DETERMINATION OF STRUCTURAL CHARACTERISTICS OF PALM KERNEL SHELL-SAWDUST PLANK LAMINATED COMPOSITE SLAB

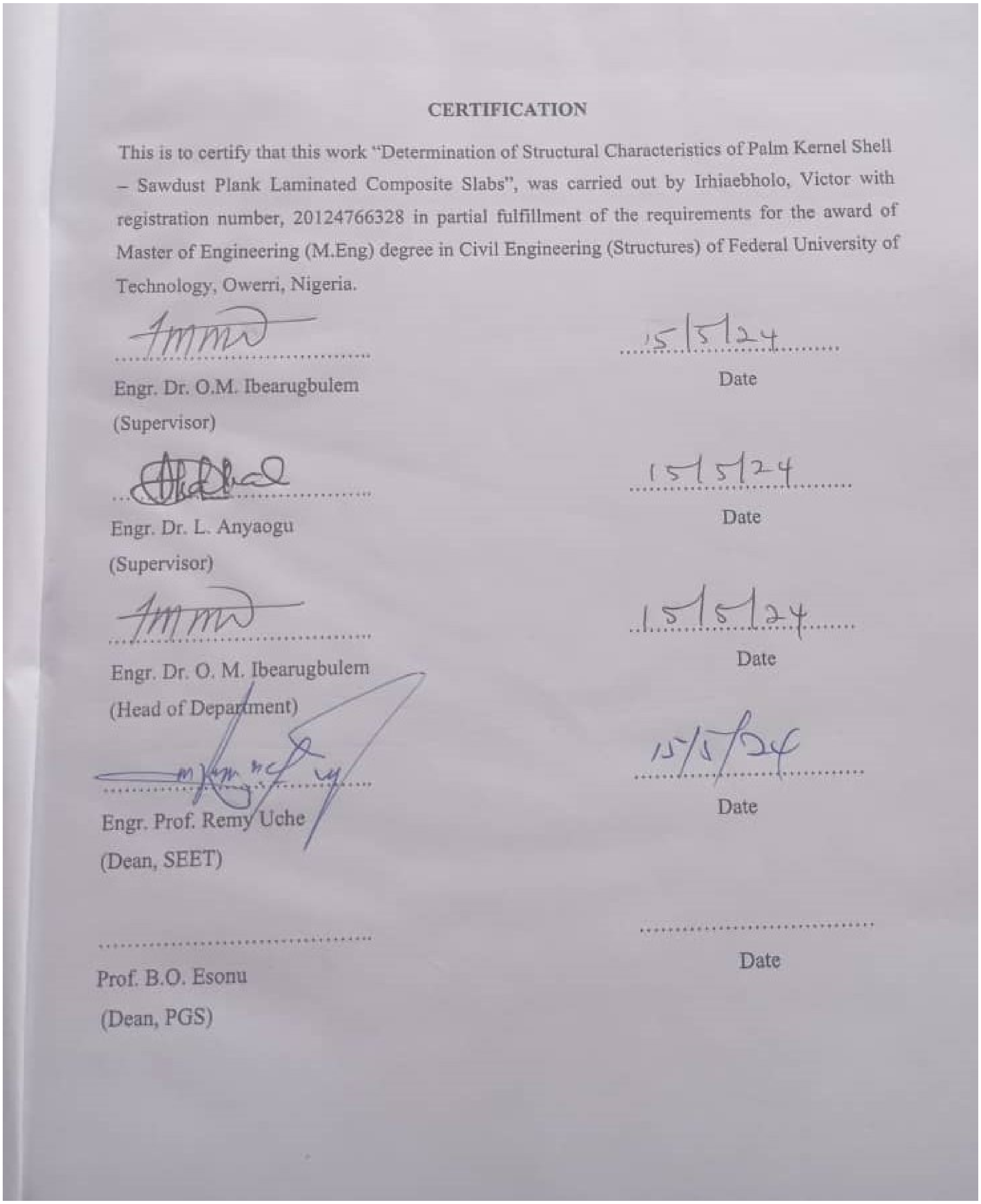
By

IRHIALEBHOLO, VICTOR (B.Eng.)
REG. No. 20124766328

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF ENGINEERING (M.ENG) DEGREE IN CIVIL ENGINEERING (STRUCTURES)

APRIL, 2024



CERTIFICATION

This is to certify that this work "Determination of Structural Characteristics of Palm Kernel Shell – Sawdust Plank Laminated Composite Slabs", was carried out by Irhiaebholo, Victor with registration number, 20124766328 in partial fulfillment of the requirements for the award of Master of Engineering (M.Eng) degree in Civil Engineering (Structures) of Federal University of Technology, Owerri, Nigeria.

Engr. Dr. O.M. Ibearugbulem
(Supervisor)

15/5/24
Date

Engr. Dr. L. Anyaogu
(Supervisor)

15/5/24
Date

Engr. Dr. O. M. Ibearugbulem
(Head of Department)

15/5/24
Date

Engr. Prof. Remy Uche
(Dean, SEET)

15/5/24
Date

Prof. B.O. Esonu
(Dean, PGS)

Date

DEDICATION

I dedicate this work to God almighty the creator of heaven and earth. I also dedicate this work to my parents Sir and Lady Ambrose Irhiaebholo for their unfailing support throughout the course of my study

ACKNOWLEDGEMENTS

My sincere thanks go to my project supervisors Engr. Dr. O. M. Ibearugbulem and Engr. Dr. L. Anyaogu who both tirelessly granted me all the necessary assistance I needed to make this research work a huge success.

I also want to specially thank Engr. Dr. U.C Anya, who went out his way to assist me with rare texts which I found very helpful for the completion of this work. I again sincerely appreciate the efforts of Engr. Prof. J.C. Ezeh (Dean Emeritus, SEET), Engr. Prof. Mrs. B.U. Dike, Prof. D.O. Onwuka, Engr. Prof. . B.C. Okoro, Rev Engr. Prof. L.O. Ettu, Engr. Dr. H.U. Nwoke, Engr. Prof.. J.C. Osuagwu, Engr. Prof. Mrs. C.E. Okere, Rev. Engr. Dr. N.L. Nwakwasi, Engr. Dr. A.N. Nwachukwu, Engr. Dr. C. F. Njoku, Engr. Dr. Mrs. J. I Arimanwa, Engr. K. N. Onyema, Engr. K.C. Nwachukwu, Engr. S. I. Agbo, Engr. K. O. Njoku, Engr.Dr. Mrs. C. Awodiji, Engr. Dr. R. Onosakponome, Mr. S Iwuoha, Mr. C. Ajoku and Mr. E.E Anike for their immense invaluable contribution to whom I am today.

To the Head of Civil Engineering Department- Engr. Dr. O. M. Ibearugbulem, and to the Dean school of Engineering and Engineering Technology - Engr. Prof. Remmy Uche whose administrations provided a peaceful and conducive environment for my academic pursuits to be achieved here in FUTO, I say a very big “God Bless You”.

To my friends Engr. Christopher Amaechi, Mr. S.U Okoroafor, Engr. Nwachukwu I. Nwachukwu and to all those who consistently supported me in any way, I am grateful.

I am eaqually grateful to Mr. Obiora Iwu and Olugbemiga my bosses in the office whose support and approval made me embark in this programme in the first place.

Finally, I am grateful to the Almighty God for his Grace, Strength and the Enablement which He granted me throughout my stay in FUTO for my Master’s program and also throughout this research work

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

This work investigates the structural characteristics of Palm Kernel Shell-Sawdust-Plank laminated composite slab. The materials used in the laboratory experiments include: Ordinary Portland Cement, river sand, gravel, sawdust, plywood, nails reinforcement bars, stirrups and water. The physical and mechanical characterization tests were performed on the aggregate and sawdust used in this work. Manual mixing operation was adopted and all palm kernel shell – sawdust ingredients where batched by weight. A total of eighteen (18) cubes of size 150 x 150 x 150 mm, nine (9) cylinders of size 150 x 300 mm and nine (9) beams of size 150 x 150 x 600 mm were produced from mix ratios 1:1:1, 1:2:2, and 1:3:3 for compressive strength test, split tensile strength test and flexural strength test respectively. Also, a total of 32 slabs of size 1200 x 1000 x 100 mm, 1200 x 1000 x 125 mm, 1200 x 1000 x 150 mm and 1200 x 1000 x 175 mm were cast for flexural strength of slab from the mix ratios 1:2:2 and 1:3:3. Out of the 32 slabs cast, 16 were produced from palm kernel shell – sawdust wooden plank laminated (25mm as the thickness of wooden plank for the laminate), 8 were produced from normal concrete ingredients (coarse aggregates, fine aggregates, cement and water) with 10mm rebar and mix ratio of 1:2:4. Water-cement ratio of 0.45 was adopted. The remaining 8 slabs were made from plain sawdust-quarry dust with mix ratio of 1:3:3. The average compressive strength for the three (3) mix ratios used were 10.25 MPa, 9.08 MPa and 4.36 MPa respectively. The average flexural strength from beams samples for the three (3) mix ratios were 2.35 MPa, 2.00 MPa and 1.85 MPa; that of slab ranges from 1.84-3.17 MPa. The average split tensile strength for three (3) mix ratios are 1.950 MPa, 1.666 MPa and 1.558 MPa. The average static modulus of elasticity for the three mix are 8.90 GPa, 8.56 GPa and 6.77 GPa. The average Poisson's ratio ranges from 0.19-0.36. The shear modulus ranges from 3.86– 2.64 MPa. The maximum deflection for the slabs were observed to occur at the size 1200 x 1000 x 100 mm no matter the core content of the slab while the minimum deflection occurs at the size 1200 x 1000 x 175 mm. The flexural strength results of slabs were compared by percentage difference and the results shows that there is significant difference between the two sets of slabs. Also comparing the results of plain palm kernel shell – sawdust slab to that of palm kernel shell – sawdust wooden plank laminated composite slab, show that laminates with plywood influence flexural strength up to 62%.

KEYWORDS: Palm kernel shell, sawdust, slab, wooden plank, composite, laminate, structural characteristics.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Structure is an arrangement and organization of interrelated elements in a material object or system, or the object or system so organized (Oxford English Dictionary 2005). The structural elements (members) can be classified as one-dimensional (ropes, struts, beams, arches), two-dimensional (membranes, plates, slab, shells, vaults), or three-dimensional (solid masses) (Carpinteri, 2002). The latter was the main option available to early structures. A one-dimensional element has one dimension much larger than the other two, so the other dimensions may not be a critical case if not considered during calculations; however, the ratio of the smaller dimensions and the composition can determine the flexural and compressive stiffness of the element. Two-dimensional elements with a thin third dimension have little of either but can resist biaxial traction. (Carpinteri, 2002). Structural elements are used in structural analysis to split a complex structure into simple elements. Within a structure, an element cannot be broken down (decomposed) into parts of different kinds. In structural Engineering, the components of building include: - beams, columns, slab, roof and foundation. These components transfer loads from one member to another since they are interconnected. A slab is a flat two-dimensional planar structural element having thickness that is very small compared to its other two dimensions and it can resist loads subjected to it either at vertical direction or inclined (Ibearugbulem, Ezeh, Ettu, 2014). It behaves primarily as a flexural member; Their primary function is to carry vertical loads, fixed and transient loads to beams and columns (Mosley, Bungey and Hulse, 1999). Slab can be produced using different construction materials like wood (timber), steel, and composite members like concrete, steel-composite, plywood etc. The early form of slab is timber (wood) slab; it has good compressive and flexural strength but the major problem of timber slab is that it can sustain a very much greater load for a short period of time than they can for a longer period of time, or permanently (Ozelton and Baird, 2006). BS 5268-2, 2002 takes account of this by quoting duration of loading factors for long-term, medium-term, short-term and very short-term loadings. Therefore, there is a need to get a material that can have equal strength in all direction. In a bid to have such material, the aid of composite construction comes up, of which concrete slab is a form of it. Concrete slab is the most commonly used slab either inform of plain, reinforced, or pre-stressed concrete in building construction. The design of concrete slab can be seen in BS 8110 part 1,2 and 3. The actual problem associate with concrete slab is self-weight. In other to solve the problem of self-weight for concrete slab, a lot of lightweight materials have been used as replacement to the components of concrete. Some of these materials are agricultural and industrial wastes which include palm kernel shell, fly ash, coconut shells among others which are produced from milling stations, and so on (Ganiron, 2014).

Therefore, in these works, a composite slab will be produced using a combination of wood, sawdust, palm kernel and cement; and investigates its deflection and flexural strength.

1.2 Problem Statement

Over the years, timber slabs have been in use for building construction, but the deficiency is that the strength in flexure along the grain and across the grain are not the same (orthotropic nature) and there is a need to have a member that can have equal strength in all direction. To overcome this, concrete slab has been introduced; but the problem of concrete slab is heavy self-weight, the heavy self-weight of concrete contributes about 50 percent of the total load a concrete slab can carry although out its life span. Such loads contribute to deflection of slab. Hence there is a need to investigate a composite material that has a good flexural strength and as well have its strength equal (or comparable) in all direction. This work addresses this problem by investigating palm kernel shell-wooden laminated composite to see if the strength in flexure as well as deflection can be adequate as a structural slab.

1.3 Objectives of Study

The main objective of this research work is to investigate the structural behavior of palm kernel shell-wooden plank laminated composite slabs. To achieve this, the following specific objectives are set:

i. To characterize the aggregates used in the research.

ii. To determine the structural characteristics of palm kernel shell – sawdust plank laminated composite slab

iii. To determine the flexural strength of palm kernel shell-sawdust plank laminated composite beams.

iv. To compare the flexural strength of palm kernel shell-sawdust plank laminated composite slabs with those of conventional slab and plain palm kernel shell-sawdust composite plain slabs.

1.4 Justification of Study

The very notable significance of this project is that it will reduces the load due to self-weight of slab. It also encourages wastes recycling which is one of the goal of vision 202020. Researches have been carried out on the use of sawdust as a sand replacement material but the use of palm kernel wooden plank laminated slab needs to be investigated. Hence, this is the basis for the present research work. It can also help to reduce cause of erosion by reducing the quantity of aggregate sourced for during construction. It also has cost benefit since the sawdust is a waste compare with sand that can be purchased.

1.5 Scope of Study

The scope of this study is limited to the determination of structural characteristics of palm kernel shell – wooden plank laminated composite slab. The palm kernel shell composite structural characteristics to be determined include: - compressive strength, flexural strength, split tensile strength, static modulus of elasticity, Poisson's ratio, shear modulus and shear strength. In addition, experimental determination of deflection and flexural strength at failure of palm kernel shell laminated composite slab and conventional slab was obtained. The structural properties of palm Kernel sawdust plank laminated composite were compared to those of conventional slab to obtain the percentage difference in flexure and deflection. More so, the results of palm kernel shell laminated composite slab were compared to those of the plain palm kernel shell to ascertain the effect of laminates on the flexural strength and deflection.

CHAPTER TWO

LITERATURE REVIEW

2.1 Slab

According to Chandradhara, 2010 a slab is a flat two dimensional planar structural element having thickness very small compared to its other two dimensions. It can also be defined as a planar structural element that can resist load applied perpendicular to the direction of larger dimension. It provides a working flat surface or a covering shelter in buildings. It primarily transfers the load by bending in one or two directions. Slab can be produced with different engineering construction materials like wood (timber), steel and composite members like plywood, particle boards, oriented strand boards, cement-bonded particle board and wood fibre boards (Ozelton and Baird, 2006).

Wood slab is the first form of slab in existence; the properties of wood that made it to be used for slab are good strength and ease of shaping. The problem associated with wood is timber is not equal in strength in all directions because it is an orthotropic material (Ozelton and Baird, 2006). Therefore, there is a need to get a material that can have equal strength in all direction. To overcome this problem, composite construction has to come into existence; of which concrete slab is a member.

Reinforced concrete slabs are used in floors, roofs and walls of buildings and as the decks of bridges. The floor system of a structure can take many forms such as in situ solid slab, ribbed slab or pre-cast units. Slabs may be supported on monolithic concrete beam, steel beams, walls or directly over the columns. Concrete slab behave primarily as flexural members and the design is similar to that of beams (BS 8110 – 1: 1997). The problems associated with concrete slab is self-weight which is as a result of the unit weight of materials used in its production. Hence there is a need to consider other composite members like plywood etc.

Many researchers have done a lot of work to solve problem of self-weight of which some of them will be reviewed here.

Erik et al. (1994) studied the wood-wool slabs: – Manufacturing, properties and uses. From results of their work, they proved that the strength of wood-wool slab, both in compression and bending stands the test of time more especially when it is not exposed to humidity. The slab can also be used for wall because of its load bearing capacity.

Waldeman et al. (2000) studied the structural and other properties of modified wood; their concentration was on the durability, dimensional stability and hardness. They proved that modified wood has advantages over the unmodified wood for construction of slab. Such modified wood includes plywood which have advantage of having the strength equal in all directions.

Nagaraj and Banu (1996) have studied the effect of rock dust and pebble as aggregate in cement and concrete. It has been reported that crushed stone dust can be used to replace the natural sand in concrete.

Kanakasabai and Rajashekaran (1992) investigated the potential of ceramic insulator scrap as coarse aggregate in concrete. It has been reported that the crushed ceramic aggregate can be used to produce lightweight concrete, without affecting strength.

Sahu, et al (2003) have reported that sand can be replaced by rock flour up to 40% without affecting strength and workability.

Kumar, (2012) studied the properties of concrete made with alternate construction materials, from his work the compressive strength of recycle aggregates was on the average 70% to 80% of that of conventional aggregates; the compressive strength of sawdust concrete was 8-10% of the conventional aggregates.

Okutu, (2012) investigated structural implications of replacing concrete floor slabs with timber in composite construction, He found out that in buildings with columns closer than 9m apart, and with imposed loads of 4 kN/m^2 or less, using timber meant a reduction in the amount of steel in the frame. The loads to the foundations were reduced significantly in every of his case study.

Fakhrul et al. (2013) carried out studies on properties of wood sawdust and wheat flour reinforced polypropylene composite. His results showed that the average tensile strength of the composite decreases with addition of sawdust and wheat flour.

Kasim *et al.* (2014) carried out research on the mechanical properties of wood shavings-cement lightweight composite. They proved that the compressive strength and tensile strength of the wood-cement matrix have satisfactory values.

In order to produce lightweight concrete, effect of sawdust as fine aggregate in concrete mixture was carried out by Ganiron, (2014). From his research, he showed that sawdust can be used to replace sand in concrete production to an extent. His investigation was centered on concrete of grade 15-22. He also studied the effect of partial replacement of sand with sawdust. From this work he concluded that the best replacement is from 25-50%.

Also a lot of work have been done on palm kernel shell of which some of them are as presented below:

Previous studies have shown that palm kernel shell can be used as a lightweight aggregate for concrete production (Alengaram et al 2010). Although the compressive strength of the concrete made with palm kernel shell fulfils the requirement for lightweight concrete, higher strength is preferred for medium strength structural members (Alengaram et al 2010). The results of another work on the ductility behaviour of reinforced palm kernel shell concrete beams showed that the mode of failure observed in palm kernel shell was ductile (Alengaram et al 2008). The work by another worker Mannan and Ganapathy, 2002 reported on the engineering properties of concrete incorporating palm kernel shell and demonstrated that that concrete made with palm kernel shell has lower modulus of elasticity when compared to conventional concrete; however, palm kernel shell concrete has sufficient strength to be accepted as structural lightweight. Shafigh et al. 2011 reported on a new method of producing high strength oil palm shell lightweight concrete and showed that crushed oil palm shells are hard and also have a stronger physical bond with the hydrated cement paste, in addition, the study demonstrated that it was possible to produce lightweight concrete with palm oil shell with significantly lower cement content.

In all these research works, there is no published work on palm kernel shell-wooden plank laminated composite slab; so this work is aim at its studies

Investigation of flexural strength of palm kernel shell-wooden laminated composite slab.is made up of the following items that will be studied in details; they are: - sawdust, palm kernel shell, cement and wood.

2.2 Sawdust

Sawdust can be defined as loose particles or wood chippings obtained as by-products from sawing timber into standard useable sizes (Olutoge, 2010 & Onwuka, Anyaogu, Chijioke, and Okoye,2013). According to Maharani *et al*. (2010), Sawdust refers to the tiny-sized and powdery wood waste produced by the sawing of wood. The size of sawdust particles depend on the type of wood from which the sawdust is obtained and also on the size of the saw teeth (Afuwape, 1983). About 10-13% of the total volume of the wood log is reduced to sawdust in milling operations; this sawdust generally depends largely on the average width of the saw kern and the thickness of the timber sawed (Paulrud *et al*., 2002).

Generally, utilization of the generated tropical commercial wood sawdust becomes an urgent problem since alternative to clean with by just employing the so-called conventional incineration may produce environmentally hazardous pollutants such as polychlorinated dibenzo-dioxins and dibenzo-furans (Terazawa, 2003; Frombo *et al*., 2009). In addition, sawdust being essentially a lignocellulosic material, is not easily deteriorated but rather stable on recalcitrant in the environment, and rarely produces odour during its long-term biodegradation process (Terazawa *et al*., 1999; Zavala *et al*., 2004). Plate 2.1 shows heaps of sawdust waste.

