84.33** | **85.15** | **85.79** |
| **Wt of bottle + water, $W_4$ (g).** | **78.07** | **78.94** | **79.56** |

**Table 4.5: Specific Gravity Result for Crushed Granite**

| **Determinants** | **Trial 1** | **Trial 2** | **Trial 3** |
|---|---|---|---|
| **Wt of empty can ($W_1$)** | **195.8** | **180.9** | **205.4** |
| **Wt of of can + saturated aggregate ($W_2$)** | **460.8** | **504.5** | **508.6** |
| **Wt of Saturated aggregate in air $W_3$ (g).** | **438.62** | **442.24** | **440.82** |
| **Wt of Oven-dried aggregate in air $W_4$ (g).** | **432.80** | **434.28** | **434.86** |

**Table 4.6: Specific Gravity Result for PKS**

| **Determinants** | **Trial 1** | **Trial 2** | **Trial 3** |
|---|---|---|---|
| **Wt of Saturated aggregate and basket in water $W_1$ (g).** | **342.7** | **311.60** | **290.47** |
| **Wt of basket in** | **152.20** | **145.61** | **137.01** |

| | | | |
|---|---|---|---|
| **Water $W_2$ (g).** | | | |
| **Wt of Saturated aggregate in air $W_3$ (g).** | **367.88** | **342.11** | **315.76** |
| **Wt of Oven-dried aggregate in air $W_4$ (g).** | **320.77** | **298.24** | **279.17** |

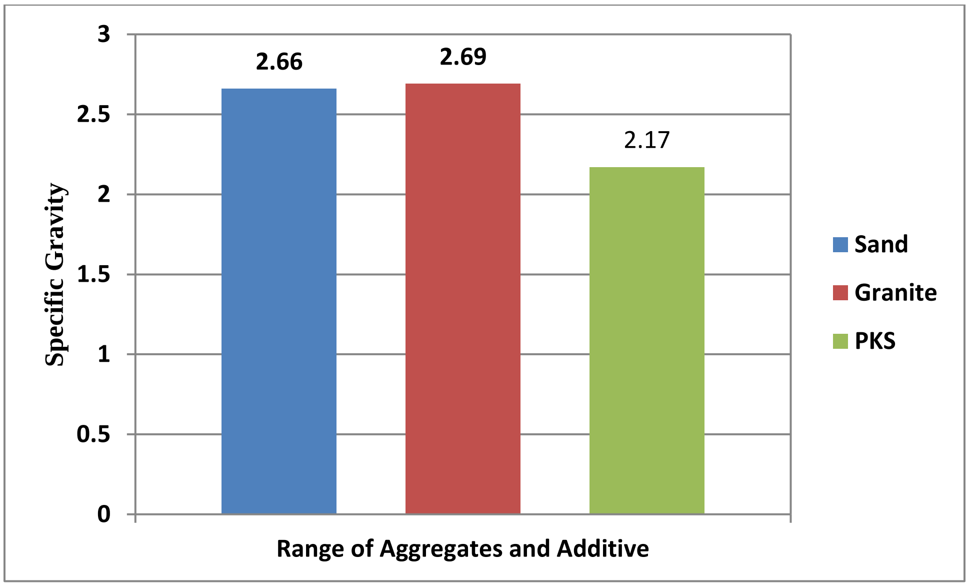


**Figure 4.2: Specific Gravity Values of Aggregate and Additives**

The specific gravity is defined as the ratio of weight of a sample to the rate of equal volume of water; it is used to obtain the unit weight of materials in the presence of water. Specific gravity test were conducted in accordance to ASTM D854-14 specification. For the sample designated as SD and GT and the additive (palm kernel shell) designated as PKS, the average apparent specific gravity computed are 2.66, 2.69 and 2.17 respectively. The range of specific gravity from 2.58 to 2.62 s satisfies ASTM D854-14 requirement which states that the specific gravity of aggregates should be between 2.55 to 2.9 and therefore justifies the use of the aggregates for this work.