Plate 2.1 Dumping site of Sawdust in Timber market Owerri Imo State Nigeria

2.3 Cement

The word ‘cement’ usually means Portland cement used in civil engineering works which sets well under water, hardens quickly and attains strength (Khurmi *et al.,* 2006). Cement can also be defined as a product of calcareous (lime) and argillaceous (clay) materials which when mixed with water forms a paste and binds the inert materials like sand, gravel and crushed stones (Bhavikatti, 2001). According to BS 5328: Part 1:1997 “cement is a hydraulic binder that sets and hardens by chemical interaction with water and is capable of doing so under water”.

According to Shetty, (2005), the history of cementing material is as the history of engineering construction. Some kind of cementing materials were used by Egyptians, Romans and Indians, in their construction. Early Egyptians mostly used cementing materials obtained by burning gypsum. Early Greeks and Romans used cementing materials obtained by burning limestone. The mortar produced from this kind of cementing material used by early Romans exhibited remarkable hardness. Superiority of Roman mortar was attributed to the thoroughness of mixing and long continued ramming.

The Greeks and The Romans later started using certain volcanic ash and tuff mixed with lime and sand which yielded mortar possessing superior strength and better durability in fresh and salty water. The Romans obtained the volcanic ash or tuff from their Pozzuoli village near Mount Vesuvius in Italy, thus the volcanic ash acquired the name Pozzolana. The name 'Pozzolana' was later used to refer to any other material or artificial having nearly the same composition in that of volcanic tuff or ash found at Pozzuoli. The Romans in the absence of material volcanic ash used powdered tiles or pottery as Pozzolana. In India, powdered brick called "surkhi" has been used in mortar. Indian practice of thorough mixing and long continued ramming of lime mortar with or without the addition of "surkhi" yielded strong and impervious mortar which confirmed the secret of superiority of Roman mortar. (Shetty, 2005).

The modern Portland cement whose name was given owing to the resemblance of this hardened cement to the natural stone occurring at Portland in England was produced by Joseph Aspdin in 1824 (Shetty, 2005).

Cement used in construction may be hydraulic or non-hydraulic. Cement which hardens and sets under water by virtue of a chemical reaction is called hydraulic cement, while non-hydraulic cement (e.g. lime and gypsum plaster) must be kept dry in order to retain their strength (Neville, 2011; Mehta, *et al*., 1993). Hydraulic cements consist mainly of silicates and aluminates of lime and can be classified broadly as natural cement, Portland cement and High-Alumina cement. The cement of particular interest in this study is Ordinary Portland cement.

2.3.1 Portland Cement

This is the most common type of cement in general use around the world and in Nigeria because it is a basic constituent of concrete and mortar.

Portland cement is a finely ground material consisting primarily of compounds of lime, silica, alumina and iron, which when mixed with water forms a paste which hardens and binds aggregates such as sand, gravel or crushed rock to form a hard overall mass called concrete (Mehta, *et al*., 1993). Portland cement can also be defined as an extremely finely ground product obtained by burning together at high temperature specifically proportioned amounts of calcareous and argillaceous raw materials, adding nothing also to the burnt product except gypsum in small percentage (Singh, 2008).

As previously started, Portland cement is hydraulic cement, meaning that if concrete is made from this type of cement, it must be kept moist for it to set and harden. The reaction between water and cement will continue for years and concrete will become progressively stronger and more durable.

2.3.1.1 Types of Portland cement

A. Ordinary Portland cement

This is the most common type of cement in general use around the world and in Nigeria because it is a basic constituent of concrete and mortar.

Portland cement is a finely ground material consisting primarily of compounds of lime, silica, alumina and iron, which when mixed with water forms a paste which hardens and binds aggregates such as sand, gravel or crushed rock to form a hard overall mass called concrete (Mehta, et al., 1993). Portland cement can also be defined as an extremely finely ground product obtained by burning together at high temperature specifically proportioned amounts of calcareous and argillaceous raw materials, adding nothing also to the burnt product except gypsum in small percentage (Singh, 2008).

As previously started, Portland cement is hydraulic cement, meaning that if concrete is made from this type of cement, it must be kept moist for it to set and harden. The reaction between water and cement will continue for years and concrete will become progressively stronger and more durable.

B. Sulphate resisting Portland cement

Sulphate attack is due primarily to the effect of sulphate in solution of C_3A. Hence, the sulphate resistance of a cement improves as the quantity of C_3A decreases; BS 4027 specifies a maximum content of 35%. This can be achieved by the addition of Iron ore to the raw materials so that more C_4AF is produced and the alumina is used up in this way instead of forming C_3A.In other respect, sulphate resisting cement is similar to ordinary Portland cement. The use of sulphate resisting cement is no substitute for the production of dense, non-permeable sandcrete (Neil et al ,1996 and Neville, 2011).

C. Portland blast furnace cement

This consist of Portland cement clinker and gypsum, grind together with up to 60% grind granulated blast furnace slag, which contains lime, silica and alumina (BS 146). The hydration of the Portland cement initiates pozzolanic action, producing a strength progression similar to that of ordinary Portland cement, though early strength may be, lower so that adequate curing is essential. Portland blast furnace cement has a higher sulphate resistance than ordinary Portland cement, hence its use may also reduce the risk of damage due to the alkali silica reaction (a slag content of at least 50% is required for this purpose). A low heat form of Portland blast cement is available and its covered by BS 4246. The heat output and strength development is similar to low heat Portland cement. Availability is limited to areas in which blast furnace is produced. Ground granulated blast furnace is also available separately giving greater flexibility in the proportion used; replacement of up to 90% has been used in this way (Neil and Ravindra ,1996 and Neville, 2011).

D. Hydrophobic Portland cement

This is ordinary Portland cement to which a small percent of ground- in water repellent, such as oleic acid, is added. Such cement can be stored for considerable time in damp atmosphere without subsequent deterioration. On mixing the acid coating breaks down and behaves as an air entering agents but mixing time should naturally be about 25% longer than ordinary Portland cement. The cement is only available to special order.

E. White cement

This is made using China clay, which contains very little Iron, which is responsible for the grey colour of ordinary Portland cement. White Portland cement is one of the most expensive Portland cements, since there are few geographical locations where China clay is found, and modification to the method of firing and grinding are required. In the absence of C_4A, other fluxes might be used to assist in manufacture. The cement conforms to BS 12, though with relatively high C_3S contents the strength grade achieved is likely to be 62.5 N. White cement is used for the production of white or colour concrete.

F. Low heat Portland cement

This contains relatively small percent of the compound C_3S and C_3A which have the greatest heat evolution. BS 1370 requires a heat output of not more than 250J/g by seven days and 290J/g by 28 days. The rate of gain of strength Is lower but this cement has an ultimate strength similar to that of ordinary Portland cement and it is suitable for mass construction where heat concentration must be avoided. Sandcrete of high cement content must not, of course, be employed. They will negate the effect of low heat cement. Its fineness, as required by BS 1370, must not be less than $275m^3/kg$ in order to ensure satisfactory strength development. Note that due to the small amount of C_3A, sulphate resistance of this cement is greater than that of ordinary Portland cement (Shetty, 2005).

G. PFA cement

PFA – pulverized fuel ash is a by – product from coal fired stations and in a similar manner to blast furnace slag. It sets in the presence of lime released by hydrating Portland cement. It may be incorporated with Portland cement during manufacture with the advantage of accurate blending and ease of batching, or it may be used as an admixture, aluminum replacement proportion of 30% being used to improve resistance to sulphate attack Early strength are lower than in corresponding OPC (ordinary Portland cement) so that adequate curing is essential. PFA cements are covered by BS 6588 (15-35% PFA) and BS 6610 50% PFA)

H. Rapid hardening Portland cement

This term is no longer used in standard, though it is still in general to refer to cement of grade 52.5 N which is covered by BS 12. It is essentially different from ordinary Portland cement only in respect of its fineness and produces a strength approximately 50% higher than ordinary Portland cement at three days, though long term strengths are similar. Accompanying the rapid strength gain is a considerable evolution of heat so that rapid hardening Portland cement is often used in cold whether to assist in development of maturity. However, on the same account it should not be used in mass concrete, where the heat concentration will cause a reduction in strength due to thermal stresses.

Ultra rapid hardening cement which are very finely ground, are also available, the same as above applying but to a greater degree. In addition, such a high degree of fineness in the cement tends to reduce workability, and therefore, there will be lost of strength if the water content of the concrete is increased to compensate.

2.3.2 Manufacture of Portland cement

The raw materials required for the production of cement includes limestone or chalk (Calcareous materials), clay or shale (Argillaceous materials) and water-which is used only in wet process. Portland cement can be manufactured either by wet process or dry process.

According to Shetty (2005), the wet process (the constituent materials are mixed to form a slurry with addition of water of 35-50%) remained popular for many years because of the possibility of more accurate control in the mixing of raw materials and also the techniques of intimate mixing of raw materials in powdered form was not available. When modern technique of dry mixing of powered materials using compressed air was developed the dry process gained momentum (Shetty, 2005). Consequently, it can be concluded that dry process required less fuel as the materials are already in dry state; whereas the wet process will need more fuel to dry the slurry that contains about 35-50 percent water. The process of manufacture of Portland cement consists of grinding the raw materials, mixing them in certain proportions depending on their purity and composition and burning them as a kiln at a high temperature between 1300ºC to 1500ºC at which the materials partially fuses to modular shaped clinker. The clinker is then cooled and ground to fine powder with addition about 3 percent to 5 percent gypsum to prevent flash setting of cement (Shetty, 2005). Figure 2.1 shows the Schematic View of Cement Production.

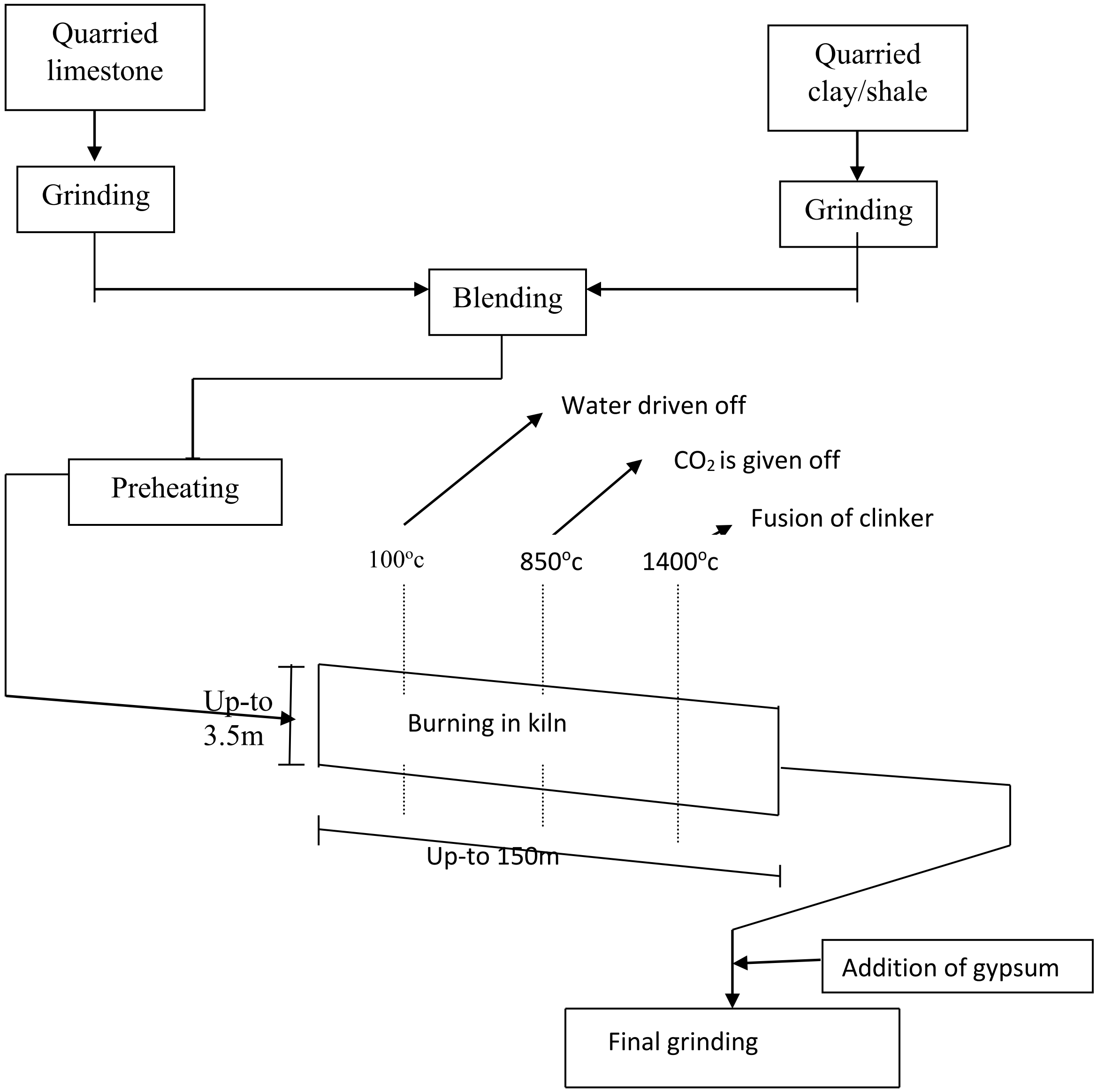


Figure 2.1 Schematic View of Cement Production (Sources: Singh, 2008 and Shetty, 2000)

2.3.3 Chemical Composition of Portland cement

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxides. (Shetty, 2005). According to Bhavikatti (2009), the functions of these components are as follows.

Lime: This is the main ingredient. It is responsible for strength. Deficiency causes decrease in strength and excessive free lime causes unnecessary expansion and disintegration of cement.

Silica: During the manufacture of cement, silica undergoes a chemical reaction with calcium to form dicalcium and tricalcium silicates which are responsible for iMPacting strength to cement. Excess of silica adds strength to cement but its setting time is prolonged.

Alumina: Alumina forms complex compounds with silica and calcium to iMPart setting property to the cement. Larger quantities of alumina quicken setting but weaken the cement.

Iron oxide: This is responsible for impacting colour to cement. It also helps to add strength and hardness to cement to a certain extent.

Alkalis: Lager quantity of alkalis (sodium and potassium) oxides are carried away by flue gases during clinkering. However, a small quantity is left behind, excess of which causes efflorescence.

These oxides (oxides of the above mentioned ingredients) interact with one another in kiln at high temperature to form more complex compounds. These compounds are referred to as four basic components of Portland cement (Shetty, 2005). They are listed in Table 2.1 and their compounds are shown in Table 2.2.

*T*able 2.1 Basic Components of Portland cement

Name of compound	Chemical formula	Abbreviated formula	Typical characters
Tricalcium silicate	$3CaO.SiO_2$	C_3S C_3=3CaO S=SiO_2	Medium reacting, medium heat evolution, early strength
Dicalcium silicate	$2CaO.SiO_2$	C_2S C_2=2CaO S=SiO_2	Slow reacting, slow hardening gives strength after 28days

Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A C_3=3CaO A=Al_2CO_3	Fast reacting, high heat evolution, early hardening
Tetra-calcium Alumina ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF C_4=4CaO A=Al_2O_3 F=Fe_2O_3	Slow reaction, least heat evolution, poor binding properties

Sources: Singh, 2008 and Shetty, 2000.

Table 2.2: Oxide Composition of a typical ordinary portland cement

Oxide	Content, (percent)
CaO	60-67
SiO_2	17 – 25
Al_2O_3	3 – 8
Fe_2O_3	0.5 – 6
MgO	0.5 – 4
Alkalis (as Na_2O or K_2O)	0.3 – 1.2
SO_3	2.0 – 3.5

Source: (Neville, 2011)

In addition to the four major compounds, there are many minor components formed in the kiln. The influence of these minor compounds on the properties of concrete or on the hydrated compounds is insignificant. Two of the minor oxides namely K_2O and Na_2O (potassium oxide and sodium oxide respectively) referred to alkalis influence the properties of cement to some extent (Shetty, 2005 and Bhavikatti, 2001).

2.3.4 Features of Cement Mineralogical Components

According to Shetty (2005), Neil et al (1996) and Neville (2011), the two silicates, C_3S and C_2S, which are the most stable of the four basic compounds, together forms 20 to 80 percent of the constituent in the cement and contribute most to the physical properties of concrete. They are the most important compounds responsible for strength. The Average C_3S content in modern cement is about 45 percent and that of C_2S is about 25 percent. C_3S found in clinker is referred to as Alite and C_2S found in clinker is called Belite. C_3S is responsible for increase rate of strength development in cement. It hydrates rapidly when it comes in contact with water, generating a considerable amount of heat and making a significant contribution to the development of the early strength, particularly during the first 14 days. In contrast C_2S hydrates slowly and is responsible for the development in strength after about 7 days and may be active for a considerable period of time. Cement rich in C_2S results in greater resistance to chemical attack and a smaller drying shrinkage.

The presence of tricalcium aluminate C_3A in cement is undesirable; it contributes little or nothing to the strength of concrete after about 24hours. A hydrate of C_3A is extremely exothermic and takes place quickly. Of the four compounds C_3A is the least stable and cement containing more than 10percent of this compounds provides concretes vulnerable to sulfate attack. It exists in clinker as Celite.

C_4AF, is of the least importance coMPared to the other compounds when considering the properties of hardened cement mortars or concrete. However, it reacts with gypsum to form calcium sulphoforrite and its present may accelerate the hydration of silicate. In clinker, C_4AF is called Felite.

The amount of gypsum added to clinker is crucial and it is dependent on the C_3A content and the alkali content of cement. Excess gypsum leads to the expansion and consequent disruption of the set cement past.

2.4 Aggregates

Aggregates is relatively inexpensive and does not enter into complex chemical reactions with water; it is an inert filler in concrete (Kumar et al, 2006). Aggregate characteristics that are significant for making concrete including porosity, grading or size distribution, moisture absorption, shape and surface texture, crushing strength, elastic modulus, and the type of deleterious substances present (Khurmi and Gupta, 2006). These characteristics are derived from mineralogical composition of the parent rock, exposure condition to which the rock has been subjected before mining, and the type of equipment used for producing the aggregates.

Natural rock in the form of aggregate particles typically makes up between 70- 80 percent of the volume of a normal concrete. Natural sand, gravel and crushed rock undoubtedly form a major and fundamental part of concrete and mortars. Particles of natural rock are by far the commonest form of aggregate, but recycled crushed concrete and manufactured materials such as furnace slags and expanded clay, shale or slate pellets are also used to a more limited extent. The aggregate as a material must be strong, durable and inert to give satisfactory performance, and the sizes of the constituent particles must be appropriate for the intended application. Aggregate are described as coarse aggregate, if particles are retained on a screen with 5 mm apertures, or 4 mm apertures. (Neville, 2011).

They are described as fine aggregate or sand if they pass through them. Aggregates are normally separated into size fractions by the use of a series of different sized screens, but within any fraction there will be a grading of sizes from those particles that can just pass the larger screen to the ones that are just fractionally too large to pass the smaller screen.

Rocks may be divided into three broad groups. The first, igneous rocks, are formed when molten rock material (called magma) is generated below or within the Earth’s crust and crystallizes as solid rock as it cools down, either on the surface as a lava or within the Earth’s crust as an intrusion. Since igneous rocks are intruded into pre-existing rocks in various ways and are now seen at the Earth’s surface.

The second group is sedimentary rocks which are formed by the accumulation of fragments of pre-existing rocks resulting from processes of erosion, organic debris such as shell fragments or plant material. These are the detrital sedimentary rocks, or alternatively, they may be formed as a chemical precipitate from oversaturated sea, or ground waters, the chemical and biochemical sedimentary rocks.

The third group, metamorphic rocks, are formed from pre-existing rocks of any type, sedimentary or igneous, which have then been subjected to long periods of increased temperature and /or pressure within the crust. Depending on the severity and the time rocks are subjected to these high temperatures and pressures they undergo progressive changes (‘metamorphism’) resulting in new minerals being formed and modifications to their original appearance (Neville, 2011)

2.4.1 Physical Properties of Aggregate

Aggregates are classified in terms of their shape. Some are rounded aggregates. Others are angular, elongated, irregular etc. in shape. The size of aggregates makes it coarse or a fine. BS 3797, (1964) and BS 877, (1967) have it that aggregates 4mm and below are considered fine aggregates while the ones above 5mm are coarse aggregates. Some aggregates are smooth in texture while others are rough.

2.4.2 Mechanical Properties of Aggregate

According to Ibearugbulam (2006), aggregates are subdivided into three classes. They are lightweight aggregates, normal weight aggregates and heavyweight aggregates. Bulk density and specific gravity are normally used to classify an aggregate. The bulk density and specific gravity of normal weight aggregate should not be less than 1120 km/m^3 and 2.2 respectively. The specific gravity ranged from 2.2 - 4.0. Bulk density ranges from 100 kg/m^3 – 1600 kg/m^3. For lightweight aggregate, the specific gravity is less than 2.2 and the bulk density is less than 960 kg/m^3. The specific gravity and bulk density of heavyweight aggregate are respectively greater than 4 and 1600 kg/m^3.