### 4.1.3 Slump (Workability) Test

**Table 4.7: Slump Test Results for PKS + RH Concrete**

| % of PKS | % of RH | Height of Cone (mm) | Height of Collapse (mm) | Slump (mm) | Slump Type |
|---|---|---|---|---|---|
| 0 | 0 | 300 | 265 | 35 | True |
| 10 | 5 | 300 | 272 | 28 | True |
| 20 | 10 | 300 | 280 | 20 | True |
| 30 | 15 | 300 | 288 | 12 | True |
| 40 | 20 | 300 | 292 | 8 | True |

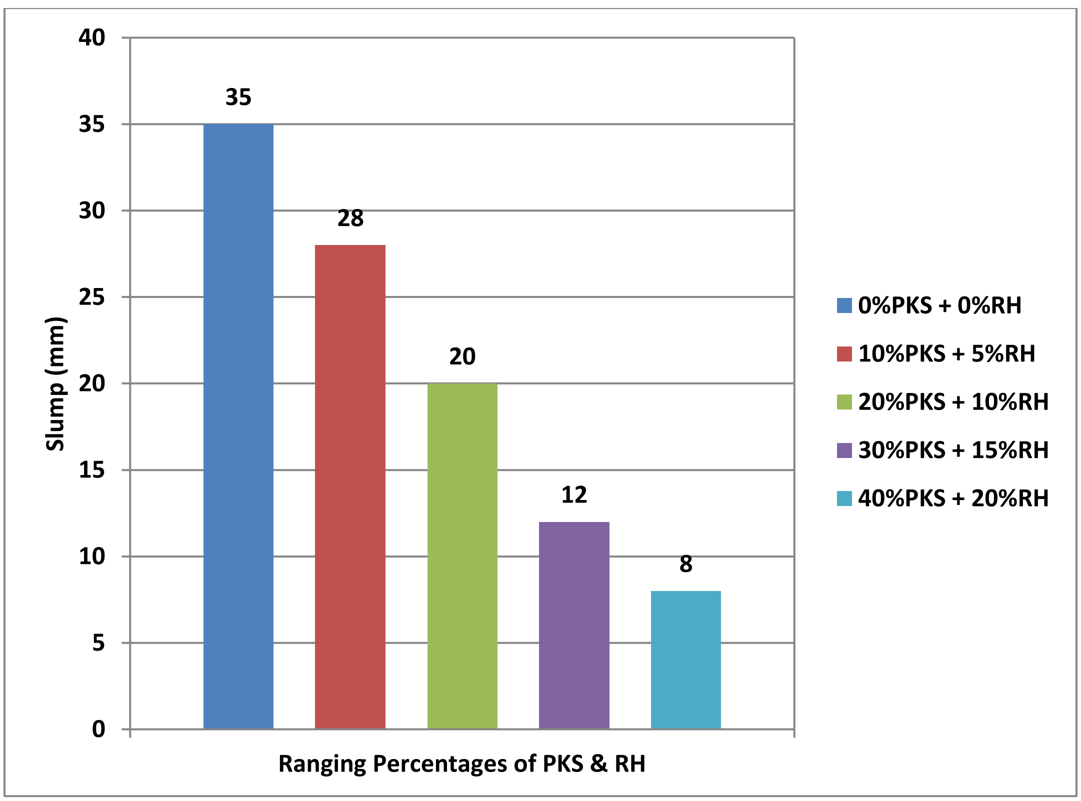


**Figure 4.3: Graph of Slump against Varying Percentages of PKS & RH**

Table 4.7 shows the slump test results for the different percentages of palm kernel shell and rice husk used in the concrete production. Result obtained revealed that the workability of the concrete decreased on addition of palm kernel shell and rice husk to the mix. The decrease in workability could be attributed to the finer particle sizes of palm kernel shell when compared to granite. This surface fineness increases the surface area and water demand of palm kernel shell concrete.