2.4.3 lightweight Aggregates

Aggregates that weigh less than 1120 kg/m^3 (70 lb/ft^3) are generally considered lightweight, and find application in the production of various types of lightweight concretes. The light weight of the aggregate is due to the cellular or highly porous microstructure. Natural lightweight aggregates are made by crushing igneous volcanic rocks such as pumice, scoria, or tuff. Synthetic lightweight aggregates are manufactured by thermal treatment of a variety of materials, for instance, clays, shale, slate, diatomite, pearlite, vermiculite, blast-furnace slag, and fly ash.

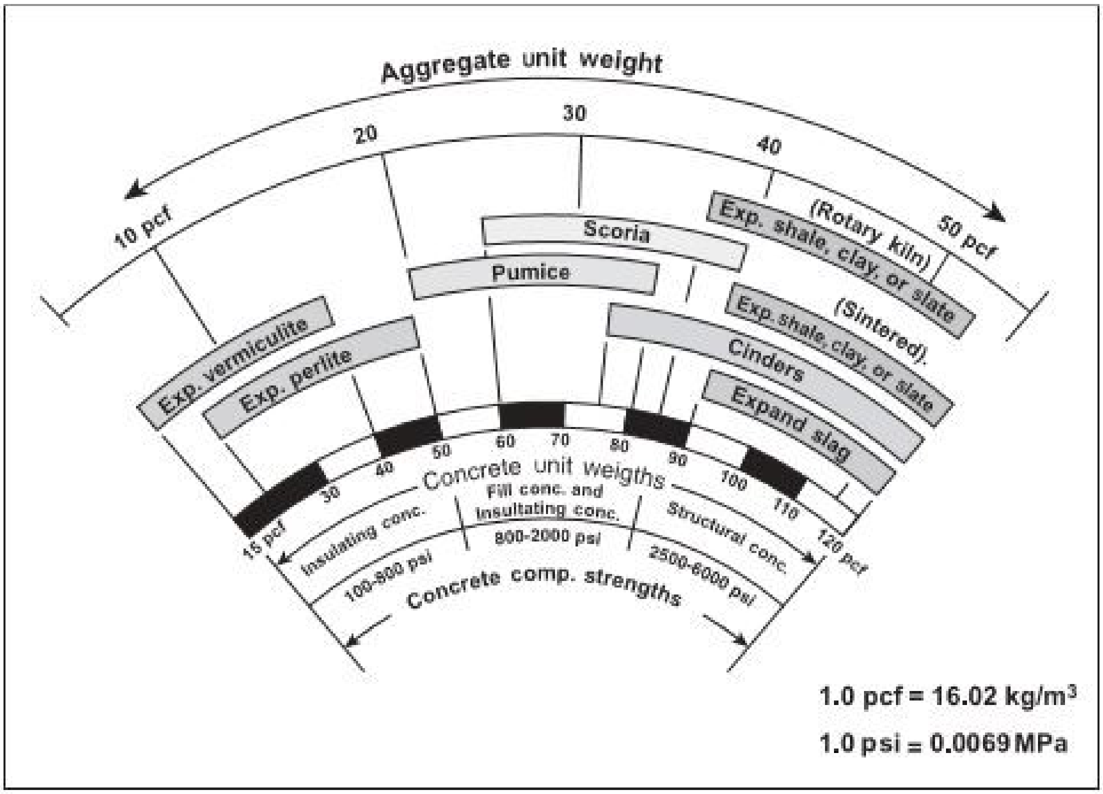


Figure 2.2: Lightweight aggregate spectrum (Source: Kumar et al, 2006.)

Actually, there is a whole spectrum of lightweight aggregates (Figure 2.2) weighing from 80 to 900 kg/m^3 (5 to 55 lb/ft^3). Very porous aggregates, at the lighter end of the spectrum, are generally weak and are therefore more suitable for making nonstructural insulating concretes. At the other end of the spectrum are those lightweight aggregates that are relatively less porous. When the pore structure consists of uniformly distributed fine pores, the aggregate particles are strong and therefore capable of producing structural concrete. ASTM has separate specifications covering lightweight aggregates for use in structural concrete (ASTM C 330), insulating concrete (ASTM C 332), and concrete for production of masonry units (ASTM C 331). These specifications contain requirements for grading, undesirable substances, and unit weight of aggregate. They also contain requirements for unit weight, strength, and drying shrinkage of concrete containing the aggregate.

2.5 Concrete

concrete is a composite construction material, composed of cement (commonly Portland cement) and other cementious material such as fly ash, aggregate (coarse aggregate made of gravels or crushed rocks such as lime stone or granite with a fine aggregate, such as sand), water and chemical admixtures.

Concrete solidifies and hardens after mixing with water and placed due to a chemical process known as hydration. Water reacts with cement, which bonds the other components together, thereby creating a robust stone – like material.

Concrete can normally be worked on when it is still in plastic stage. Plastic concrete is a freshly mixed material, which can be moulded into any desired shape. Concrete exist in the plastic state for short periods but what happens in the state affects the properties of concrete in the hardened state. The relative quality of cement, aggregates and water mixed together, controls the properties of concrete on the plastic state as well as the hardened state. Hardened concrete is a rock- like construction material and its primary requirement are: It should have satisfactory compressive strength and it should have adequate durability (Neville, 2011).

2.5.1.1 Properties of Fresh concrete

Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The relative quantities of cement, aggregates and water mixed together, control the properties of concrete in the wet state as well as in the hardened state (Shetty, 2005).

2.5.1.2 Workability

Workability can be best defined as the amount of useful internal work necessary to produce full compaction (Neville, 2011). The ASTM C 125-09a defines workability as the property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity; also the ACI defines workability as that properly of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. A theoretical water cement ratio calculated from mixed design is not going to give ideal situation for maximum strength. Maximum compaction of concrete is an important parameter for contributing to maximum strength. Lack of compaction will result in air void whose damaging effect on strength and durability is equally or more predominant than the presence of capillary cavities. The lubrication required for handling concrete without segregation, for placing without loss of homogeneity, for compacting with the amount of efforts forth-coming and to finish it sufficiently easily, the presence of certain quantity of water is of vital importance. The quality of concrete satisfying the above requirements is termed workable concrete. (Shetty, 2005). The following factors can affect the workability of concrete; they include water content, mix proportions, size of aggregates, shapes of aggregates, surface Texture of aggregate, grading of aggregates, and use of admixture. Workability of concrete can be measured or test using the following methods: - slump test, compacting, flow test, Kelly ball test and Vee Bee consistometer.

2.5.1.3 Segregation of Concrete

Segregation can be defined as separation of the constituents of a heterogeneous mixture so that their distribution is no longer uniform. In the case of concrete, it is the difference in the size of particles and in the specific gravity of the mix constituents that are the primary causes of segregation, but its extent can be controlled by the handling. It is worth noting that a higher viscosity of the fresh cement paste component militates against the downward movement of the heavier aggregate particles; consequently, mixes with low water/cement ratios are less prone to segregation. (Neville, 2011). There are two forms of segregation. In the first, the coarser particles tend to separate out because they tend to travel further along a slope or to settle more than finer particles. The second form of segregation, occurring particularly in wet mixes, is manifested by the separation of grout (cement plus water) from mix with some grading, when a lean mix is used, the first type of segregation may occur if the mix is too dry; addition of water would improve the cohesion of the mix, but when the mix becomes too wet the second types of segregation would take place. If the concrete does not have to travel and is transferred directly from skip or bucket to final position in the form, the danger of segregation is small. Segregation is difficult to measure quantitatively, but is easily detected when concrete is handled on a site (Neville, 2011)

2.5.2 Properties of hardened concrete

Concrete is regarded as hardened concrete when it has developed enough strength to support its self-weight and weight of imposed load within the limit of its design strength. Concrete like every other engineering material are selected based on its ability to withstand the applied force. Traditionally, the deformation occurring as a result of applied load is expressed as strain. (Kumar, 2006).

2.5.2.1 Strength

The strength of a material is defined as the ability to resist stress without failure. Failure is sometimes identified with the appearance of cracks. (Kumar, 2006). Strength of concrete is commonly considered its most valuable property, although, in many practical cases, other characteristics, such as durability and permeability, may in fact be more important. Nevertheless, strength usually gives an overall picture of quality of concrete because strength is directly related to structure of the hydrated cement paste. Moreover, the strength of concrete is almost invariably a vital element of structural design. Strength of concrete can be studied under the following.

2.5.2.2 Flexural strength

The flexural strength is the ability to withstand bending. Concrete is generally subjected to compressive loads. However, in some instances, such as when as pavements, they are subjected to flexure. Flexural strength is determined using laboratory test on beam specimens whose lengths are at least 3 times the width and the depth by the so called three-point load method BS12930-5 (2009). The width of the beam is made equal to the depth. The flexural strength is as given in Equation (2.1)

$$ft = \frac{Fa}{bd^2} \tag{2.1}$$

Where: ft = flexural strength, F = failure load, a = distance between the load bearing point of the flexural machine, b = width of the beam, d = depth of the beam

2.5.2.3 Compressive Strength

The compressive strength is by far the most important strength property used to judge the overall quality of concrete. It may often be the only strength property of the concrete that may be determined with a few exceptions almost all the properties of concrete can be related to its compressive strength. Compressive strength is usually determined by subjecting the hardened concrete, after appropriate curing, usually 28 days, to increasing compressive load until it fails by crushing, and determining the crushing force.

Mathematically, it is given as shown in Equation (2.2)

$$f_c = {}^{F}/_{A} \tag{2.2}$$

Where; f_c = Compressive strength, F = Crushing load, A = Cross sectional area of the test specimen.

2.5.2.4 Split tensile strength

This is another property that relates indirectly to the tensile strength of concrete. It is determined by subjecting a specimen 300 by 150mm diameter to increasing load along its horizontal axis until failure occurs. The split tensile strength is as given in Equation (2.3)

$$f_{st} = \frac{2F}{\pi l d} \tag{2.3}$$

Where: f_{st} = Split tensile strength, F = failure, L = length of specimen, d = diameter of the specimen.

2.5.2.5 Static Modulus of Elasticity

The modulus of elasticity relates the relationship between the applied stresses and the strain they cause. It has a direct relationship with the compressive strength, increasing as the compressive strength increases. There are many empirical formulae to determine the static modulus of elasticity, one of which (Neville, 2011 and Brooks, 1987) is as shown in Equation (2.4)

$$E_S = 1.7p^2 {f_c}^{0.33} \text{ x } 10^{-6} \tag{2.4}$$

Where E_S =Static modulus of Elasticity

p = density

f_c = compressive strength

The average compressive strength for concrete grade 21-70 is 21.4 GPa to 46.4 GPa. The modulus of elasticity of concrete depends on the wetness of concrete when other conditions are the same. This is in contrast to strength properties that dry concrete has higher strength than wet concrete. (Shetty, 2005)

2.5.2.6 Shear strength

This is a measure of the ability of the concrete to resist shearing. It can be determined from a flexural test and is as given in Equation (2.5)

$$f_S = \frac{F}{A} \tag{2.5}$$

Where f_S = shear strength

F = shear load at failure

A= cross- sectional area of the test specimen

According to Shetty, (2005), the permissible shear stress in concrete ranges from 0.18 N/mm^2 to 0.63 N/mm^2.

2.5.2.7 Poisson ratio

It is the ratio of lateral strain to the axial strain in longitudinal axis. It is realized, when uniaxial force is applied to concrete specimen it produces a longitudinal strain in the direction of applied load at same time a lateral strain of opposite sign. (Neville, 2011). It varies generally between 0.15 to 0.22 for strong concrete members (Shetty, 2005). However, this property is dependent on the property of concrete specimen. The value of Poisson μ is given as shown in Equation (2.6)

$$\mu = \frac{\delta_f}{\delta_c} \tag{2.6}$$

where: δ_f = Tensile stress at cracking in flexure

δ_c = Compressive stress at cracking for compression members

2.5.2.8 Shear modulus

It is the value obtained when shear stress is divided by shear strain γ. Another name for shear modulus is modulus of rigidity. It is denoted by the letter G.

Shear modulus of rigidity is given as shown in Equation (2.7)

$$G = \frac{E_c}{2(\mu + 1)} \tag{2.7}$$

According to Neville, (2011), the shear modulus is not obtained by direct measurement.

Lateral strain γ_i is as shown in Equation (2.8)

$$\gamma_i = \mu \frac{\delta_i}{Ec} \tag{2.8}$$

Where μ= Static Poisson's ratio

δ_i = Compressive stress at cracking

Ec = modulus of elasticity of concrete over the linear range of the deformation.

2.6 Heavy weight Concrete

Compared to normal-weight aggregate concrete with a typical unit weight of 2400 kg/m^3 (150 lb/ft^3), heavy-weight concretes weigh from 2900 to 6100 kg/m^3 (180 to 380 lb/ft^3), and are primarily used for making nuclear radiation shields.

Heavyweight aggregates (i.e., those that have a substantially higher density than normal-weight aggregate) are used for the production of heavyweight concrete. Natural rocks suitable for heavyweight aggregate consist predominately of two barium minerals, several iron ores, and a titanium ore. A synthetic product called Ferro-phosphorus slag can also be used as heavyweight aggregate. ASTM C 637 and C 638, which cover Standard Specifications and Descriptive Nomenclature, respectively, of aggregates for radiation-shielding concrete warn that ferro-phosphorus aggregate, when used for making Portland cement concrete, will generate flammable and possibly toxic gases that can develop high pressures. Hydrous iron ores and boron minerals and frits are at times included in the aggregates for making heavyweight concretes because boron and hydrogen are very effective in neutron attenuation (capture). Steel punching, sheared iron bars, and iron shots have also been investigated as heavyweight aggregates; however, the tendency of aggregate to segregate in a concrete mixture increases with the density of the aggregate.

2.7 Wood as an Engineering Material

Timber has always been one of the more plentiful natural resources available and consequently is one of the oldest known materials used in construction. It is a material that is used for a variety of structural forms such as beams, columns, trusses, girders and is also used in building systems such as piles, deck members, railway foundations and for temporary forms in concrete. Timber structures can be highly durable when properly treated and built. Examples of this are seen in many historic buildings all around the world. Timber possesses excellent insulating properties, good fire resistance, light weight and aesthetic appeal. A great deal of research carried out since the early part of this century has provided us with comprehensive information on structural properties of timber and timber products'. A knowledge of engineering materials is essential for engineering design. Timber is a traditional building material and over the years considerable knowledge has been gained on its important material properties and their effects on structural design and service behaviour (Somayaji, 1990).

All wood is composed of cellulose, lignin, hemicelluloses, and minor amounts (5% to 10%) of extraneous materials contained in a cellular structure. Variations in the characteristics and volume of these components and differences in cellular structure make woods heavy or light, stiff or flexible, and hard or soft. The properties of a single species are relatively constant within limits; therefore, selection of wood by species alone may sometimes be adequate. However, to use wood to its best advantage and most effectively in engineering applications, specific characteristics or physical properties must be considered (USDA, 2010).

2.7.1 Mechanical Properties of Wood

The mechanical properties of a wood describe how it will react to physical forces. Mechanical properties occur as a result of the physical properties inherent to each material, and are determined through a series of standardized mechanical tests.

2.7.1.1 Modulus of elasticity of wood

Elasticity implies that deformations produced by low stress which is completely recoverable after loads are removed. When loaded to higher stress levels, plastic deformation or failure occurs. The three moduli of elasticity, which are denoted by E_L, E_R, and E_T, respectively, are the elastic moduli along the longitudinal, radial, and tangential axes of wood. These moduli are usually obtained from compression tests; however, data for E_R and E_T are not extensive.

The elastic ratios, as well as the elastic constants themselves, vary within and between species and with moisture content and specific gravity.

The modulus of elasticity determined from bending, E_L, rather than from an axial test, may be the only modulus of elasticity available for a species. Average E_L values obtained from bending tests ranges from 1029- 6107 N/mm^2 for temperature of 12% (USA Department of Agriculture 2010; Finnish Forest Industries Federation Finland, 2002)

2.7.1.2 Poisson's ratio of wood

When a member is loaded axially, the deformation perpendicular to the direction of the load is proportional to the deformation parallel to the direction of the load. The ratio of the transverse to axial strain is called Poisson's ratio. The Poisson's ratios are denoted by μ_{LR}, μ_{RL}, μ_{LT}, μ_{TL}, μ_{RT}, and μ_{TR}. The first letter of the subscript refers to direction of applied stress and the second letter to direction of lateral deformation. For example, μ_{LR} is the Poisson's ratio for deformation along the radial axis caused by stress along the longitudinal axis. Values for μ_{RL} and μ_{TL} are less precisely determined than are those for the other Poisson's ratios. Poisson's ratios vary within and between species and are affected by moisture content and specific gravity, for 12% moisture, Average values of Poisson's ratios (μ_{LR}) ranges between 0.276 to 0.641 for both hardwood and softwood (USA Department of Agriculture, 2010)

2.7.1.3 Modulus of rigidity of wood

The modulus of rigidity, also called shear modulus, indicates the resistance to deflection of a member caused by shear stresses. The three moduli of rigidity denoted by *GLR*, *GLT*, and *GRT* are the elastic constants in the *LR*, *LT*, and *RT* planes, respectively. For example, *GLR* is the modulus of rigidity based on shear strain in the *LR* plane and shear stresses in the *LT* and *RT* planes. As with moduli of elasticity, the moduli of rigidity vary within and between species and with moisture content and specific gravity. Modulus of rupture reflects the maximum load carrying capacity of a member in bending and is proportional to maximum moment borne by the specimen.

Modulus of rupture is an accepted criterion of strength, although it is not a true stress because the formula by which it is computed is valid only to the elastic limit. The average modulus of rupture in GPa ranges from 0.35 to 0.62 (USA Department of Agriculture, 2010; Finnish Forest Industries Federation Finland, 2002).

2.7.1.4 Specific gravity of wood

The substance of which wood is composed is actually heavier than water; its specific gravity is about 0.3-1.05 regardless of wood species. In spite of this, dry wood of most species floats in water, and it is thus evident that part of the volume of a piece of wood is occupied by cell cavities and pores.

Variations in the size of these openings and in the thickness of the cell walls cause some species to have more wood substance per unit volume than other species and therefore higher specific gravity. Thus, specific gravity is an excellent index of the amount of wood substance contained in a piece of wood; it is a good index of mechanical properties as long as the wood is clear, straight grained, and free from defects.

However, specific gravity values also reflect the presence of gums, resins, and extractives, which contribute little to mechanical properties (USA Department of Agriculture, 2010). Table 2.3 shows other mechanical strength of wood

Table 2.3 Mechanical strength properties of Wood

Name of strength properties	**Brief description**	**Ranges**
Compressive stress perpendicular to grain	Reported as stress at proportional limit. There is no clearly defined ultimate stress for this property	15.2 MPa – 20.2MPa
Compressive stress parallel to grain	Resistance of wood to forces acting across the grain that tend to split a member. Values presented are the average of radial and tangential observations	14.8-31.8MPa
Shear strength parallel to grain	Ability to resist internal slipping of one part upon another along the grain. Values presented are average strength in radial and tangential shear planes	9.5 MPa
IMPact bending	In the iMPact bending test, a hammer of given weight is dropped upon a beam from successively increased heights until rupture occurs or the beam deflects 152 mm (6 in.) or more. The height of the maximum drop, or the drop that causes failure, is a coMParative value that represents the ability of wood to absorb shocks that cause stresses beyond the proportional limit.	300mm-1240mm
Tensile strength parallel to grain	Maximum tensile stress sustained in direction parallel to grain. Relatively few data are available on the tensile strength of various species of clear wood parallel to grain. In the absence of sufficient tension test data, modulus of rupture values are sometimes substituted for tensile strength of small, clear, straight grained pieces of wood. The modulus of rupture is considered to be a low or conservative estimate of tensile strength for clear specimens (this is not true for lumber).	45.8-9.1 MPa
Tensile strength perpendicular to grain	Resistance of wood to forces acting across the grain that tend to split a member. Values presented are the average of radial and tangential observations.	29.2-8.9 MPa
Hardness	Generally defined as resistance to indentation using a modified Janka hardness test, measured by the load required to embed a 11.28-mm (0.444-in.) ball to one-half its diameter. Values presented are the average of radial and tangential penetrations.	2140l bf

Table 2.3 Cont'd

Creep and duration of load	Time-dependent deformation of wood under load. If the load is sufficiently high and the duration of load is long, failure (creep–rupture) will eventually occur. The time required to reach rupture is commonly called duration of load. Duration of load is an important factor in setting design values for wood	No specific value given
Torsion strength	Resistance to twisting about a longitudinal axis. For solid wood members, torsional shear strength may be taken as shear strength parallel to grain. Two-thirds of the value for torsional shear strength may be used as an estimate of the torsional shear stress at the proportional limit.	No specific value given
Toughness	Energy required to cause rapid complete failure in a centrally loaded bending specimen	4200-11400J
Fatigue	Resistance to failure under specific combinations of cyclic loading conditions: frequency and number of cycles, maximum stress, ratio of maximum to minimum stress, and other less-important factors.	No specific value given
Rolling shear strength	Shear strength of wood where shearing force is in a longitudinal plane and is acting perpendicular to the grain. Few test values of rolling shear in solid wood have been reported. In limited tests, rolling shear strength averaged 18% to 28% of parallel-to-grain shear values. Rolling shear strength is about the same in the longitudinal– radial and longitudinal–tangential planes	18%-20% of grain shear value
Fracture toughness	Ability of wood to withstand flaws that initiate failure. Measurement of fracture toughness helps identify the length of critical flaws that initiate failure in materials. To date, there is no standard test method for determining fracture toughness in wood.	330-1510 (kPa√m

Source: USA Department of Agriculture, 2010, Finnish Forest Industries Federation Finland, 2002.