### 4.1.4 Water Absorption Test

**Table 4.8: Water Absorption Test Results against Percentages of PKS and RH**

| % of PKS + % of RH | Water Absorption (%) |
|---|---|
| 0%PKS + 0%RH | 0.75 |
| 10%PKS + 5%RH | 3.2 |
| 20%PKS + 10%RH | 4.1 |
| 30%PKS + 15%RH | 5.1 |
| 40%PKS + 20%RH | 10.9 |

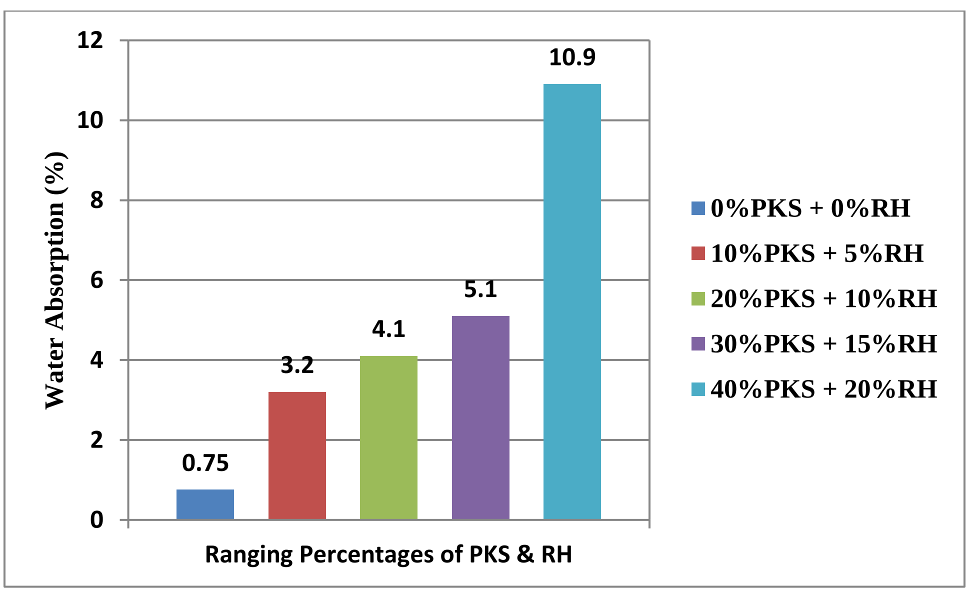


**Figure 4.4: Graph of Water Absorption against Varying Percentages of PKS & RH**

Figure 4.4 depict the water absorption values of the concrete at different percentage addition of palm kernel shell and rice husk. From the findings, it was observed that the water absorption of the concrete increased on addition of palm kernel shell and rice husk to the mix. The increase in water absorption on addition of palm kernel shell and rice husk could be attributed to the porous nature of palm kernel and rice husk. Since palm kernel shell is highly absorptive, increasing its content will increase the water absorption of the concrete.

### 4.1.5 Hardened Density Results

**Table 4.9: Hardened Density Result against Curing Days**

| Curing Days (Age) | Density (kg/m$^3$) |
|---|---|
| 7 | 1876 |
| 28 | 1993 |

**Table 4.10: Hardened Density Results against Percentages of PKS and RH**

| % of PKS + % of RH | Density (kg/m$^3$) |
|---|---|
| 0%PKS + 0%RH | 2337 |
| 10%PKS + 5%RH | 2054 |
| 20%PKS + 10%RH | 1894 |
| 30%PKS + 15%RH | 1784 |
| 40%PKS + 20%RH | 1605 |

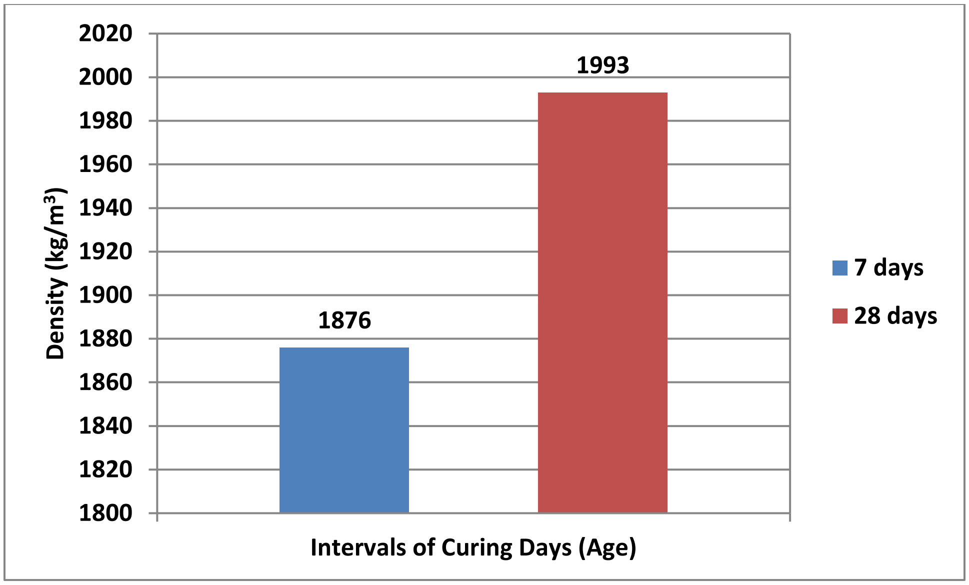


**Figure 4.5: Graph of Dry Density against Curing Days**

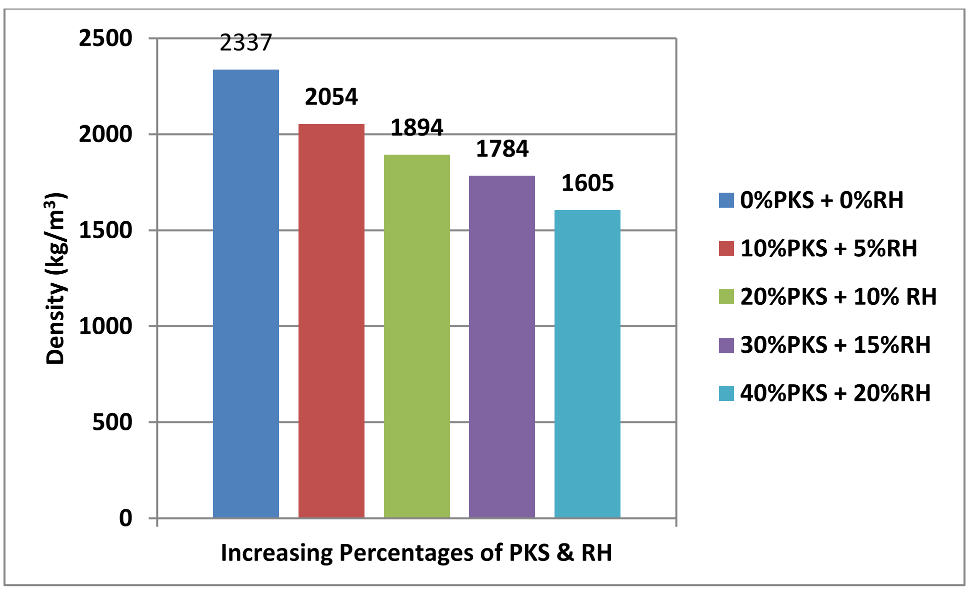


**Figure 4.6: Graph of Dry Density against Percentages of PKS & RH**

Assessment of the effect of palm kernel shell and rice husk on concrete hardened density revealed that the density of the concrete decreased on consistent addition of palm kernel shell and rice husk to the mix. The decrease in density could be attributed to the low specific gravity value of palm kernel shell and rice husk as palm kernel shell and rice husk are categorized as light weight material. Similar results were obtained by Itam, et al. (2016), Ikponwosa, et al. (2014) and Jackson, (2012).

### 4.1.6 Compressive Strength Test

**Table 4.11: Compressive Strength Result against Curing Days**

| Curing Days (Age) | Compressive Strength ($N/mm^2$) |
|---|---|
| 7 | 18.1 |
| 28 | 19.64 |

**Table 4.12: Compressive Strength Result against Percentages of PKS and RH**

| % of PKS + % of RH | Compressive Strength ($N/mm^2$) |
|---|---|
| 0%PKS + 0%RH | 23.01 |
| 10%PKS + 5%RH | 20.13 |
| 20%PKS + 10%RH | 18.3 |
| 30%PKS + 15%RH | 17.4 |
| 40%PKS + 20%RH | 15.58 |