2.8 Palm kernel shell

Palm kernel shell is a waste product of the palm mill industry; this industry extracts oil from oil palm fruits (Oti, 2015).

Palm kernel shell are hard, flaky and of irregular shape. The most important aspects of using palm kernel shell as aggregate replacement was to ensure that the palm kernel shells are properly prepared. This is of extreme importance during the mixing of material for the various mixes. First, pre-treatment of the palm kernel shell was carried out by removing oil coating with detergent and water, washing and sieving the palm kernel shell into the required particle sizes for the current work (Oti, 2015)

Palm kernel shell (PKS) was partially a waste in the 1990s and early 2000 as more than 350,000 tons were available for sale. The PKS had been a little known then for its potential usage on a large scale especially in concrete work (Mohammad, 2007). Beyond 2000, research into utilization of Palm Kernel Shell as lightweight concrete and other uses had received a big boost. Palm kernel shells (PKS) are organic waste materials obtained from crude palm oil producing factories in Asia and Africa (Alengaram, et al, 2010). The Palm Oil Plant (Elais Guinensis), considering its three different varieties Durà, Pesipherà and Tenerà, produces an edible fruit similar to an apricot, which has a nut inside. During the crude palm oil process, the fruit's flesh is melted through a steaming treatment. The residual nuts are further mechanically crushed to extract the seeds or kernels. The Palm Kernel Shells (PKS) is a virgin biomass with a high calorific value, typically about 3,800 Kcal/kg (ASTM, 1978). Oil Palm trees grow in the coastal belt in Nigeria which varies in depth from 100 to 150 miles and a riverine belt which follows the valleys of the Niger and Benue for a distance of about 450 miles from the sea. The main palm oil producing states include Ogun, Ondo, Oyo, Edo, Cross River, Anambra, Enugu, Imo, Abia, Ekiti, Akwa-Ibom, Delta and Rivers. Palm kernel shells in the past had been used solely as fueling material at home and for industries. The quest for alternative civil engineering construction material which is economical and light in weight has been a major drive in carrying out this work. Plates 2.2 and 2.3 show a Palm Oil Plant plantation and different sizes of palm kernel shell respectively (Onyejiobi et al, 2012).

Plate 2.2: Oil Palm plantation

Plate 2.3: Palm kernel Shell

Palm kernel shell possesses a hard characteristics as coarse aggregate and there have been attempts to use it as a coarse aggregate to replace conventional coarse aggregates traditionally used for concrete production (Mohd, Johnson and Hilimi, 2008). Ata, Olanipekun and Oluola (2006) compared the mechanical properties of palm kernel shell concrete with that of coconut shell concrete and reported the economy of using palm kernel shell as lightweight aggregate. Generally, palm kernel shell consists of 60 – 90% of particles in the range of 5 – 12.7mm (Okafor, 1988). The specific gravity of palm kernel shell varies between 1.17 and 1.37, while the maximum thickness of the shell was found to be about 4mm (Okpala, 1990).

The density of palm kernel shell ranges from 1700 to 2050 kg/m^3 and it depends on factors such as type of sand and palm kernel shell contents (Mohd et al, 2008). Generally, when the density of concrete is lower than 2000kg/m^3, it is categorized as light weight concrete. Thus, the palm kernel shell concrete can be produced within this target density of 2000 kg/m^3, hence palm kernel shell concrete is a light weight concrete. According to (Mohd et al, 2008), the 28 days cube compressive strength obtained was 15 – 25MPa while the structural behavior of palm kernel shell is very limited.

Ndoke (2006) in his work observed the performance of palm kernel shells as partial replacement for coarse aggregate in asphalt cement. According to Teo et al (2006), for structural concrete using oil palm shell (OPS) as light weight aggregate, the compressive strength of OPS concrete was 28.1MPa at 28days curing which is approximately 65% higher than the minimum required strength of 17MPa for structural light weight concrete recommended by American Standard of Testing Materials (ASTM 1330).

Yusuf and Jimoh (2011) worked on the appropriateness of the various nominal mixes of the ‘palm kernel shell concrete’ as rigid pavement. They evaluated the mixes accordingly at both fresh and matured ages with corresponding costs. They reported that the Nigerian PKS satisfies the density criterion for normal concrete and lightweight concrete in all respects while the palm kernel shell concrete at nominal mixes of 1:1.5:3 and 1:1:2 satisfied the specifications for rigid pavement. In addition, the cost of producing PKS concrete/m^2 for all levels of traffic and mix proportions is cheaper than those of normal concrete and asphaltic concrete. Saman and Omidreza (2011) reported the influence of oil palm shell on workability and compressive strength of high strength concrete. They noted that the general strength of oil palm shell (OPS) concrete samples produced high strength concrete with compressive strength reaching up to 52.2 N/mm^2 at 28 days.

2.9 Wood -Cement Composite

Wood-cement composites are generally placed into two categories: wood particle-cement composites and wood fiber-reinforced cement products. Wood particle- cement composites have been in use as architectural, fire-resistant, and acoustic panels. Wood fiber reinforced cement products were developed primarily as a substitute for asbestos-cement and are relatively new, developed and promoted mostly in the last 25 to 30 years (Wolfe *et al*, 1999).

Mineral-bonded wood or other lignocellulosic composites are moulded or compressed blocks and panels containing approximately 30-70% by weight of wood in various forms and 70-30% mineral binder (Simatupang *et al,* 1977). Chittenden (1972) divides mineral-bonded wood composites into two distinct groups, (i) composites in which wood is incorporated as an aggregate in the mineral matrix (as fibres, sawdust, shavings or particles) and (ii) composites in which the cement (or other mineral binder) acts purely as a binder, such as wood wool cement board or flake board.

Wood can serve as a low-cost filler and/or reinforcing material which greatly improve the stiffness, fracture toughness, strength-to-weight ratio, creep deflection, and thermal and acoustic resistance of cement when incorporated into a composite bonded with cement (Goodell *et al,* 1997). The most common types are cement-bonded particleboard (CBP), wood wool cement board (WWCB) and cement bonded fibre-board, commercially known as 'Hardiplank'.

Wood-cement composites have much higher resistance to both decay (i.e. mould, rot, borers and termites) and to combustion than resin bonded boards or solid wood (Pease, 1994, Ramirez Coretti *et al,* 1998, Moslemi ,1989, 1993; Goodell *et al,* 1997, Cziesileski ,1975; Dix, 1989).

Density and flexural properties of a range of different wood-cement composites coMPared with those of some conventional wood composites are shown in Table 2.4 (Data sourced from Elmondorf, 1963, Youngquist, 1999; Wolf and Gjinolli, 1997; 1999, Cabangon *et al,* 2002, Ma *et al.,* 2002). Cement-bonded oriented strand board (OSB) can be manufactured with similar mechanical properties to its resin-bonded counterpart.

Table 2.4 Mechanical properties of different types of reconstituted wood panels

Panel Type	**Density (kg/m^3)**	**MOR (MPa)**	**MOE (GPa)**	**Ref.**
WWCB (non-structural)	375-550	1.7 - 5.5	0.6 - 1.3	i
WWCB (Structural)	650-750	7 to 15	1.8 - 2.7	ii
WWCB (Oriented)	700-800	17	4	ii
Resin-bonded particleboard	≈750	11 - 16.5	1.7 - 2.8	iii
Plywood	≈750	20 – 48	6.9 - 13.1	iii
Orientated Strand Board (OSB)	≈750	47	8.3	iii
Cement-bonded OSB	1000-1200	23 – 50	6.5 – 8	iv,v
Medium Density Fibreboard	640 – 800	24 - 34.5	2.4 - 3.4	iii
Cement-bonded Fibreboard	1200-1300	25	10	vii
Cement-bonded Particleboard	1250 – 1450	19-20	4.5	iii,iv

Where MOR is modulus of Rupture, MOE is the modulus of Elasticity

Source ((i)Kollmann, 1963b; (ii) Cabangon et al, 2000; (iii) Youngquis,t 1999; (iv) Elmondorf, 1963, (v) Ma et al, 2002; (vi) Wolfe and Gjinolli, 1997, 1999)

Wood-cement composites assume considerable importance where the technology and materials for manufacturing conventional resin-bonded wood composites are expensive or unavailable (Kavvouras, (1987); Badejo, (1988); Alberto *et al., (*2000)). They can also be manufactured where available wood or plant waste resources are unsuitable for production for sawn timber or conventional resin-bonded wood composites (Kelly, (1977); Ledhem *et al, (*2000b)). More importantly, they are much better suited to high fire, weathering and bio-deterioration risk applications to which solid wood and resin bonded composites are vulnerable (Stillinger and Wentworth, (1977); Dinwoodie and Paxton, (1991); Chapola, (1989)).

Cement-bonded composites emit no toxic wastes during manufacture (van Elten, (2000)) and employ an inert binder free from the health risks associated with the use of resin bonded composites (Chen and Hwang, 1998).

Wood-cement composites, especially the aggregate types are commonly referred to as being virtually incombustible (Ramirez-Coretti *et al.*1998; Moslemi, 1993, Topf, 1989a, b; Deppe, 1977; Stillinger and Wentworth, 1977). The resistance to fire of aggregate-cement composites such as cement board particles (CBP) is attributed to the lower content of organic matter and the crystal water in the binder. Heat evolution and spread in the material, and smoke and flame behaviour are strongly correlated with the wood-cement ratio used (Topf, 1989b). Although often high in density the relatively low strength of wood-cement composite panels limits them largely to non-structural paneling or roofing applications (Karam and Gibson, 1994; Oyagade *et al,* 1995; Xiong 1996; Wolf and Gjinolli, 1999). Paradoxically, a significant advantage of wood-cement composites to engineering applications appears to lie in their ability to absorb and dissipate mechanical energy (Wolf and Gjinolli, 1997, 1999). This, as well as good sound dissipation and absorption properties, has attracted research and development of wood-cement composites as very practical and cost-effective highway sound barriers (Wolf and Gjinolli, 1999; Lan and Huang, 2000; Boothby *et al,* 2001). Wood-cement composites can also be manufactured to exhibit a range of energy dissipating properties advantageous in areas subject to seismic activity and/or heavy wind loads such as hurricanes (Wolfe and Gjinolli, 1997, 1999). For these reasons, cement-bonded wood panels have become a significant component of residential cladding materials (Kuroki *et al.,* 1993, 1995).

Despite their higher weight-to-strength ratio, wood-cement composites have become popular, particularly in Europe and Asia, for use as exterior siding, roofing and flooring applications to meet increasingly stringent building design regulations for fire, and failure in service due to deterioration. Some typical external applications well suited to products such as Cement Board particles include agricultural buildings, pre-fabricated and mobile buildings, flat roofing, industrial and exterior domestic cladding, tunnel linings, highway sound-barriers, fire-barriers and paving tiles (van Elten, 2000).

In recent years, Cement Board Particle manufacturing and utilisation in housing construction has grown in countries such as Mexico where there is a ready market for mass-produced low-cost, 'fold-out' kit homes (Solorzano, 1989; Buys, 1989, 1995).

Products such as CBP have been shown to have a long service life, retaining and even increasing its strength after years of exposure to the elements. For example, boards exposed outdoors to temperatures ranging from -55°C to 55°C in the Moscow region over 12 years retained a high average bending strength of 16 MPa (Sergeev *et al,* 1995). The strength properties including stiffness of CBP actually increase markedly with time in a given storage condition (Dinwoodie and Paxton, 1989). Enhanced strength and durability of wood-cement composites with aging has been attributed to the 'mineralisation' or 'petrification' of the wood elements by cement minerals (Parameswaran *et al,(*1977; Bentur and Ackers, 1989). In a study by Sekino and Suzuki (2002) cement-bonded boards also showed excellent dimensional stability and only slight reduction in mechanical properties after outdoor exposure for 10 years, greatly out-performing other wood-based panels.

Despite their obvious benefits compared with other types of wood panels, there are several factors that have prevented wood-cement composites from becoming more widespread (Moslemi, 1989). The most significant of these is the long initial and post-press curing time of the Portland cement binder, which leads to reduced production capacity and a requirement for a large inventory of boards during curing (Lipinski, 1989; Hsu, 1992; Mallari *et al.,* 1997). The high weight-to-strength ratio and machine wear of products such as CBP (due to their high cement content) compared with resin bonded particleboards has also reduced their popularity (Lee and Short, 1989), despite the higher toughness and durability of cement-bonded boards. A third major obstacle to further successful development of wood-cement composite industries is variation in wood compatibility with cement. There is extreme variation in compatibility among both hardwoods and softwoods with Portland cement (Sandermann and Kohler, 1964; Hachmi and Campbell, 1989) resulting in strong species specificity among potential raw materials for wood cement composite manufacturing industries. There is no information about the compatibility of many wood species with Portland cement or experience in converting and using them for cement bonded boards of different types.

The mechanical properties of composite materials including wood-cement composites are a direct function of the interface bonding between the reinforcing or filler fibre and the matrix and are greatly affected by the type, content, geometry and arrangement of the reinforcement or filler (Brandt, 1995; Razi *et al,* 1999).

Bond strength in wood cement composites is largely dependent on hydrogen bonding between the wood or fibre surface and the cement matrix (Coutts, 1983; Coutts and Knightly, 1984).

The wood or fibre surface, modified chemically and physically by method of cutting, extractive enrichment, deposition of foreign materials, and reaction with oxygen and light significantly affects its interaction with most binders (Zavarin, 1984). Surface roughness of wood flakes or strands has a positive effect on the bond strength with Portland cement (Kayahara *et al,* 1979). The properties of wood-cement composites are significantly influenced by the content, form, arrangement and other characteristics of the wood reinforcement (Kayahara *et al,* 1979; Stahl *et al,* 1997; Badejo, 1988).

There have been numerous different strategies for improving the compatibility of wood with cement and other mineral binders, and increasing the strength of wood-cement composites, some of which are employed successfully. Strategies include modifying the wood through extractive removal, pretreatment with chemicals, and modification of wood content, form and arrangement in the composite. For example, wood in the form of strands imparts greater flexural properties to cement-bonded composite boards than particles and hence permits a much lower cement wood ratio to be used (Kayahara *et al,* 1979).

Modification of binder and its curing include altering the cement type (composition, mineral supplements) and amount, curing conditions (temperature, time, atmosphere), and the use of chemical accelerators and/or fortifying agents.

The compatibility of wood with cement can be strongly influenced by such factors as the season in which it is cut (Weatherwax and Tarkow, 1964; Biblis and Lo, 1968) and the delay between cutting and use (Sudin *et al,* 1989). The sugars and starches present in wood have been identified as the most critical compounds causing incompatibility between wood and cement, especially in softwoods (Sandermann *et al,* 1960; Davis, 1966; Bruere, 1966; Biblis and Lo, 1966). This means that even simple measures like selecting the time of cut or log pre-storage can significantly influence wood-cement board quality (Schubert *et al,* 1990).

2.10 Deflection of a Structural Member

In engineering, deflection is the degree to which a structural element is displaced under a load. It may refer to an angle or a distance. The deflection distance of a member under a load is directly related to the slope of the deflected shape of the member under that load and can be calculated by integrating the function that mathematically describes the slope of the member under that load. Deflection can be calculated by standard formula (will only give the deflection of common beam configurations and load cases at discrete locations), or by methods such as virtual work, direct integration, Castigliano's method, Macaulay's method or the direct stiffness method, amongst others. The deflection of beam elements is usually calculated on the basis of the Euler–Bernoulli beam equation while that of a plate or shell element is calculated using plate or shell theory.

The knowledge of properties of concrete is necessary to calculate deflection of structures and design of concrete members with respect to their section, quantity of steel and stress analysis. (Shetty, 2005). Beams can vary greatly in their geometry and composition. For instance, a beam may be straight or curved. It may be of constant cross section, or varying cross-section as the case may be. It may be made entirely of the same material (homogeneous), or it may be composed of different materials (composite). Some of these things make analysis difficult, but many engineering applications involve cases that are not so complicated. Analysis is simplified if:

i) The beam is originally straight, and any taper is slight
ii) The beam experiences only linear elastic deformation
iii) The beam is slender (its length to height ratio is greater than 10)
iv) Only small deflections are considered (max deflection less than 1/10 the span).

2.10.1 Deflection of a Simply Supported Slab

A simply supported slab is a slab that has supports at all the four edges. According to BS 8110 -1 :(1997), A simply supported slab is a slab that does not have adequate provision to resist torsion at the corners, and to prevent the corners from lifting and which the maximum moments per unit width is given by:

$$M_{sx} = \alpha_{sx} n {l_x}^2 \tag{2.10}$$

$$M_{sy} = \alpha_{sy} n {l_x}^2 \tag{2.11}$$

Where

$$\alpha_{sx} = \frac{({}^{L_y}/_{L_x})^4}{8\{1+\left({}^{L_y}/_{L_x}\right)^4\}} \tag{2.12}$$

$$\alpha_{sx} = \frac{({}^{L_y}/_{L_x})^2}{8\{1+\left({}^{L_y}/_{L_x}\right)^4\}} \tag{2.13}$$

M_{sx}= moment in the x-direction, M_{sy}= moment in the y-direction, L_x = the shorter length of the slab, L_y = longer length of the slab.

The deflection of a simply supported beam (a strip from slab) member can be obtained by the Equation (2.14) and y is as shown in Figure 2.3a and Figure2.3b

$$y = {}^{5wl^4}/_{384EI} \tag{2.14}$$

Where E= Elastic modulus, I = Second moment of Area

According to BS 8110 -1:1997, the allowable deflection of a simply supported slab should be less than 20mm*modification factor. where the modification factor ranges from 0.76 to 2 for tension reinforcement and 1.0 to 1.5 for compression reinforcement.

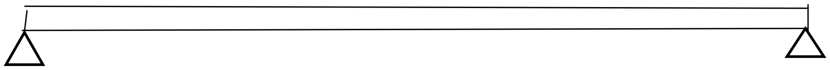


Figure 2.3a: Simply support beam strip without deflection

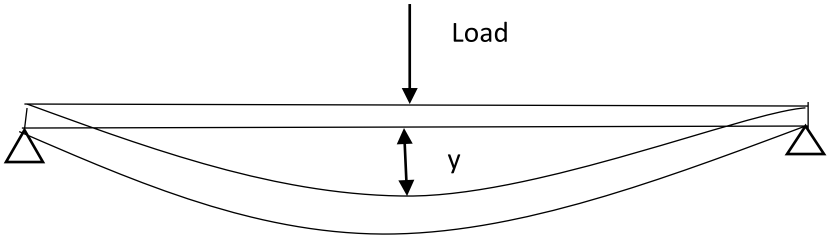


Figure 2.3b: Deflected Simply supported beam strip under a load

CHAPTER THREE

MATERIALS AND METHODS

3.1 MATERIALS

The materials used for this work are (i) Ordinary Portland cement (ii) sawdust (iii) seasoned plank (iv) Palm kernel shell and coarse aggregate (v) Nails (vi) Water (vii) 10mm reinforcement bars (viii) stirrups (ix) binding wire

The materials are discussed below in details.

3.1.1 Cement

Ordinary Portland cement which conforms to the requirements of BS EN 197-1: (2000) was used for all the work.

3.1.2 Palm kernel shell

Palm kernel shell was obtained from Palm kernel processing mill Umuagwo in Ohaji-Egbeme L.G.A, Imo State, Nigeria.

3.1.3 Aggregate

The coarse aggregates used for this work were obtained from Lokpaukwu, in umunnochi LGA Abia State, Nigeria. It was sun-dried for seven days inside the laboratory before usage. The aggregates used were free from deleterious matters. The coarse aggregate used was 19 mm in size. The compacted bulk density of the coarse aggregate is 1615 kg/m^3 and the non-compacted bulk density is 1400 kg/m^3.

3.1.4 Water

Water was obtained from a borehole within the premises of Federal University of Technology, Owerri, Imo State. The water is potable and conforming to the standard of BS EN 1008: (2002).

3.1.5 Nails

The nails used for this research work were obtained from Owerri timber Market and the size used was two inches' steel nails conforming to BS1202-3: (1974).

3.1.6 Seasoned plank

The woods were obtained from Owerri timber Market. They were seasoned wood belonging to hard-wood with dimensions 3000 x 300 x 25 mm.

The wood was visually selected to make sure that there is no defect on it in line with BS EN 635-1:1995. The woods were cut to 1200 x 300 mm and used to produce slabs to the following dimensions.

- i. 1200 x 900 x 100 mm
- ii. 1200 x 900 x 125 mm
- iii. 1200 x 900 x 150 mm
- iv. 1200 x 900 x 175 mm.

3.1.7 Reinforcement Bars

The reinforcement bars were purchased from a dealer in Owerri Timber market. The rebar's were as specified in BS 4449:1997 and 10mm size Reinforcement Bars was use for the control slab.

The stirrups were purchased from Owerri Timber market in Imo State and the Grade are as specified in BS 4449: 1997.

3.2 Methods

The Palm kernel shells were washed to remove any oil from mills and also the fibres were removed (See Appendix A). The particles were classified according to their granulometry, in sieves of different sizes. The particles had a moisture content of approximately less than 12.

The mixing method used for the production of palm kernel shell – plank laminated composite slab concrete was manual method and the batching was by weight except the sawdust that were batched by volume. The mix ratios for batching were 0.75: 1:1:1, 0.75:1:2:2 and 0.75 :1:3:3; the mix ratios stand for water cement ratio, cement, palm kernel shell and sawdust respectively. The mix ratio for control slab was 0.45:1:2:4 which stands for water/cement ratio, cement, sand and coarse aggregates respectively.

3.2.1 Laboratory investigation on materials

The properties of materials investigated include the physical properties of palm kernel shell, sawdust, wood, reinforcement and chemical properties of cement.

3.2.1.1 Physical property tests

The palm kernel shell and sawdust were tested to determine their specific gravities, bulk densities and gradation (sieve analysis). The water absorption of sawdust was specifically obtained to know the water/cement ratio to be used. Collection of samples was in accordance to BS EN 932-1(1997) while the sieve analysis was in accordance to BS 812-103.1(2000)

3.2.1.1.1 Test on steel and wood

The tensile strength of steel used for this work was determined to check if it is in line with BS 4449: (1997); also the strength in tension of wooden plank both in perpendicular to the face and parallel to the face were determined. The modulus of elasticity of the plywood in bending was as well determined in accordance to BS-EN 12390-5:(2000).

3.2.1.2 Chemical property test

Chemical analysis was conducted on the cement to determine the chemical composition in accordance to USEPA 6200 (2007). Loss on ignition was determined in accordance to BS EN 196-2(1995)

3.2.2 Test for structural characteristics of palm kernel shell - sawdust composite concrete

The following tests were carried out to determine the structural characteristic of palm kernel shell - sawdust composite concrete.

3.2.2.1 Compressive strength test for palm kernel shell - sawdust composite concrete.

The palm kernel shell-sawdust composite concrete cubes were produced using manual mixing method in a mould measuring 150 x 150 x 150 mm in size. The moulds were first oiled for easy removal of the samples after setting. The palm kernel shell-sawdust composite sample was introduced into the mould in three layers with proper vibration. A total of 18 cubes were produced from the 3 mix ratios used and the mix ratios were 0.75: 1:1:1, 0.75: 1:2:2, 0.75: 1:3:3, three cubes from each mix. The first set of 9 cubes made from the mix ratios, were used to obtain the seventh (7th) day compressive strength, while the second set of 9 cubes, were used to obtain the 28-day compressive strength. The palm kernel shell-sawdust composite concrete cubes were cured by spraying water on it for both 7days and 28 days, and tested in Okhard Machine Tool's WA-1000B digital display Universal Testing Machine (UTM) thereafter. The machine conforms to the requirement of BS EN 12390-4 (2000) and has a testing range of 0-1000kN. The compression load at failure was recorded and used in Equation (3.4) to determine the compressive strength of the palm kernel shell-sawdust

$$fc = \frac{P\ (N)}{A\ (mm^2)} \qquad (3.4)$$

Were fc = compressive strength, P = compressive load of cube at failure and A = cross sectional area of the mould.

The density of the 28-day compressive strength was obtained since some structural characteristic depends on it. The cubes for the compressive Strength Test were weighed in a digital weighing balance that has accuracy of 0.01g and recorded and the density of the samples were computed using Equation 3.5.

$$\rho = \frac{M}{V} \tag{3.5}$$

Where ρ = density, M = mass of sample, V= volume of sample.

3.2.2.2 Split tensile strength test for palm kernel shell - sawdust composite concrete

The palm kernel shell - sawdust composite concrete sample, were cylinder measuring 150 x 3000mm in size in accordance to the requirements of BS EN 12390-1 (2000) and BS EN 12390 – 6 (2009). A total of nine (9) cylinder were produced from the three mix ratios used and the mix ratio are 0.75: 1:1:1, 0.75: 1:2:2 and 0.75: 1:3:3, three cylinders from each mix. The s palm kernel shell - sawdust cylinders were cured by spraying water on it for 28 days, and tested in Okhard Machine Tool's WA-1000B digital display Universal Testing Machine (UTM) compression machine thereafter. The cylinder specimens were placed with its horizontal axis between the platens of the machine and the load gradually applied until failure by splitting along the centre line occurred. The compression load at failure were recorded and used in Equation (3.7) to determine the split tensile strength of the palm kernel shell sawdust

$$\text{Splitting strength tensile strength } \sigma_c = \frac{2F\ (N)}{\pi L d\ (mm^2)} \tag{3.7}$$

F is the maximum load (in N); L is the length of the specimen; d is the cross-sectional dimension of the specimen. The test will be in according to BS 1881-117, (1983), BS EN 12390-1, (2000) BS EN 12390-6, (2009).

3.2.2.3 Static modulus of elasticity of palm kernel shell - sawdust composite concrete

The static modulus of elasticity of the palm kernel shell - sawdust composite concrete was determined as a function of the compressive strength and density using Equation 3.8

$$E_S = 1.7\rho^2 {f_c}^{0.33} \text{x } 10^{-6} \tag{3.8}$$

Where E_S =Static modulus of Elasticity ρ = density; f_c = compressive strength

3.2.2.4 Poisson ratio of palm kernel shell-sawdust composite concrete

The Poisson ratio of palm kernel shell - sawdust composite concrete was determined as a function of the tensile stress at cracking in flexure and compressive stress at cracking for compression members using Equation (2.7) reproduced here as Equation (3.9). The value of Poisson μ is given as

$$\mu = \frac{\delta_f}{\delta_c} \tag{3.9}$$

3.2.2.5 Shear strength of palm kernel shell - sawdust composite concrete

The failure load in shear was obtained from the flexural strength test and the shear strength calculated using Equation (3.10)

$$f_S = \frac{F}{A} \tag{3.10}$$

Where f_S = shear strength

F = shear load at failure

A= cross- sectional area of the test specimen

3.2.2.6 Shear Modulus of palm kernel shell - sawdust composite concrete

The Shear modulus of the palm kernel shell - sawdust composite concrete was determined as a function of the modulus of elasticity over the linear range of the deformation and Static Poisson's ratio using Equation (2.8) reproduced here as Equation (3.11).

$$G = \frac{E_c}{2(\mu + 1)} \tag{3.11}$$

μ = Static Poisson's ratio

E_c = modulus of elasticity of concrete over the linear range of the deformation.

3.2.3 Test for flexural strength of slab and beams

To determine the flexural strength of palm kernel shell - sawdust wooden plank laminated composite slabs and flexural strength of palm kernel shell - sawdust composite beams the following tests were conducted: -

3.2.3. 1 Flexural strength test of slab

The test was carried out in according to BS EN 12390-5:2000. The flexural strength f_{cf} (in N/mm^2) is given by Equation (3.12)

$$f_{cf} = \frac{F \, x \, L}{d_1 x d_2{}^2} \tag{3.12}$$

Where.

F is the breaking load (in N);

d_1 and d_2 are the lateral dimensions of the cross-section (in mm) (see Plate 3.1);

L is the distance between the supporting rollers (in mm).

3.2.3.2 Production of laminated palm kernel shell - sawdust composite and control slab

The wood for the laminates were saw into size 1200 x 900 x 100 mm, 1200 x 900 x 125 mm, 1200 x 900 x 150 mm, and 1200 x 900 x 175 mm; after sawing, with the help of nails the laminates were formed. To make sure that there was proper bond between palm kernel shell-sawdust composite concrete and the wooden plank, stirrups were used at intervals of 300 mm to hold the top and bottom members of the laminates.

The control slabs were produced using mix ratio of 0.45:1:2:4. The size of slabs produced were 1200 x 900 x 100 mm, 1200 x 900 x 125 mm, 1200 x 900 x 150 mm, and 1200 x 900 x 175 mm. The 10 mm reinforcements were cut into 1.1m (main bar at 200 mm c/c) and 900mm (distribution bar at 200 mm c/c) and they were arranged to form a mesh which was used to reinforced control samples.

Plate 3.1: Arrangement of slab during crushing as required by BS EN 12390-5:2009

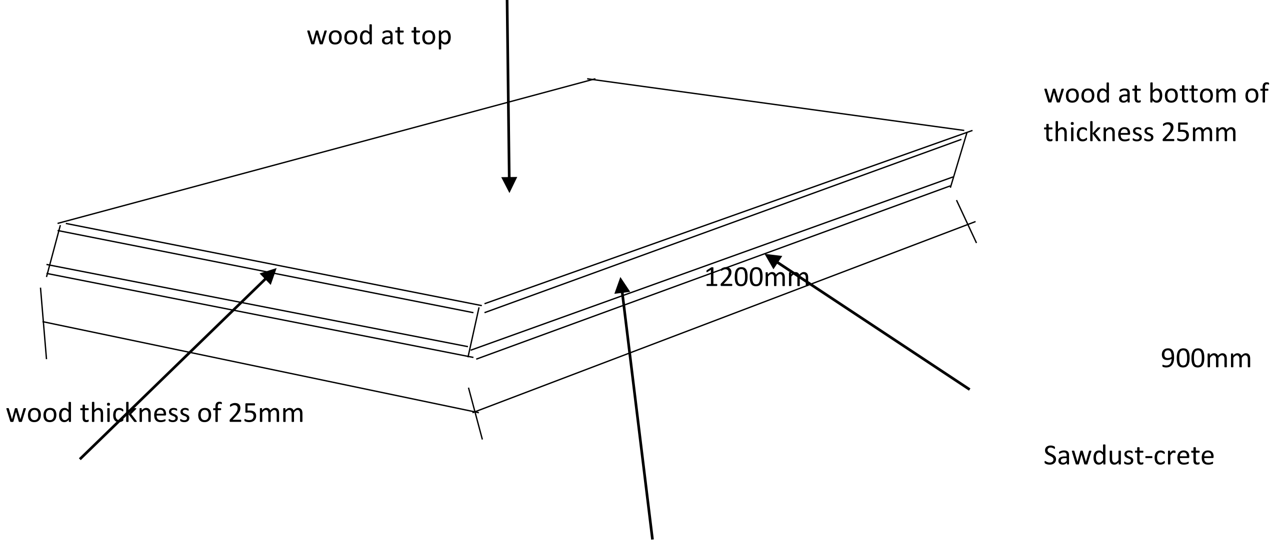


Figure 3.1: Typical example of the plywood laminate

The palm kernel shell-sawdust composite concrete laminated wooden plank laminated slab, measured 1200 x 900 x 175 mm, 1200 x 900 x 150 mm, 1200 x 900 x 125 mm and 1200 x 900 x 100 mm in size were produced using manual mixing method and proper vibration so as to obtain good compaction of the composite. Figure 3.1 shows the components of the laminated slab. A total of 16 slabs were produced using two different mix ratios used, and the mix ratios were 1:2:2

and 1:3:3 with water-cement ratio of 0.75; two slabs from each mix and for a thickness of plywood of 25 mm. Also 16 more slabs were produced as a conventional slab with dimensions 1200 x 900 x 175 mm, 1200 x 900 x 150 mm, 1200 x 900 x 125 mm and 1200 x 900 x 100 mm; 8 of the convectional slabs were produced from normal concrete components with water-cement ratio of 0.45. The concrete mix ratio was 1:2:4, reinforced with 10 mm steel bars while the remaining 8 were produced with quarry dust composite concrete with water-cement ratio of 0.75. The mix ratio was 1:3:3 and without reinforcement. The convectional slabs were used to compare the results from palm kernel shell-sawdust wooden plank laminated composite slab. The whole slabs (both with quarry dust-sawdust composite concrete laminated wooden plank and with reinforcement) were cured by spraying water on it for 28 days, and tested with Magunus frame (as can be seen in Plate 3.1) thereafter. The compression load at failure were recorded and used in Equation (3.4) to determine the flexural strength of the quarry dust-sawdust composite concrete laminated wooden plank slab

3.2.3.3 Flexural strength test of palm kernel shell - sawdust composite concrete beams

Nine (9) prototype beams, each of size 150 x 150 x 600 mm were cast from three mix ratios with water-cement ratio of 0.75. The mix ratios were 1:1:1; 1:2:2 and 1:3:3 respectively. Manual mixing method was used during casting of the beams. The beams were cast in layers to make sure that proper vibration of the composite was obtained. The beam samples were tested using Okhard Machine Tool’s WA-1000B digital display Universal Testing Machine (UTM). The curing method adopted was spraying of water for 28 days. The machine conforms to the requirement of BS EN 12390-4 (2000) and has a testing range of 0-1000 kN. The results obtained were used to determining flexural strength of the quarry dust composite concrete composite used in the production of palm kernel shell-sawdust composite concrete laminated composite slab. Equation (3.4) was used also to obtain the flexural strength.

3.2.4 Deflection of palm kernel shell - sawdust laminated composite

The deflection of palm kernel shell - sawdust composite concrete laminated composite and conventional slab were measured using instrument as can be seen in Plate 3.2. The instrument used was constructed using the principle of incompressibility of water. The load from the slab was allowed to act on the T- flange pump that was filled with water and connected to burette that contain water to a particular level. When the slab fails, the changes in height of water in the burette and pump pipe were recorded and having known the areas of the T-flange pump and the burette the deflection was computed.

Plate 3.2: Deflection measurement using principle of incompressibility of water

3.2.5 comparison of flexural strength of palm kernel shell - sawdust composite concrete with conventional method

To know the level of deflection and flexural strength of laminated palm kernel shell - sawdust composite concrete slab and control slabs, the results from palm kernel shell - sawdust composite concrete laminated composite were compared to the results of the conventional slab and those of plain palm kernel shell composite concrete using percentage difference.

$$\% \, deflection = \frac{\partial p - \partial k}{\partial p} \text{ x } \frac{100}{1} \qquad (\,3.12)$$

Where ∂p is the deflection for conventional slab, ∂k is the deflection from palm kernel shell laminated composite slab. While that of flexural strength is as given in Equation 3.13

$$\% \, deflection = \frac{Fsp - Fsk}{Fsp} \text{ x } \frac{100}{1} \qquad (3.13$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Presentation of Results

The results obtained for characteristics strength tests of palm kernel shell – sawdust composite and palm kernel shell - sawdust plank laminated composite slab are presented in Table 4.1 to Table 4.13; while Figure 4.1 shows penetration resistance of palm kernel shell sawdust composite. The results of characterization of the materials used for this work are presented in Appendices A-C.

Table 4.1: Workability Test Result for palm kernel shell – sawdust composite

Mix ratios	**Slump Value (mm)**	**Type of slump**
1:1:1	110	Collapse
1:2:2	80	True
1:3:3	75	True

Table 4.2: Penetration Resistance Test for Palm Kernel Shell-Sawdust Composite

Penetration Resistance in (N/mm^2)	Elapsed Time in (min)
0	50
0	100
95	200
130	350
160	400
234	550
304	600
480	750
600	850

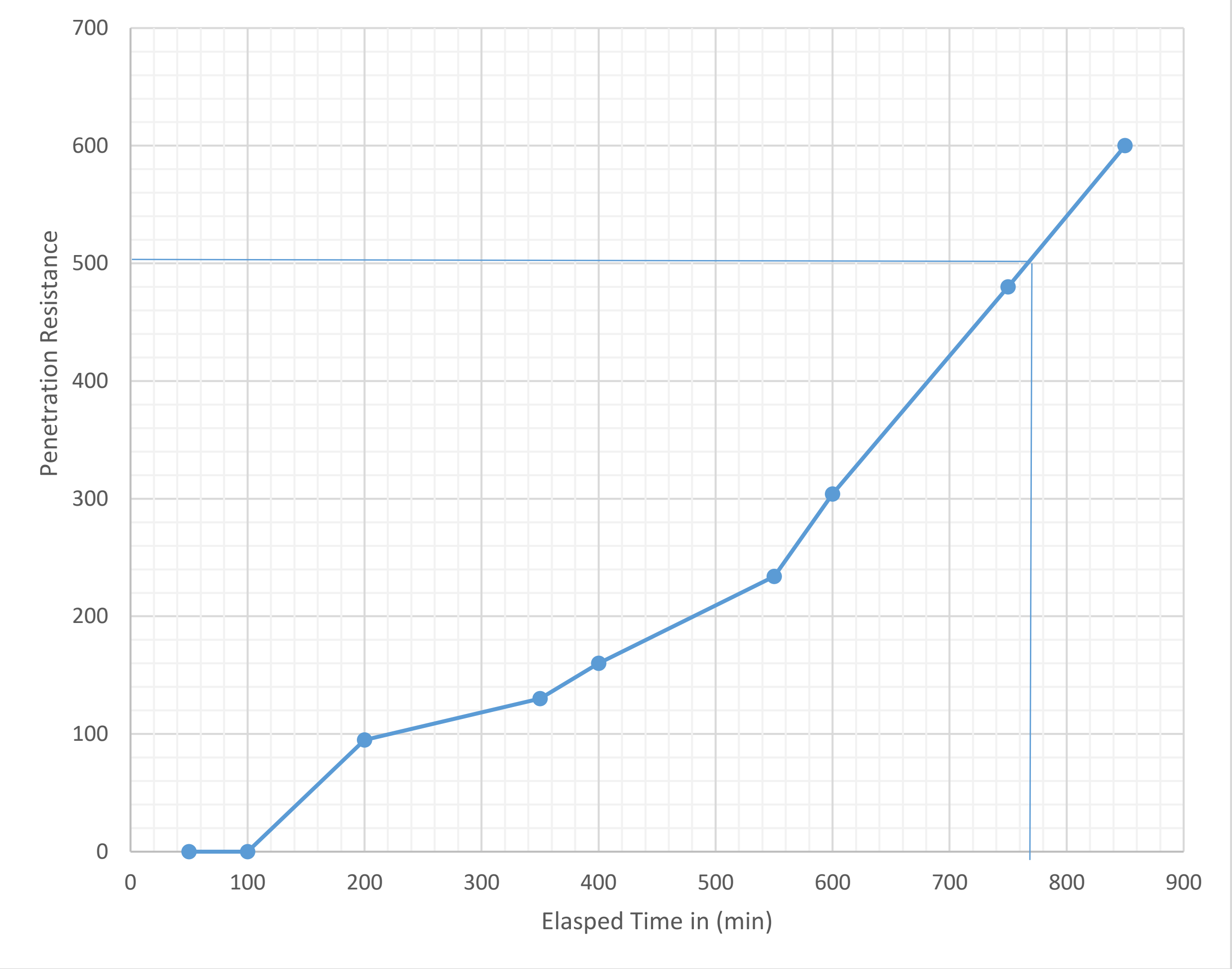


Fig 4.1 Penetration Resistance Curve for Palm Kernel Shell-Sawdust Composite

Table 4.3: 7th day Compressive Strength Result for Palm Kernel Shell

– Sawdust composite

Mix ratio	Sample No	Area of Sample in (mm^2)	Weight of Sample in (kg)	Crushing load in kN	Compressive Strength (N/mm^2)	Average Compressive strength (N/mm^2)
1:1:1	A	22500	5.3	115.4	5.13	5.35
1:1:1	B	22500	5.23	120.2	5.34	
1:1:1	C	22500	5.05	125.4	5.57	
1:2:2	A	22500	5.2	103.23	4.59	4.52
1:2:2	B	22500	5.3	109.23	4.85	
1:2:2	C	22500	5.14	92.4	4.11	
1:3:3	A	22500	5.2	52.12	2.32	2.34
1:3:3	B	22500	5.3	53.45	2.38	
1:3:3	C	22500	5.12	52.14	2.32	

Table 4.4: 28th day Compressive Strength Result for palm kernel Shell

– Sawdust Composite

Mix ratio	Sample No	Area of Sample in (mm^2)	Weight of Sample in (kg)	Crushing load in kN	Compressive Strength (N/mm^2)	Average Compressive strength (N/mm^2)
1:1:1	A	22500	5.35	225.56	10.02	10.25
1:1:1	B	22500	5.31	234.2	10.41	
1:1:1	C	22500	5.12	232.4	10.33	
1:2:2	A	22500	5.25	205.6	9.14	9.08
1:2:2	B	22500	5.34	208.9	9.28	
1:2:2	C	22500	5.2	198.45	8.82	
1:3:3	A	22500	5.41	98.67	4.39	4.36
1:3:3	B	22500	5.23	98.46	4.38	
1:3:3	C	22500	5.21	96.89	4.31	