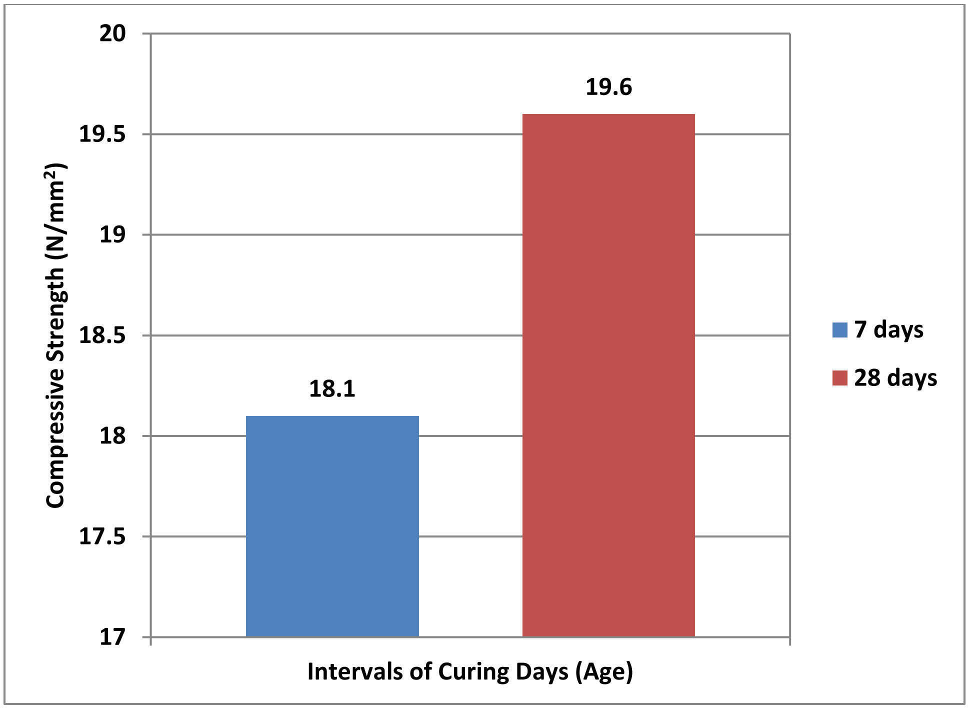


**Figure 4.7: Graph of Compressive Strength against Curing Days**

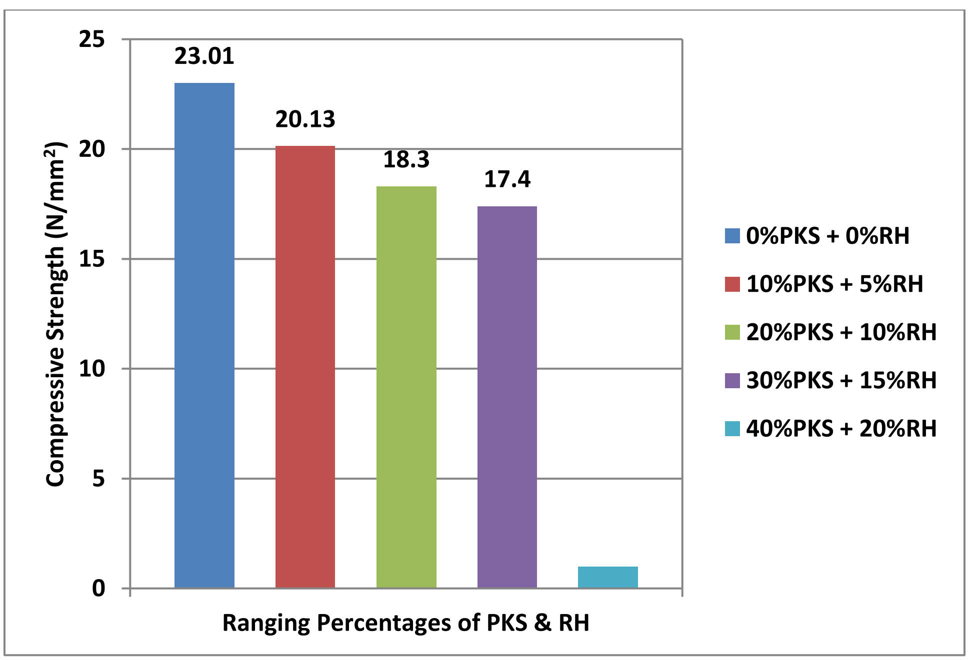


**Figure 4.8: Graph of Compressive Strength against Percentages of PKS & RH.**

Table 4.11-4.12 shows the results of compressive strength against curing days and percentage replacement of palm kernel shell and rice husk, It was observed that compressive strength of plain concrete (control specimen) and palm kernel plus rice husk modified concrete increased with curing days. This finding is in agreement with that obtained by Ikponwosa, et al. (2014) which stated that concrete gains it maximum compressive strength at 28 days of curing. On addition of palm kernel shell and rice husk to the concrete, the compressive strength of the concrete decreased with the optimum compressive strength recorded for the control specimen. The density in compressive strength could be attributed to the low density of palm kernel shell and rice husk. In addition, reduction in workability might have resulted to poor compaction thereby compromising the compressive strength of the concrete.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

From the findings obtained on production of light weight concrete through utilization of palm kernel shell and rice husk, the following conclusion can be drawn:

1. Preliminary investigation of the index properties of the aggregate and additives suggest that the materials satisfied standard requirement for use in concrete production.
2. The workability of the fresh concrete decreased on consistent addition of palm kernel shell and rice husk to the concrete.
3. The water absorption of the concrete increased on addition of palm kernel shell and rice husk to the concrete.
4. The wet and dry density of the concrete of the fresh concrete decreased on consistent addition of palm kernel shell and rice husk to the concrete with the concrete categorized as light weight concrete.
5. The compressive strength of the concrete increased with curing days but decreased on consistent addition of palm kernel shell and rice husk to the concrete.
6. Palm kernel shell and rice husk were adjudged as suitable material for production of light weight concrete.

## 5.2 Recommendation

From the findings obtained from the study, the following recommendation can be made:

1. Concrete produced with palm kernel shell and rice husk are light weight and can only be suitable for non structural purposes.
2. The recommendation 1 should be subjected to further studies to ascertain the type of material to be used in other to enhance the concrete density with the primary consideration of reducing concrete production cost.

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## APPENDICES

## APPENDIX A

### Compressive Strength Test

**Table A1: Compressive Strength Test Results for 0%PKS + 0%RH**

| Curing Days | Mix by Volume | Failure Load (kN) | Compressive Strength (N/mm$^2$) | Average Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|
| 7 | 1:2:4 | 504.5 | 22.42 | 22.1 |
| | | 499.8 | 22.21 | |
| | | 487.5 | 21.67 | |
| | | | | |
| 28 | 1: 2:4 | 545.8 | 24.26 | 23.92 |
| | | 538.4 | 23.93 | |
| | | 530.2 | 23.56 | |

**Table A2: Compressive Strength Test Results for 10%PKS + 5%RH**

| Curing Days | Mix by Volume | Failure Load (kN) | Compressive Strength (N/mm$^2$) | Average Compressive Strength (N/mm$^2$) |
|---|---|---|---|---|
| 7 | 1:2:4 | 440.5 | 19.58 | 19.24 |
| | | 433.2 | 19.25 | |
| | | 424.8 | 18.88 | |
| | | | | |
| 28 | 1: 2:4 | 472.4 | 21.0 | 21.02 |
| | | 480.5 | 21.36 | |

| | | | | |
|---|---|---|---|---|
| | | **465.5** | **20.7** | |

**Table A3: Compressive Strength Test Results for 20%PKS + 10%RH**

| **Curing Days** | **Mix by Volume** | **Failure Load (kN)** | **Compressive Strength (N/mm$^2$)** | **Average Compressive Strength (N/mm$^2$)** |
|---|---|---|---|---|
| **7** | **1:2:4** | **402.5** | **17.89** | **17.81** |
| | | **410.8** | **18.26** | |
| | | **388.7** | **17.27** | |
| | | | | |
| **28** | **1: 2:4** | **421.5** | **18.73** | **18.82** |
| | | **418.8** | **18.61** | |
| | | **430.3** | **19.12** | |