Table 4.5: Density Result for Palm Kernel Shell – Sawdust Composite

Mix ratio	Sample No	Volume of Sample in (m^3)	Weight of Sample in (kg)	Density of the Palm kernel shell-Sawdust composite in kg/m^3
1:1:1	A	0.003375	5.35	1585.19
1:1:1	B	0.003375	5.31	1573.33
1:1:1	C	0.003375	5.12	1517.04
1:2:2	A	0.003375	5.25	1555.56
1:2:2	B	0.003375	5.34	1582.22
1:2:2	C	0.003375	5.2	1540.74
1:3:3	A	0.003375	5.41	1602.96
1:3:3	B	0.003375	5.23	1549.63
1:3:3	C	0.003375	5.21	1543.70

Table 4.6: 28th day Splitting tensile Strength Result for Palm kernel Shell – Sawdust Composite

Mix ratio	Sample No	πdL (mm^2)	Weight of Sample in (kg)	Crushing load in kN	splitting Tensile N/mm^2	Average splitting Tensile strength (N/mm^2)
1:1:1	A	141371.67	10.7	278.3	1.969	1.951
1:1:1	B	141371.67	10.62	268.95	1.902	
1:1:1	C	141371.67	10.24	280.3	1.983	
1:2:2	A	141371.67	10.5	235.78	1.668	1.666
1:2:2	B	141371.67	10.68	240.56	1.702	
1:2:2	C	141371.67	10.4	230.34	1.629	
1:3:3	A	141371.67	10.82	216.78	1.533	1.558
1:3:3	B	141371.67	10.46	218.45	1.545	
1:3:3	C	141371.67	10.42	225.5	1.595	

Table 4.7: Static Modulus of Elasticity Result for Palm kernel Shell – Sawdust Composite

Mix ratio	Sample No	Density of Sample in (mm^2)	Weight of Sample in (kg)	Crushing load in kN	Compressive Strength N/mm^2	Static modulus of elasticity GPa	Average Static modulus of elasticity GPa
1:1:1	A	1585.19	5.35	225.56	10.02	9.14	8.90
1:1:1	B	1573.33	5.31	234.2	10.41	9.12	
1:1:1	C	1517.04	5.12	232.4	10.33	8.45	
1:2:2	A	1555.56	5.25	205.6	9.14	8.54	8.56
1:2:2	B	1582.22	5.34	208.9	9.28	8.88	
1:2:2	C	1540.74	5.2	198.45	8.82	8.28	
1:3:3	A	1602.96	5.41	98.67	4.39	7.12	6.77
1:3:3	B	1549.63	5.23	98.46	4.38	6.65	
1:3:3	C	1543.70	5.21	96.89	4.31	6.56	

Table 4.8: Poisson Ratio Result for Palm Kernel Shell – Sawdust Composite

Mix ratio	Sample No	Density of Sample in (kg/m^3)	Crushing load in kN	Compressive Strength N/mm^2	Tensile Stress N/mm^2	Poisson Ratio μ	Average Poisson ratio μ
1:1:1	A	1585.19	225.56	10.02	1.969	0.20	0.19
1:1:1	B	1573.33	234.2	10.41	1.902	0.18	
1:1:1	C	1517.04	232.4	10.33	1.983	0.19	
1:2:2	A	1555.56	205.6	9.14	1.668	0.18	0.18
1:2:2	B	1582.22	208.9	9.28	1.702	0.18	
1:2:2	C	1540.74	198.45	8.82	1.629	0.18	
1:3:3	A	1602.96	98.67	4.39	1.533	0.35	0.36
1:3:3	B	1549.63	98.46	4.38	1.545	0.35	
1:3:3	C	1543.70	96.89	4.31	1.595	0.37	

Table 4.9: Shear Modulus Result for Palm Kernel Shell – Sawdust Composite

Mix ratio	Sample No	Density of Sample in (mm^2)	Tensile stress (N/mm^2)	Compressive Stress (N/mm^2)	Static modulus of elasticity	Poisson Ratio μ	Shear Modulus GPa	Average Shear Modulus GPa
1:1:1	A	1585.19	1.969	10.02	9.14	0.20	3.81	3.74
1:1:1	B	1573.33	1.902	10.41	9.12	0.18	3.86	
1:1:1	C	1517.04	1.983	10.33	8.45	0.19	3.55	
1:2:2	A	1555.56	1.668	9.14	8.54	0.18	3.62	3.63
1:2:2	B	1582.22	1.702	9.28	8.88	0.18	3.76	
1:2:2	C	1540.74	1.629	8.82	8.28	0.18	3.51	
1:3:3	A	1602.96	1.533	4.39	7.12	0.35	2.64	

1:3:3	B	1549.63	1.545	4.38	6.65	0.35	2.46	2.50
1:3:3	C	1543.70	1.595	4.31	6.56	0.37	2.39	

Table 4.10: Shear Strength Result for Palm Kernel Shell – Sawdust Composite

Mix ratio	Sample No	Cross Sectional Area (mm^2)	Mass of Sample in (kg)	Crushing load in kN	Flexural strength (N/mm^2)	Shear Strength (N/mm^2)
1:1:1	A	90000	16.05	25.23	2.24	0.280
1:1:1	B	90000	15.93	26.78	2.38	0.298
1:1:1	C	90000	15.36	27.45	2.44	0.305
1:2:2	A	90000	15.75	22.65	2.01	0.252
1:2:2	B	90000	16.02	23.65	2.10	0.263
1:2:2	C	90000	15.6	21.3	1.89	0.237
1:3:3	A	90000	16.23	20.98	1.86	0.233
1:3:3	B	90000	15.69	20.23	1.80	0.225
1:3:3	C	90000	15.63	21.32	1.90	0.237

Table 4.11: 28th day Flexural Strength Result for palm kernel shell – sawdust wooden plank

Laminted Composite Slab, Convectional Slab and Plain Palm Kernel – Sawdust Slab

Mix ratio	Thickness of plies	Sample Size	Sample number	Crushing Load in kN	Flexural Strength of the Slab (MPa)	Average Flexural Strength (MPa)
1:2:2	25mm	1200 x 900 x 100mm	A	22.98	2.068	2.17
1:2:2	25mm	1200 x 900 x 100mm	B	23.09	2.078	
1:2:2	25mm	1200 x 900 x 125mm	A	43.63	2.513	2.41
1:2:2	25mm	1200 x 900 x 125mm	B	44.38	2.556	
1:2:2	25mm	1200 x 900 x 150mm	A	70.20	2.808	2.70
1:2:2	25mm	1200 x 900 x 150mm	B	71.13	2.845	

1:2:2	25mm	1200 x 900 x 175mm	A	103.24	3.034	3.17
1:2:2	25mm	1200 x 900 x 175mm	B	105.79	3.109	
1:3:3	25mm	1200 x 900 x 100mm	A	20.48	1.843	1.82
1:3:3	25mm	1200 x 900 x 100mm	B	21.86	1.967	
1:3:3	25mm	1200 x 900 x 125mm	A	35.61	2.051	2.11
1:3:3	25mm	1200 x 900 x 125mm	B	36.86	2.123	
1:3:3	25mm	1200 x 900 x 150mm	A	60.53	2.421	2.38
1:3:3	25mm	1200 x 900 x 150mm	B	58.90	2.356	
1:3:3	25mm	1200 x 900 x 175mm	A	90.89	2.671	2.85
1:3:3	25mm	1200 x 900 x 175mm	B	91.98	2.703	
		Normal concrete Slab with 10mm reinforcement				
1:2:4		1200 x 900 x 100mm	A	76.61	6.895	6.93
1:2:4		1200 x 900 x 100mm	B	77.36	6.962	
1:2:4		1200 x 900 x 125mm	A	137.64	7.928	7.87
1:2:4		1200 x 900 x 125mm	B	135.83	7.824	
1:2:4		1200 x 900 x 150mm	A	206.83	8.273	8.31
1:2:4		1200 x 900 x 150mm	B	208.55	8.342	
1:2:4		1200 x 900 x 175mm	A	321.56	9.45	9.55
1:2:4		1200 x 900 x 175mm	B	328.37	9.65	
		palm kernel shell – sawdust composite Slab (without reinforcement)				
1:3:3		1200 x 900 x 100mm	A	7.74	0.697	0.699
1:3:3		1200 x 900 x 100mm	B	7.79	0.701	
1:3:3		1200 x 900 x 125mm	A	14.29	0.823	0.818
1:3:3		1200 x 900 x 125mm	B	14.10	0.812	
1:3:3		1200 x 900 x 150mm	A	25.58	1.023	1.063
1:3:3		1200 x 900 x 150mm	B	27.55	1.102	
1:3:3		1200 x 900 x 175mm	A	44.98	1.322	1.287
1:3:3		1200 x 900 x 175mm	B	42.60	1.252	

Table 4.12: 28th day Flexural Strength and Deflection Result for Palm Kernel Shell – Sawdust Plank laminated Composite Slab and Convectional Slabs

Mix ratio	Thickness of plies	Sample Size	Sample number	Flexural Strength of the Slab in MPa	Average Flexural Strength in MPa	Deflection in mm at crushing
1:2:2	25mm	1200 x 900 x 100mm	A	2.068	2.17	102
1:2:2	25mm	1200 x 900 x 100mm	B	2.078		100
1:2:2	25mm	1200 x 900 x 125mm	A	2.513	2.41	87
1:2:2	25mm	1200 x 900 x 125mm	B	2.556		83
1:2:2	25mm	1200 x 900 x 150mm	A	2.808	2.70	47
1:2:2	25mm	1200 x 900 x 150mm	B	2.845		45
1:2:2	25mm	1200 x 900 x 175mm	A	3.034	3.17	20
1:2:2	25mm	1200 x 900 x 175mm	B	3.109		22
1:3:3	25mm	1200 x 900 x 100mm	A	1.843	1.82	120
1:3:3	25mm	1200 x 900 x 100mm	B	1.967		118
1:3:3	25mm	1200 x 900 x 125mm	A	2.051	2.11	97
1:3:3	25mm	1200 x 900 x 125mm	B	2.123		98
1:3:3	25mm	1200 x 900 x 150mm	A	2.421	2.38	60
1:3:3	25mm	1200 x 900 x 150mm	B	2.356		64
1:3:3	25mm	1200 x 900 x 175mm	A	2.671	2.85	35
1:3:3	25mm	1200 x 900 x 175mm	B	2.703		37
		Normal concrete Slab with 10mm reinforcement				
1:2:4		1200 x 900 x 100mm	A	6.895	6.93	40
1:2:4		1200 x 900 x 100mm	B	6.962		35
1:2:4		1200 x 900 x 125mm	A	7.928	7.87	20
1:2:4		1200 x 900 x 125mm	B	7.824		24
1:2:4		1200 x 900 x 150mm	A	8.273		10

1:2:4		1200 x 900 x 150mm	B	8.342	8.31	15
1:2:4		1200 x 900 x 175mm	A	9.45		10
1:2:4		1200 x 900 x 175mm	B	9.65	9.55	12
		palm kernel shell – sawdust composite Slab (without reinforcement)				
1:3:3		1200 x 900 x 100mm	A	0.697	0.699	20
1:3:3		1200 x 900 x 100mm	B	0.701		20
1:3:3		1200 x 900 x 125mm	A	0.823	0.818	15
1:3:3		1200 x 900 x 125mm	B	0.812		15
1:3:3		1200 x 900 x 150mm	A	1.023	1.063	10
1:3:3		1200 x 900 x 150mm	B	1.102		10
1:3:3		1200 x 900 x 175mm	A	1.322	1.287	5
1:3:3		1200 x 900 x 175mm	B	1.252		5

Table 4.13: 28th day Flexural Strength result for palm kernel shell – sawdust beams

Mix ratio	Sample No	Weight of Sample in (kg)	Crushing load in (kN)	Flexural strength (N/mm^2)	Average Flexural strength (N/mm^2)
1:1:1	A	16.05	25.23	2.24	2.35
1:1:1	B	15.93	26.78	2.38	
1:1:1	C	15.36	27.45	2.44	
1:2:2	A	15.75	22.65	2.01	2.00
1:2:2	B	16.02	23.65	2.10	
1:2:2	C	15.6	21.3	1.89	
1:3:3	A	16.23	20.98	1.86	
1:3:3	B	15.69	20.23	1.80	1.85
1:3:3	C	15.63	21.32	1.90	

4.2 Discussion of Results

4.2.1 Physical properties of sawdust, plank and steel

The specific gravity of the palm kernel shell and sawdust were 2.65 and 0.35 respectively as can be seen in Appendices A and B. These values are within the normal range recommended for the respective materials. The specific gravity given by Maharani (2010) is 0.22 – 0.51 for sawdust; and the one given by University of Massachusetts (2000) for fine aggregates ranges from 2.2 - 4.0 for fine aggregates.

The bulk densities of the palm kernel shell and sawdust were respectively found to be 740 kg/m^3 and 734 kg/m^3. Again these values compared favourably with those in the literature; Okoroigwe, Cristopher and Paschal (2014) obtained similar values. The water absorption of sawdust is 14%.

The sieve analysis of sawdust shows that it falls in Zone II of the grading of fine aggregates as given in NIS 87 zone 4 and BS 882 (1992) and are suitable for making concrete. The coefficient of uniformity, Cu and coefficient of gradation, Cc for sawdust is 1.0. The Sawdust is approximately well graded since Cc is equal to 1.

The plank has flexural strength of 4.34 - 4.56 N/mm^2 for the face parallel to span. The flexural strength in perpendicular to the face ranges from 9.20-9.89 N/mm^2. The static modulus of elasticity ranges from 2345-2500 N/mm^2, the values compared favorably with those from literature. The steel has the average ultimate tensile strength as 606.52N/mm^2 which is in line with BS 4449: (1997).

4.2.2 Chemical analysis of cement

The results of chemical test performed on the OPC (Dangote brand) used for this work is presented in Table E of Appendix E.

The percentage concentration of the major compounds namely CaO, Al_2SO_3, SiO_2 and Fe_2O_3 are 67.62, 6.03, 20.39, and 2.29% respectively. These values are within the ranges given in Table 2.5 for ordinary Portland Cement. The concentration of the other compounds – Na_2O, K_2O, TiO_2 and loss on ignition are 0.3, 0.84, 0.2 and 2.8% respectively. These are also within the limit given in Table 2.5 and BS EN 197-2 (2000). The cement is therefore suitable for general purpose concrete work.

4.2.3 Analysis of results of structural characteristics of palm kernel shell – sawdust composite

The slump results for 1:1:1, 1:2:2 and 1:3:3 for 0.75 water cement ratio are 110 mm, 80 mm and 75 mm respectively. The mix ratio of 1:2:2 and 1:3:3 have true slump while the mix ratio 1:3:3 has a collapse slump.

The penetration resistance of sawdust - palm kernel shell composite is 710 minutes while those of normal concrete range from 240 to 480 minutes; that means, the presence of sawdust increases the final setting time of concrete by more than 50%.

The average compressive strength of mix ratio of 1:1:1 is 10.25 MPa, the average compressive strengths of 1:2:2 and 1:3:3 are 9.08 MPa and 4.36 MPa respectively. It can be seen from the results that as the quantities of sawdust increases in the mix, the compressive strength decreases. The values of compressive strength obtained are less than the minimum value of light weight concrete for 28-day strength which should not be less than 17.5 MPa for structural purposes.

The average density of sawdust-palm kernel shell composite is 1561.15 kg/m^3; from literature, the density of light-weight concrete should not exceed 1840kg/m^3. Therefore, palm kernel shell-sawdust composite is a light-weight concrete in terms of density.

The split tensile strength of sawdust-palm kernel shell composite ranges from 1.558 MPa to 1.951MPa. The tensile strength of light weight concrete according to literature ranges from 1.87 to 2.75 MPa. From the results of the split tensile strength, it can be seen that the sawdust has results that is comparable to those of normal weight concrete.

The static modulus of elasticity of sawdust-palm kernel shell composite ranges from 6.77 MPa to 8.90 MPa; but the static modulus of elasticity of normal concrete ranges from 21.4 GPa to 46.4 GPa that means the values obtained from sawdust-palm kernel shell is less than those of normal weight concrete.

The Poisson ratio of sawdust-palm kernel shell composite ranges from 0.19 to 0.36 while that of normal concrete ranges from 0.15 to 0.3.

The shear modulus of sawdust-palm kernel shell ranges from 2.40 GPa to 3.74 GPa while the shear strength of sawdust-palm kernel shell composite ranges from 0.237 to 0.298 N/mm^2

The average flexural strength of sawdust-palm kernel shell laminated composite slab ranges from 1.82 MPa to 2.85 MPa while that of palm kernel shell-sawdust beams composite ranges from 1.85 to 2.35 MPa. The flexural strength of reinforced concrete slab with 10mm rebar's gives 6.93 to 9.55 MPa but the permissible stress in bending for concrete ranges from 2.5 MPa to 16 MPa.

4.2.4 Analysis of results of flexural strength and deflection

The deflection at failure for sawdust-palm kernel shell plank laminated composite are discussed below alongside with its flexural strength.

The average flexural strength of mix ratio 1:2:2 for 25mm laminate ranges from 2.17 - 3.17 MPa while the deflection value of mix ratio 1:2:2 for both 25mm range from 22-102 mm

The average flexural strength of mix ratio 1:3:3 for 25mm laminate ranges from 1.82 - 2.85 MPa while the deflection value of mix ratio 1:2:2 for 20mm laminate ranges from 37 – 97 mm.

The average flexural strength of mix ratio 1:2:4 for normal concrete range from 6.93 – 9.55 MPa while deflection value of mix ratio 1:2:4 ranges from 12 – 40 mm.

The average flexural strength of mix ratio 1:3:3 for plain sawdust-quarry dust composite ranges from 0.699-1.287 MPa while deflection value of 1:3:3 ranges from 5-20 mm.

4.2.5 Relationship between compressive strength and other strength properties of palm kernel shell – sawdust composite

Most often only compressive strength tests are conducted on concrete. Relationships could be established between the compressive strength and the other properties such as, flexural strength, split tensile strength and static modulus elasticity. Table 4.14 is a summary of the average results from the three mix ratios that are notably used for production of sawdust-crete.

Table 4.14: Average Values of Structural properties of palm kernel shell – sawdust composite

Mix ratio	Compressive strength, Fc (N/mm^2)	Shear Strength, Fs (N/mm^2)	Flexural Strength, Ft (N/mm^2)	Split tensile strength, Fst (N/mm^2)	Shear Modulus (GPa)	Static modulus elasticity (GPa)
1:1:1	10.25	0.280	2.32	1.951	3.74	8.90
1:2:2	9.08	0.263	2.09	1.666	3.63	8.56
1:3:3	4.36	0.237	1.89	1.558	2.50	6.77

4.2.6 Comparison percentage difference for conventional slab and palm kernel shell – sawdust laminated composite slab

The results of flexural strength of convectional slab and palm kernel shell – sawdust laminated composite slab are as shown in Table 4.15 to Table 4.19.

Table 4.15: Percentage difference for Conventional Slab and palm kernel shell – sawdust Slab for 25mm plank at 1:2:2 mix ratio.

Slab Thickness (mm)	X_1	X_2	X_2-X_1	% Difference
100	6.895	2.068	4.827	70.01
100	6.962	2.078	4.884	70.15
125	7.928	2.513	5.415	68.30
125	7.824	2.556	5.268	67.33
150	8.273	2.808	5.465	66.06
150	8.342	2.845	5.497	65.90
175	9.45	3.034	6.416	67.89
175	9.65	3.109	6.541	67.78

Legend: -

X_1 = Conventional slab flexural strength in MPa

X_2 = Palm kernel shell plank laminated Composite slab (containing 25mm wood) flexural strength in MPa

Table 4.16: Percentage difference for Conventional Slab and palm kernel shell – sawdust Slab for 25mm plank at 1:3:3 mix ratio

Slab Thickness (mm)	X_1	X_2	X_2-X_1	% Difference
100	6.895	1.843	5.052	73.27
100	6.962	1.967	4.995	71.75
125	7.928	2.051	5.877	74.13
125	7.824	2.123	5.701	72.87
150	8.273	2.421	5.852	70.74
150	8.342	2.356	5.986	71.76
175	9.45	2.671	6.779	71.74
175	9.65	2.703	6.947	71.99

Legend: -

X_1 = Convectional slab flexural strength in MPa

X_2 = palm kernel shell – sawdust laminated Composite slab (containing 25mm wood) flexural strength in MPa

Table 4.17: Percentage difference for Plain palm kernel shell – sawdust and Laminated palm kernel shell – sawdust Slab for 25mm with 1:3:3 mix ratio.

Slab Thickness (mm)	X_1	X_2	X_2-X_1	% Difference
100	1.843	0.697	1.146	62.18
100	1.967	0.701	1.266	64.36
125	2.051	0.823	1.228	59.87
125	2.123	0.812	1.311	61.75
150	2.421	1.023	1.398	57.74
150	2.356	1.102	1.254	53.23
175	2.671	1.322	1.349	50.51
175	2.703	1.252	1.451	53.68

Legend: -

X_1 = Palm kernel shell – sawdust slab flexural strength in MPa for 25mm wood laminate

X_2 = Plain palm kernel shell – sawdust Composite slab flexural strength in MPa

From Table 4.17, it can be clearly seen that the percentage difference between plain concrete and palm kernel shell – sawdust laminated composite slab is between 53.68% to 62.18%; From this same Table 4.17, it can be clearly seen that palm kernel shell – sawdust laminated composite increases the flexural strength up to 62.18%.