**Table A4: Compressive Strength Test Results for 30%PKS + 15%RH**

| **Curing Days** | **Mix by Volume** | **Failure Load (kN)** | **Compressive Strength (N/mm$^2$)** | **Average Compressive Strength (N/mm$^2$)** |
|---|---|---|---|---|
| **7** | **1:2:4** | **382.5** | **17.0** | **16.71** |
| | | **375.4** | **16.68** | |
| | | **370.2** | **16.45** | |
| | | | | |
| **28** | **1: 2:4** | **408.5** | **18.16** | **18.05** |
| | | **398.7** | **17.72** | |
| | | **410.8** | **18.26** | |

**Table A5: Compressive Strength Test Results for 40%PKS + 20%RH**

| Curing Days | Mix by Volume | Failure Load (kN) | Compressive Strength ($N/mm^2$) | Average Compressive Strength ($N/mm^2$) |
|---|---|---|---|---|
| **7** | **1:2:4** | **340.8** | **15.15** | **14.77** |
| | | **325.5** | **14.47** | |
| | | **330.3** | **14.68** | |
| | | | | |
| **28** | **1: 2:4** | **380.4** | **16.91** | **16.39** |
| | | **365.2** | **16.23** | |
| | | **360.8** | **16.04** | |

## APPENDIX B

**Table B1: Dry Density Test Results for 0%PKS + 0%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density (kg/m$^3$) | Average Density (kg/m$^3$) |
|---|---|---|---|---|
| 7 | 7.4 | 7.70 | 2199 | 2280 |
| | 7.72 | | 2287 | |
| | 7.95 | | 2356 | |
| | | | | |
| 28 | 8.12 | 8.20 | 2406 | 2429 |
| | 8.20 | | 2430 | |
| | 8.27 | | 2450 | |

**Table B2: Dry Density Test Results for 10%PKS + 5%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density (kg/m$^3$) | Average Density (kg/m$^3$) |
|---|---|---|---|---|
| 7 | 7.08 | 7.07 | 2098 | 2096 |
| | 7.12 | | 2110 | |
| | 7.02 | | 2080 | |
| | | | | |
| 28 | 7.25 | 7.22 | 2148 | 2140 |
| | 7.14 | | 2116 | |
| | 7.28 | | 2157 | |

**Table B3: Dry Density Test Results for 20%PKS + 10%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density (kg/m$^3$) | Average Density (kg/m$^3$) |
|---|---|---|---|---|
| 7 | 6.42 | 6.37 | 1902 | 1888 |
| | 6.38 | | 1890 | |
| | 6.32 | | 1873 | |
| | | | | |
| 28 | 6.93 | 6.93 | 2053 | 2053 |
| | 6.88 | | 2039 | |
| | 6.98 | | 2068 | |

**Table B4: Dry Density Test Results for 30%PKS + 15%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density (kg/m$^3$) | Average Density (kg/m$^3$) |
|---|---|---|---|---|
| 7 | 6.28 | 6.15 | 1861 | 1823 |
| | 6.04 | | 1790 | |
| | 6.14 | | 1819 | |
| | | | | |
| 28 | 6.45 | 6.49 | 1911 | 1924 |
| | 6.48 | | 1920 | |
| | 6.55 | | 1940 | |

**Table B5: Dry Density Test Results for 40%PKS + 20%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density (kg/m$^3$) | Average Density (kg/m$^3$) |
|---|---|---|---|---|
| 7 | 5.25 | 5.23 | 1556 | 1549 |
| | 5.62 | | 1573 | |
| | 5.12 | | 1517 | |
| | | | | |
| 28 | 5.45 | 5.60 | 1615 | 1660 |
| | 5.62 | | 1665 | |
| | 5.74 | | 1701 | |

## APPENDIX C

### Wet Density Test

**Table C1: Wet Density Test Results for 0%PKS + 0%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density (kg/m$^3$) | Average Density (kg/m$^3$) |
|---|---|---|---|---|
| 7 | 7.4 | | 2199 | |
| | 7.72 | 7.70 | 2287 | 2280 |
| | 7.95 | | 2356 | |
| | | | | |
| 28 | 8.12 | | 2406 | |
| | 8.20 | 8.20 | 2430 | 2429 |
| | 8.27 | | 2450 | |