4.2.7 Relationship between palm kernel shell – sawdust laminated slab thickness and deflection and flexural strength

The relationship between the slab thickness and flexural strength for different plies is as presented in Table 4.18 and the graphs are presented as shown in Figure 4.2 to Figure 4.6; Equation (4.1) to Equation (4.5) describes the relationship between flexural strength and slab thickness. From this Table 4.18, the relationship between the slab thickness and deflection is as shown in Equation (4.6) to Equation (4.10). It can be seen that the deflection decreases with increase in depth of the slab; Also, the deflection decreases with increase in flexural strength. The relationship can be obtained using Equations (4.6) to Equations (4.10).

For 25 mm laminate and mix ratio of 1:2:2, the flexural strength (Ft) related to slab thickness x as shown in Equations (4.1)

$$Ft = 0.0132x + 0.803 \tag{4.1}$$

For 25mm laminate and mix ratio of 1:3:3, the flexural strength related to slab thickness x as shown in Equations (4.2)

$$Ft = 0.0134x + 0.442 \tag{4.2}$$

For control slab the flexural strength related to the slab thickness x as shown in Equation (4.5) for mix ratio of 1:2:4 and 10mm rebars.

$$Ft = 0.0332x + 3.6 \tag{4.3}$$

For 25mm laminate and mix ratio of 1:2:2, the deflection related to slab thickness x as shown in Equations (4.4)

$$Y = -1.0968x + 215.2 \tag{4.4}$$

For 25mm laminate and mix ratio of 1:3:3, the deflection related to slab thickness x as shown in Equations (4.5)

$$Y = -1.138x + 235.1 \tag{4.5}$$

For control slab the deflection related to the slab thickness x as shown in Equation (4.6) for mix ratio of 1:2:4 and 10mm rebars.

$$Y = -0.356x + 69.7 \tag{4.6}$$

The summaries of the equations can be seen in Table 4.20 and Table 4.21.

Table 4.18: Relationship between palm kernel shell
− sawdust compositeslab thickness and deflection

Mix ratio	Thickness of plies (mm)	Sample Size	Average Flexural Strength In MPa	Average Deflection At Crushing in mm
1:2:2	25	1200 x 1000 x 100mm	2.17	101
1:2:2	25	1200 x 1000 x 125mm	2.41	85
1:2:2	25	1200 x 1000 x 150mm	2.70	51
1:2:2	25	1200 x 1000 x 175mm	3.17	21
1:3:3	25	1200 x 1000 x 100mm	1.82	119
1:3:3	25	1200 x 1000 x 125mm	2.11	97.5
1:3:3	25	1200 x 1000 x 150mm	2.38	62
1:3:3	25	1200 x 1000 x 175mm	2.85	36

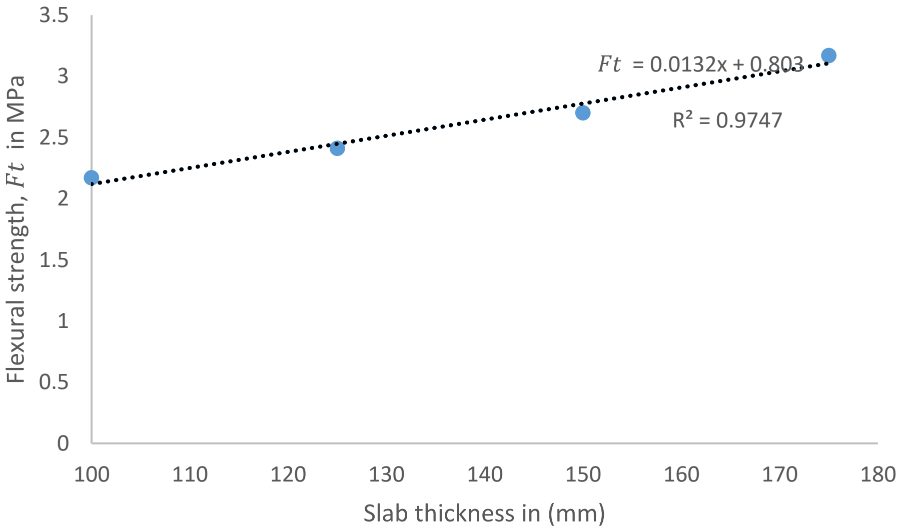


Figure 4.2: Flexural strength of palm kernel shell – sawdust composite laminated slab for mix ratio of 1:2:2 and 25 mm plies thickness

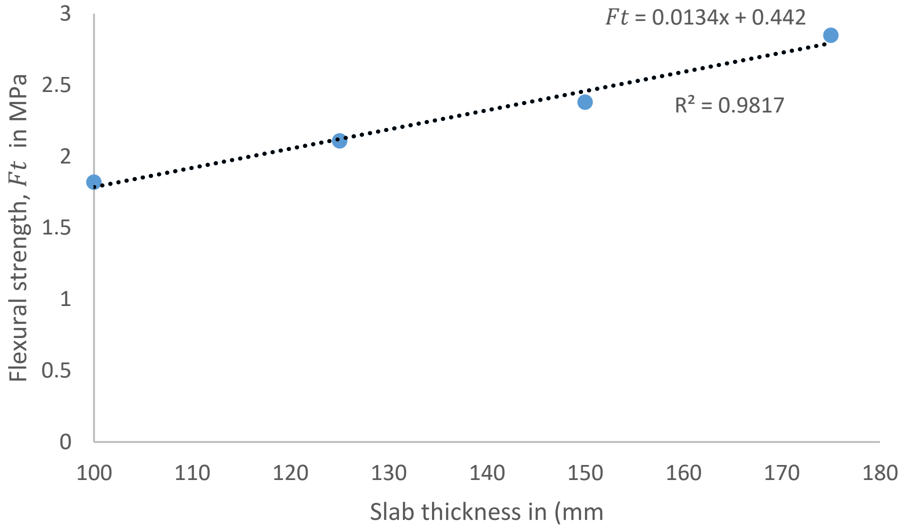


Figure 4.3: Flexural strength of palm kernel shell – sawdust composite laminated slab for mix ratio of 1:3:3 and 25 mm plies thickness

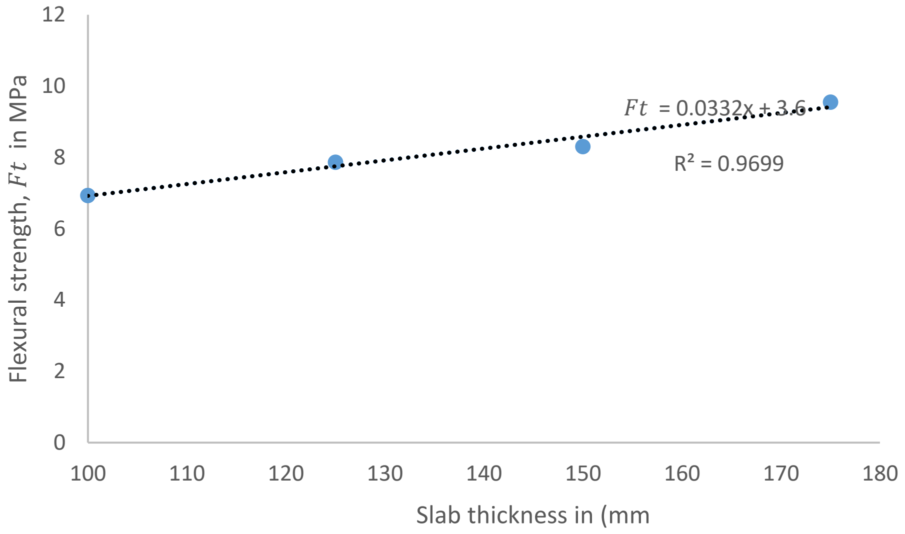


Figure 4.4: Flexural strength of control slab for mix ratio of 1:2:4 and 25 mm plies thickness

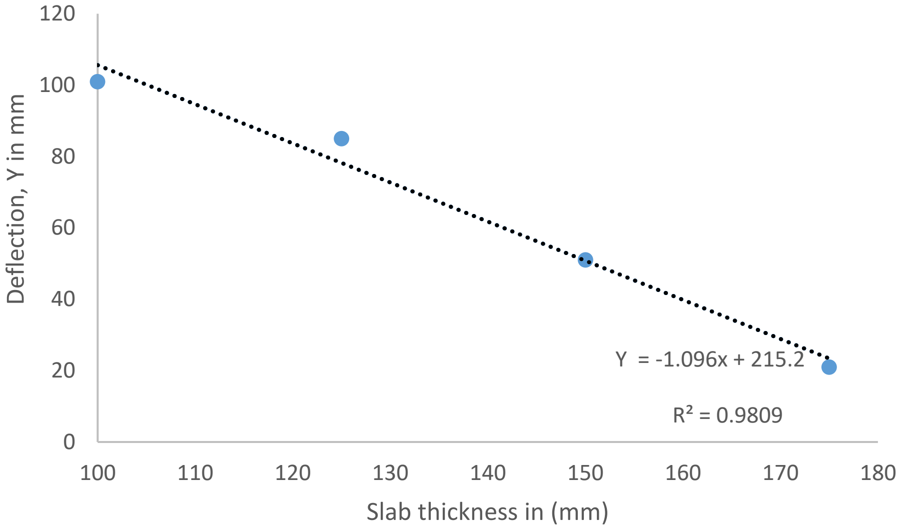


Figure 4.5: Deflection of palm kernel- sawdust composite laminated Slab for mix ratio of 1:2:2 and 25mm plies thickness

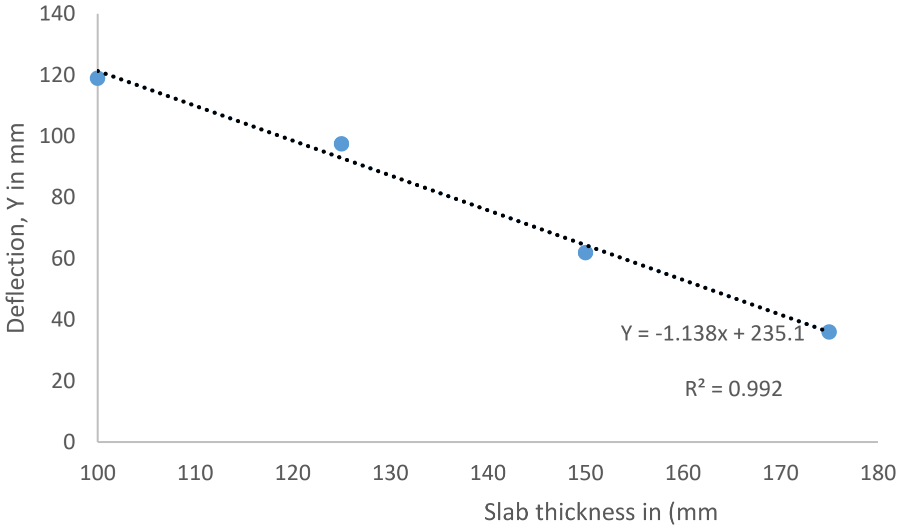


Figure 4.6: Deflection of Palm kernel- Sawdust Composite laminated Slab for mix ratio of 1:3:3 and 25mm plies thickness

Table 4.19: Summary of equations of flexural strength against slab thickness

Mix Ratio	Thickness of wood (mm)	Equations	R^2 value
1:2:2	25	$Ft = 0.0132x + 0.803$	0.9747
1:3:3	25	$Ft = 0.0134x + 0.442$	0.9817
1:2:4	Reinforced with steel (10mm)	$Ft = 0.0332x + 3.6$	0.9699

Table 4.20: Summary of equations of deflection against slab thickness

Mix Ratio	Thickness of plywood (mm)	Equations	R^2 value
1:2:2	25	$Y = -1.096x + 215.2$	0.9809
1:3:3	25	$Y = -1.138x + 235.1$	0.992
1:2:4	Reinforced with steel (10mm)	$Y = -0.356x + 69.7$	0.9981

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions can be drawn from this research work:

i. The average compressive strength of palm kernel shell-sawdust composite for mix ratio of 1:1:1 is 10.25 MPa, while that of 1:2:2 is 9.08 MPa and that of 1:3:3 is 4.36 MPa.

ii. The average density of palm kernel shell-sawdust is 1561.15 kg/m^3; from literature, the density of light-weight concrete should not exceed 1840 kg/m^3. Therefore, palm kernel shell-sawdust composite is a light-weight concrete in terms of density

iii. The split tensile strength of palm kernel shell-sawdust composite ranges from 1.55MPa to 1.951 MPa for mix ratio of 1:1:1, 1:2:2, and 1:3:3. Therefore, the split tensile strength of palm kernel shell-sawdust composite is okay for lightweight concrete.

iv. The static modulus of elasticity of palm kernel shell-sawdust composite ranges from 6.77 MPa to 8.90 MPa; but the static modulus of elasticity of normal concrete ranges from 21.4 GPa to 46.4 GPa. The value obtained from experiment is less than the value for normal concrete.

v. The Poisson ratio of palm kernel shell-sawdust composite ranges from 0.19 to 0.36 while that of normal concrete ranges from 0.15 to 0.3. The Poisson ratio is within the limits as those of normal concrete.

vi. The shear strength results range from 0.23 to 0.3 MPa, the Poisson's ratio ranges from 0.36 to 0.19. The shear modulus ranges from 4.24 to 4.32.

vii. The average flexural strength of palm kernel shell-sawdust laminated composite slab ranges from 1.82 MPa to 3.17 MPa while that of palm kernel shell-sawdust beams ranges from 1.89 MPa to 2.32 MPa comparing it to the flexural strength of reinforced concrete slab (convectional slab) with 10mm rebar's gives 6.93 MPa to 9.55 MPa but the permissible stress in bending for concrete ranges from 2.5 MPa to 16 MPa for slab, therefore, the flexural strength is within limit for light structural slab.

viii. The deflection at failure of palm kernel shell-sawdust laminated composite slab ranges from 37 to 120 mm while those of normal concrete slab ranges from 10 mm to 40 mm.

ix. Comparing the palm kernel shell-sawdust laminated composite slab with that of conventional slab shows that the percentage difference for 25 mm laminate ranges from 65.90% to 74.15% for mix ratio of 1:2:2 and 1:3:3 respectively. For plain palm kernel shell-sawdust and laminated composite slab the percentage difference between plain concrete and palm kernel shell-sawdust laminated composite slab is between 57.38% to 68.40%; from the result it can be clearly seen that palm kernel shell-sawdust laminated composite increases the flexural strength up to 62%.

5.2 Recommendations

The following Recommendations are made: -

i. Palm kernel shell-sawdust composite slabs should be used as light structural members that are not carrying much loads and the weight is much less compared with those of conventional slabs.

ii. Further studies should be carried out on how to improve the strength of palm kernel shell-sawdust composite by the use of additives.

iii. The relationship between deflection and flexural strength should be observed at different loading other than crushing load.

iv. Further research should be carried out on the structural properties of sawdust- palm kernel concrete slab laminated with wood. This will help to see if the strength can be closer to those of conventional slab for heavy structural purposes.

5.3 Contributions to Knowledge

This work has contributed to knowledge in the following ways: -

i. Through this work, information on structural characteristics of palm kernel shell-sawdust composite can be obtained. There is now information on such properties such as static modulus of elasticity, split tensile strength, shear modulus, shear strength, flexural strength and Poisson’s ratio. Previous works normally give information on only compressive strength.

ii. Compressive strength is often the only test conducted on palm kernel shell-sawdust composite. This work has established a relationship between the flexural strength and thickness of laminated palm kernel- sawdust- cement composite slabs for mix ratios of 1:2:2 and 1:3:3.

iii. This work also, developed relationship between deflection and slab thickness both for conventional and palm kernel shell-sawdust laminate.

REFERENCES

Afuwape F.K. (1983). Design and Testing of a Sawdust Compactor. B.Sc Thesis, Department of Agricultural Engineering Obafemi Awolowo University, Lie Ife, Nigeria.

Alberto, M.M., Mougel, E., and Zoulalian, A. (2000). Compatibility of some tropical hardwood species with Portland cement using isothermal calorimetry. Forest Products Journal 50(9), 83-88.

Alengaram J. U, Jumaat M.Z and Mahmud H., 2008. Ductility Behaviour of Reinforced Palm Kernel Shell Concrete Beams. European Journal of Scientific Research 23(3), p.406-420

Alengaram J. U, Jumaat M.Z and Mahmud H., 2010. Comparison of mechanical and bond properties of oil palm kernel shell concrete with normal weight concrete. International Journal of the Physical Sciences 5(8), p. 1231-1239.

ASTM (1978)- Significance of tests and properties of concrete -making materials

ASTM C 125 (2009). Standard Terminology Relating to Concrete and Concrete Aggregates. ASTM International West Conshohocken, PA, 2014.

ASTM C 330 (2009). Standard Testing method for determining Density of Structural Lightweight Concrete. ASTM International West Conshohocken, PA, 2014.

ASTM C 567 (2009). Standard Specification for lightweight Aggregates. ASTM International West Conshohocken, PA, 2014.

ASTM C332 (2003). Standard specification for lightweight aggregates for insulating concrete

ASTM C332 (2005). Standard specification for lightweight aggregates for concrete masonry

ASTM C637 (2020). Standard specification for aggregates for radiation shielding

ASTM C638 (2020). Standard descriptive nomenclature of constituents of aggregates for radiation-shielding concrete

Ata O., Olanipekun, E. A. and Oluola, K. O. (2006). A Comparative Study of Concrete Properties Using Coconut Shell and Palm Kernel Shell as Coarse Aggregates.', Building and Environment 41, pp.297- 301

Badejo, S.O. (1988). Effect of flake geometry on properties of cement-bonded particleboard from mixed tropical hardwoods. Wood Science and Technology 22(4), 357-370.

Bentur, A., and Ackers, S.A. (1989). The microstructure and ageing of cellulose fibre reinforced cement composites cured in a normal environment. The International Journal of Cement Composites and Lightweight Concrete 11(2), 99-110.

Bergstrom D., Isrealsson, S., Ohman, m., Dahlquist, S.A., Gref, R., Boman, C., and Wasterlund, P. (2008). Effects of Raw material Particle Size Distribution on the Characteristics of Scots Pine Sawdust Fuel Pellets. Fuel processing Technology.Vol 6.

Bhavikatti, S.S. (2000). Elements of civil engineering. New Delhi:Vikas publishing house.

Biblis, E.J, and C. Lo (1968). Sugar and other wood extractives-effect on the setting of southern pine-cement mixes. Forest production journal. 18(8); pp 28 – 34

Boothby, T.E., Borroughs, C.B., Bernecker, C.A., Manbeck, H.B., Ritter, M.A., Grgurevich, S., Cegelka, S., and Lee, P.D. (2001). Design of Wood Highway Sound Barriers. Research Paper No. 596, Forest Products Research Laboratory, USDA Forest Service. Pp 63.

Brandt, A.M. (1998). Cement based composites: Materials, Mechanical Properties and Performance. First edition, Chapman and Hall London.

BS 1202. (1974). Nails -Aluminum nails. Part 3: British Standard Institute.

BS 146 (2002): The standard for specification for blast-furnace cements with strength properties outside the scope of BS EN 197-1

BS 3797. (1964). Lightweight aggregate for concrete. Part 1: British Standard Institute.

BS 3797. (1976). Lightweight aggregate for concrete. British Standard Institute.

BS 4449 (1997). Specification for Carbon steel bars for the reinforcement of concrete: British Standard Institute.

BS 5268 (2000). Structural use of timber: Code of practice for permissible stress design, materials and workmanship Part 2: British Standard Institute.

BS 5328. (1990). Specification for the procedures to be used in Producing and Transporting concrete. Part 3. British Standard Institute. London.

BS 8110. (1997). Structural use of concrete: - Code of practice for design and Construction. Part 1. British Standard Institute. London.

BS 812. (1995). Aggregate test: - Method for determination of particle size distribution. Part 103 British Standard Institute. London.

BS 882. (1978). Specification for aggregates from natural sources for concrete. British Standard Institute. London.

BS EN 1008 (2002). Mixing water for concrete: - Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete. British Standard Institute London

BS EN 12350. (2000). Testing Fresh Concrete-Slump test. Part 2. British Standard Institute London.

BS EN 12390. (2000). Testing Hardened Concrete. Shape, dimension and other requirement for specimens and moulds. Part 1. British Standard Institute. London.

BS EN 12390. (2009). Testing Hardened Concrete. Flexural strength of test specimens. Part 5. British Standard Institute. London.

BS EN 12390. (2009). Testing Hardened Concrete. Tensile Splitting strength test of specimens. Part 6. British Standard Institute. London.

BS EN 196 (1978). Method of Testing Cement. Chemical Analysis of Cement. Part 2. British Standard Institute London.