**Table C2: Wet Density Test Results for 10%PKS + 5%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density (kg/m$^3$) | Average Density (kg/m$^3$) |
|---|---|---|---|---|
| 7 | 7.08 | | 2098 | |
| | 7.12 | 7.07 | 2110 | 2096 |
| | 7.02 | | 2080 | |
| | | | | |
| 28 | 7.25 | | 2148 | |
| | 7.14 | 7.22 | 2116 | 2140 |
| | 7.28 | | 2157 | |

**Table C3: Wet Density Test Results for 20%PKS + 10%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density ($kg/m^3$) | Average Density ($kg/m^3$) |
|---|---|---|---|---|
| 7 | 6.42 | 6.37 | 1902 | 1888 |
| | 6.38 | | 1890 | |
| | 6.32 | | 1873 | |
| | | | | |
| 28 | 6.93 | 6.93 | 2053 | 2053 |
| | 6.88 | | 2039 | |
| | 6.98 | | 2068 | |

**Table C4: Wet Density Test Results for 30%PKS + 15%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density ($kg/m^3$) | Average Density ($kg/m^3$) |
|---|---|---|---|---|
| 7 | 6.28 | 6.15 | 1861 | 1823 |
| | 6.04 | | 1790 | |
| | 6.14 | | 1819 | |
| | | | | |
| 28 | 6.45 | 6.49 | 1911 | 1924 |
| | 6.48 | | 1920 | |
| | 6.55 | | 1940 | |

**Table C5: Wet Density Test Results for 40%PKS + 20%RH**

| Curing Days | Weight (kg) | Average Weight (kg) | Density (kg/m$^3$) | Average Density (kg/m$^3$) |
|---|---|---|---|---|
| 7 | 5.62 | 5.7 | 1665 | 1689 |
| | 5.78 | | 1713 | |
| | 5.7 | | 1689 | |
| | | | | |
| 28 | 5.88 | 5.86 | 1742 | 1765 |
| | 5.95 | | 1763 | |
| | 6.04 | | 1790 | |

## APPENDIX D

### Water Absorption Test

**Table D1: Water Absorption Test Results for 0%PKS + 0%RH**

| Curing Days | Water Absorption (%) | Average Water Absorption (%) |
|---|---|---|
| 7 | 0.5 | 0.7 |
| | 1.0 | |
| | 0.6 | |
| | | |
| 28 | 0.9 | 0.8 |
| | 0.6 | |
| | 0.9 | |

**Table D2: Water Absorption Test Results for 10%PKS + 5%RH**

| Curing Days | Water Absorption (%) | Average Water Absorption (%) |
|---|---|---|
| 7 | 2.8 | 3.4 |
| | 3.3 | |
| | 4 | |
| | | |
| 28 | 3.0 | 2.9 |
| | 3.2 | |
| | 2.5 | |

**Table D3: Water Absorption Test Results for 20%PKS + 10%RH**

| Curing Days | Water Absorption (%) | Average Water Absorption (%) |
|---|---|---|
| 7 | 2.7 | 3.6 |
| | 4.2 | |
| | 3.9 | |
| | | |
| 28 | 5.2 | 4.6 |
| | 3.9 | |
| | 4.8 | |

**Table D4: Water Absorption Test Results for 30%PKS + 15%RH**

| Curing Days | Water Absorption (%) | Average Water Absorption (%) |
|---|---|---|
| 7 | 7.5 | 6.1 |
| | 5.0 | |
| | 5.9 | |
| | | |
| 28 | 4.4 | 4.1 |
| | 3.8 | |
| | 4.0 | |

**Table D5: Water Absorption Test Results for 40%PKS + 20%RH**

| Curing Days | Water Absorption (%) | Average Water Absorption (%) |
|---|---|---|

| | | |
|---|---|---|
| **7** | **7.2** | **9.1** |
| | **8.9** | |
| | **11.3** | |
| | | |
| **28** | **7.9** | **4.1** |
| | **12.1** | |
| | **18.0** | |