BS EN 197 (2000). Cement. Composition, specifications and conformity criteria for common cements. Part 1. British Standard Institute London.

BS EN 313. (2000). Principal Characteristics of Plywood. Part 2: British Standard Institute.

BS EN 635. (1995). Plywood – Classification by Surface Appearance. Part 1: British Standard Institute.

BS EN 932. (1997). Test for general properties of aggregate. Method of sampling. Part 1. British Standard Institute. London.

Buys, H. (1989). Construction and construction elements with wood-cement particleboard, in Proceedings 1st Inorganic Bonded Fiber Composites Symposium, ed A.A. Moslemi, Forest Products Research Society 1989, pp 151-188.

Buys, H. (1995). Foldex Homes made of cementbonded particleboard, in Proceedings 3rd International Inorganic bonded wood and fibre composite materials, ed A.A. Moslemi, Forest Products Research Society, Madison. pp 32-35.

Cabangon, R.J., Cunningham, R.B., and Evans, P.D. (2002). Manual strand orientation as a means of improving the flexural properties of wood wool cement boards in the Philippines. Forest Products Journal 52(4), 53-59.

Cabangon, R.J., Cunningham, R.B., Evans, P.D. (2002). Manual strand orientation as means of improving the flexural properties of wood-wool cement boards in the Philippines. Forest Products Journal 52 (4): 53-59.

Carpinteri, A. (2002). Structural Mechanics: A unified approach. CRC Press.

Chapola, G.B.J. (1989). Effect of curing heat, alkali and cement set in cement particleboard on the viscoelastic properties of chip mattresses. Wood Science and Technology 23(2), 131-138.

Chen, T.Y., and Hwang, S.R. (1998). Effect of wood species on the properties of cement-bonded wood particleboard. in Adhesive Technology and Bonded Tropical Wood Products, eds C.Y. Hse, S.J. Branham, and C. Chow, Taiwan Forestry Research Institute (TFRI) Extension Series No. 96, pp 554-564.

Chittenden, A.E. (1972). Wood and cement: past and future, in Proceedings 7th World Forestry Congress 4-18 Oct. 1972 Buenos Aires. Vol V, pp 6128-6133.

Coutts, R.S.P. (1983). Wood fibers in inorganic matrices. Chemistry in Australia 50(5), 143-148

Coutts, R.S.P. and Kightly, P. (1984). Bonding in wood fibre-cement composites. Journal of Materials Science 19(10), 3355-3359.

Czielielski, E. (1975). Concrete with wooden particles. Holz als Roh- und Werkstoff, 33(8), 303-307.

Del Menezzi, C. H. S., and Souza, M. R. (2000). Influence of bark on properties of wood-cement Particleboards made with eucalypt. In: International Conference on Wood and Wood Fiber Composites, 1. Stuttgart, Proc. p. 423-428.

Deppe, H.J. (1977). On the production and application of cement bonded wood chipboards, in Proceedings 11th Washington State University Symposium on Particleboard, ed T.M. Maloney, Pullman, Washington. pp 267-285.

Dinwoodie, J.M., and Paxton, B.H. (1989). A technical assessment of cement-bonded particleboard, in Proceedings 1st Inorganic Bonded Fiber Composites Symposium, ed A.A. Moslemi, Forest Products Research Society 1989. pp. 115-124.

Dinwoodie, J.M., and Paxton, B.H. (1991). The long term performance of cement bonded wood particleboard, in Proceedings 2nd Inorganic Bonded Wood and Fiber Composites Symposium, ed A. A. Moslemi, Forest Products Research Society 1991. pp. 45-54.

Dix, R.J.H. (1989). The principles of cement-bonded particleboard manufacture, in Proceedings 1st Inorganic Bonded Fiber Composites Symposium, ed A.A. Moslemi, Forest Products Research Society 1989. pp. 61-67.

Elmondorf, A. (1966). Method of Making a NonPorous Board Composed of Strands of Wood and Portland cement, US Patent No. 3271492.

Erik J, (1994). Woodwool Slabs – Manufacture, Properties and uses. Building Issue Vol.6 (3) pp 1-25.

Farkhrul, T., Mahbub, R., and Islam, M. A. (2013) Properties of wood Sawdust and Wheat Floor Reinforced Polypropylene Composites. Journal of Modern Science and Technology Vol 1 pp 135-148.

Finnish Forest Industries Federation. (2002). Hand Book of Finnish plywood.

Frombo, F., Minciardi R., Robba, M., Rosso, F., and Sacile. (2009). Planning Woody Biomass Logistics for Energy Production: A Strategic Decision Model. Biomass and Bioenergy Vol 33 pp 372-382.

Ganiron, T.U, (2014). Effect of Sawdust as Fine Aggregate in Concrete Mixture for Building Construction. International Journal of Advance Science and Technology. Vol.63 pp 73-82.

Goodell, B., Daniel, G., Liu, J., Mott, L., and Frank, R. (1997). Decay resistance and microscopic analysis of wood-cement composites. Forest Products Journal 47(11/12), 75-80.

Hachmi, M., and Moslemi, A.A. (1989) Correlation between wood-cement compatibility and wood extractives. Forest Prod J 39(6):55–58.

Himmel, M., Tucker M., Baker, J., Rivard, K., and Grohman. (1985). Communition of Biomass: Hammer and Knife Mills. In Proceedings of Biotechnology and Bioengineering Symposium 15.

Hsu, E.W. (1992). Process for making wood composite employing blast-furnace slag as the binder. US Patent No. 5171496. Pp 6.

Ibearugbulem, O.M. (2006). Mathematical models for Optimization of Compressive Strength of Periwinkle Shells-Granite Concrete .M.Eng Thesis, Federal University of Technology Owerri, Nigeria.

Ibearugbulem, O.M., Ezeh, J. C., Ettu, L.O. (2014). Energy Methods in Theory of Rectangular Plates (Use of Polynomial Shape Functional). Liu House of Excellence Ventures Owerri, Nigeria.

Karam, G.N., and Gibson, L.J. (1994). Evaluation of commercial wood-cement composites for sandwichpanel facing. Journal of Materials and Engineering 6(1), 100-116.

Kasim, M.M., and Zeynal, E. (2015) Mechanical properties of Wood Shaving Cement Lightweight Composite. Al-Rafidian Engineering Vol 23 (2) pp 88-85.

Kavvouras, P.K. (1987). Suitability of Quercus conferta wood for the manufacture of cement bonded flake boards. Holzforschung 41(3), 159-163.

Kayahara, M., Tajika, K., and Nakagawa, H. (1979). Increase of strength of wood-cement composites. Mokuzai Gakkaishi 25(8), 552-557.

Kelly, M.W. (1977). Critical Literature Review of Relationships between Processing Properties and Physical Properties of Particleboard. USDA Forest Service, Forest Products Laboratory, General Technical Report FPL10, pp 65.

Kermani, A. (1999). Structural Timber Design. Blackwell Science Ltd, 25 John Street, London WClN 2BL.

Khurmi, R. S., and Gupta, J.K. (2006). Civil Engineering Materials. New Delhi: Eurasia publishing house.

Kuroki, Y., Nagadomi, W., and Yamada, J. (1993). Manufacture of lightweight cement-bonded particleboard in Japan, in Proceedings 3rd International Inorganic Bonded Wood and Fiber Composite Materials, ed A.A. Moslemi, Forest Products Research Society, pp. 136-142.

Kuroki, Y., Nagadomi, W., Sasaki, H., Kawai, S., and Eusebio, D. (1995). Cement-bonded board industry and market in Japan and new technology developments, in Proceedings 4th International Inorganic Bonded Wood and Fiber Composite Materials, ed A.A. Moslemi, Forest Products Research Society, pp. 105-112.

Lan, H.F. and Huang, Y.F. (2000). Manufacturing of cement-bonded wood particle composites and acoustic characteristics. Forest Products Industries (Taiwan) 19(1), 85-99.

Ledhem, A., Dheilly, R.M., Benmalek, M.L., and Quéneudec, M. (2000b). Properties of wood-based composites formulated with aggregate industry waste. Construction and Building Materials 14, 341-350.

Lee, A.W.C., and Short, P.H. (1989). Pretreating hardwood for cement-bonded excelsior board. Forest Products Journal 39(10), 68-70.

Lipinsky, E.S. (1989). Potential technologies for effectively bonding wood with inorganic binders, in Proceedings 1st Inorganic Bonded Fiber Composites Symposium, ed A.A. Moslemi, Forest Products Research Society 1989, pp. 53-57.

Ma, L.F., Yamaguchi, H., Pulido, O.R., Sasaki, H., and Kawai, S. (2002). Production and properties of orientated cement-bonded boards from sugi, in Wood-Cement Composites in the Asia-Pacific Region, ed P.D. Evans, ACIAR Proceedings No. 107. Australian Centre for International Agricultural Research, Canberra, pp 140-147.

Maharani, R., Yutaka T.,Yajima, T., and Minoru, T. (2010). Scrutiny on Physical Properties of Sawdust from Tropical Commercial Wood Species: Effect of Different Mills and Sawdust's Particle size. Journal of Forest Research Vol 7(1) pp 20-32.

Mallari, Jr., V.C., Pulido, O.R., Cabangon, R.J., and Novicio, L.A. (1997). Development of a rapid curing process for cement-bonded board manufacture, in Proc. 5th Inorganic Wood and Fiber Composite Materials, ed A.A. Moslemi, Forest Products Research Society, Madison. pp 147-152.

Mannan M.A and Ganapathy C., 2002. Engineering properties of concrete with oil palm shell as coarse aggregate. Construction and Building Materials 16, p29-3

Mehta, P.K and Monteiro, P.J.M. (1993). Concrete: Microstructure, Properties and Materials, 3rd McGraw Hill New York.

Mohammad, D. (2007). Palm Kernel Shell (PKS) is More thanBiomass for Alternative Fuel After 2005. Proceedings of Chemistry and Technology Conference, Malaysia

Mohd, Z. J., Johnson, U. A. and Hilimi, M. (2008). Ductility Behavior of Reinforced Palm Kernel Shell Concrete Beams, European Journal of Scientific, Vol. 23, No 3, pp. 406-420

Moslemi, A.A. (1989). Wood-cement panel products: coming of age, in Proceedings 1st Inorganic Bonded Fiber Composites Symposium, ed A.A. Moslemi, Forest Products Research Society 1989, pp. 12-18.

Moslemi, A.A. (1993). Inorganic-bonded wood composites: From sludge to siding. Journal of Forestry November 1993, 27-29.

Moslemi, A.A., and Lim, Y.T. (1984) Compatibility of southern hardwoods with Portland cement. Forest Prod J 34(7/8):22–26.

Mosley, W.H., Bungey, J.H., and Hulse, R. (1999). Reinforced Concrete Design, 5th ed. Palgrave New York.

Ndoke, P. N. (2006). Performance of Palm Kernel Shells as a Partial Replacement for Coarse Aggregate in Asphalt Concrete. Leonardo Electronic Journal of Practices and Technologies, http:// lejpt.academicdirect.org, pp. 145-152.

Neil, J., and Ravindra K. Ohir. (1996). Civil Engineering Materials,5th ed Honkong: Macmillan press Ltd.

Neville, A.M. (2011). Properties of Concrete, 5th ed. Pearson Education Ltd., England.

Okpala, D. C, (1990). Palm Kernel Shell as a Lightweight Aggregate in Concrete, Building and Environment 25, Accessed online on 30th April, 2016, pp. 291-296.

Okutu, K. A. (2012). Structural implications of replacing concrete floor slabs with timber in composite construction. Dissertation submitted as part requirement for the Degree of Master of Science in Structural Engineering the University of Sheffield Department of Civil and Structural Engineering.

Olutoge, F.A. (2010). Investigations on Sawdust and Palm Kernel Shells as Aggregate Replacement. ARPN Journal of Engineering and Applied Science Vol 5 (4) pp 7-13.

Onwuka, D.O., Anyaogu L., Chijioke, C., and Okoye P.C, (2013). Prediction and Optimization of Sawdust Ash- Cement Concrete Using Scheffe's Simplex Design. International Journal of Scientific and Research Publications, 3(5) 1-9.

Onyejiobi, D.O., Abdulkadir T.S., Yusuf, T.S., and Badiru, M.J, (2012). Effects of Palm Kernel Shells Sizes and Mix Ratios on Lightweight Concrete. Journal of Research Information in Civil Engineering, 9(2), 2012.

Oti, J.E., Kinuthia, J.M., Robinson, R and Davies. P. (2015)- The use of palm kernel shell and ash for concrete production. World Academy of Science, Engineering and Technology. International Journal of Civil and Environmental Engineering. Vol 9. No. 3

Oxford English Dictionary (Online ed.). Retrieved 16 June 2016.

Oyagade, A.O., Badejo, S.O., and Omole, O.A. (1995). A preliminary evaluation of the flexural properties of wood veneer laminated cement-bonded particleboard from tropical hardwood species. Journal of the Timber Development Association of India 41(3), 25-29.

Ozelton, E. C. and Baird, J. A. (2006). Timber designers' manual. 5th ed. Blackwell Science Publishing Inc., 350 Main Street, Malden, MA 02148-5020, US.

Parameswaran, N., Broker, F.W. and Simatupang, M.H. (1977). Microtechnological studies on mineralbonded wood composites: Interactions between binders and wood. Holzforschung 31(6), 173-178.

Paulrud, S., Mattson J.E., and Nelson C. (2002). Particle and Handling Characteristic of Wood Fuel Powder: Effect of Different Mills. Fuel Processing Technology Vol 76 pp 23-39.

Pease, D.A. (1994). Mineral Bonded composites, in Panels: Products, Applications and Production Eucalyptus species with Portland cement. Holz als Roh- und Werkstoff 58(12), 315-316.

Punch Neswpaper, (December, 2012). FHA seek 300b naira intervention fund for housing sector Lagos, Nigeria.

Ramirez-Coretti, A., Eckelman, C.A., and Wolfe, R.W. (1998). Inorganic-bonded composite wood panel systems for low-cost housing: a Central American perspective. Forest Products Journal 48(4), 62-68.

Razi, P.S., Portier, R., and Raman, A. (1999). Studies on polymer-wood interface bonding: effect of coupling agents and surface modification. Journal of Composite materials 33(12), 1064-1079.

Saman, D., and Omidreza, S. (2011). Influence of Oil Palm shell on workability and compressive strength of High strength concrete. Annals of Faculty of Engineering Hunedeora- International Journal of Engineering, Tonne IX. Fascicule 2. pp 51-56

Sandermann, W., and Kohler, R. (1964). Studies on mineral bonded wood materials VI. A short test of the aptitudes of woods for cement bonded materials. Holzforschung 18(12), 53-59.

Sandermann, W., Preusser, H and Schweers, W (1960). Studies on mineral-bonded wood products. Holforschung 14(3): pp 70-77

Sekino, N., and Suzuki, S. (2002). Durability of woodbased panels subjected to ten-year outdoor exposure in Japan, in Proceedings 6th Pacific Rim Bio-Based Composites Symposium, ed P.E. Humphrey, Oregon State University, Corvallis, pp. 323-332

Shafigh P, Jumaat M.Z, Mahmud H.B and Alengaram U.J., 2011. A new method of producing high strength oil palm shell lightweight concrete. Materials & Design 32(10), p. 4839–4843.

Shetty, M.S. (2005). Concrete Technology. New Delhi: Rejendra ravindra printers.

Simatupang, M.H., Schwarz, G.H., and Broker, F.W. (1977). Small scale plants for the manufacture of mineral-bonded wood composites, in Proceedings 8th World Forestry Congress, 16-28 Oct. Jakarta, Vol VI 13th Technical Session, pp 717-728.

Singh, P. (2008). Civil Engineering Materials. New Delhi: S.K Kataria.

Solorzano, A.G.R. (1989). Experience in manufacturing wood-cement particleboard in Mexico, In Proceedings 1st Inorganic Bonded Fiber Composites Symposium, ed A.A. Moslemi, Forest Products Research Society 1989. pp. 184-87.

Spratt, B. H. (1974). The structural use of lightweight aggregate concrete. Cement and Concrete Association publication 45. 023. Wexham Springs, Slough SL3 6PL.

Stillinger, J.R., and Wentworth, I.W. (1977). Product, processes, and economics of producing structural wood-cement panels by the Bison-Werke system, in Proceedings 11th Washinton State University Symposium on Particleboard, ed T.M. Maloney, Pullman, Washington, pp. 383-410.

Sudin, R., Chew, L.T., Ong, C.L., and Amin, Z.M. (1989). Storage effects of rubber wood on cement bonded particleboard. Journal of Tropical Forest Science 1(4), 365-370.

Tarazawa, M. (2003). Sawdust Save Globe- Bioconversion of Biomass Waste into Multifunctional recyclates Using Sawdust as an Artificial Soil Matix. In : proceedings of the 1st International Symposium on Sustainable Sanitation, Nanjing, China. Vol 1 pp 9-12

Teo, D.C.L., Mannan, M.A. and Kurian, J. V (2006a)- Structural Concrete using Oil palm shell (OPS) as Lightweight aggregate , Turkish Journal of Engineering and Environmental science .Accessed online on 14th May, 2012, pp 1- 7.

Teo, D.C.L., Mannan, M.A. and Kurian, J. V (2006b)- Flexural behavior of reinforced lightweight concrete beams made with oil palm shell (OPS). Journal of Advanced Concrete Technology. Vol 4 No.3, pp 456- 468

Terazawa, M., Tamai,Y., and Yamashita, K. (1999). Biodegradation of lignocellulisic Substance 1: System for Complete Degradation of Garbage Using Sawdust and Aerobic Soil Bacteria. Journal of Wood Science Vol 45 pp 353-358.

United State of Ministry of Agriculture. (2010). Wood handbook: Wood as Engineering Material. Forest Product Laboratory Centennial ed.

USDA (2010)- Soil classification system

USEPA 6200 (2007)- Field portable X-ray fluorescence spectrometry for the determination of elemental concentration in soil and sediment

Van Elten, G.J. (2000). Production, properties and world wide application of various wood-cement products, in Proceedings 34th International Particleboard and Composite Materials Symposium, eds M.P. Wolcott, R.J. Tichy and D.A. Bender, Washington State University, pp. 169-174.

Waldmar, H., Boke, T, Becker, E., and Jorissen, A. (2000). Structural and other properties of Moodified Wood. Timber Research Wageninger.

Washington State Air Toxic Source and Emission Estimation Methods (1998). Chemical Characterization of plywood Veneer Dryer Emissions, Final Report April.

Watson, J.R (2001). Plywood Basics. Epoxyworks No 18 pp 1-2.

Weatherwax, R.C. and Tarkow, H (1964). Effect of Wood on Setting of Portland Cement. Forest Products Journal 14, pp 567-568

Wolfe, R.W., and Gjinolli, A. (1997). Cement-bonded wood composites as an engineering material, in The Use of Recycled Wood and Paper in Building Applications. USDA Forest Service and Forest Products Society Proceedings No. 7286, pp 84-9.

Wolfe, R.W., and Gjinolli, A. (1999). Durability and strength of cement-bonded wood particle composites made from construction waste. Forest Products Journal 49(2), 24-31.

Xie, M., and Karbhari, V. M. (1997) Peel Test for Characterization of Polymer Composite/Concrete Interface, Journal of Composite Materials.

Xiong, G. (1996). Steel strip reinforced high density wood shaving-cement board ribbed roof panel, Cement and Concrete Composites 18, 429-436.

Youngquist, J.A. (1999). Wood-based composites and panel products. in Wood Handbook: Wood as an Engineering Material, Forest Product Laboratory, USDA Forest Service, Madison, Wisconsin, pp. 101 to 10-31.

Yusuf, I. T. and Jimoh, Y. A. (2011). Palm Kernel Shell Waste Recycled Concrete Road as Cheap and Environmentally Friendly Freeway on Very Poor Subgrades. Proceedings of the National Engineering Conference organized by the Nigerian Society of Engineers, Theme: Effective Transportation System in Nigeria: The Way Forward, 5th – 9th December, 2011, pp. 21-27.

Zavala, M.A.L., Funamizu N., and Takakuwa, T. (2004). Modeling of Aerobic Biodegradation of Feces using Sawdust as a matrix. Water Resources Vol 38 pp 1327-1339.

Zavarin, E. (1984). Part 10 Activation of wood surface and non-conventional bonding, in The Chemistry of Solid Wood, ed R.M. Rowel, American Chemical Society Advances in Chemistry Series No. 207. ACS, Washington. pp 349-400.

Zziwa, A., Kizito, S., Banana, A.Y., Kaboggoza, J.R.S., Kambugu, R.K., and Sseremba O.E. (2006). Production of Composite Bricks from Sawdust Using Portland cement as a Binder. Uganda Journal of Agriculture Science Vol 12 (1) pp 38-44.

APPENDIX A

Properties of sawdust used for the project

Table A1: Sieve Analysis of Sawdust

Sieve size (mm)	Mass retained (g)	% mass retained	Cumulative mass retained (g)	% cumulative mass retained	% passing
5.6	0.00	0.00	0.00	0.000	100.00
3.35	1.34	0.54	1.34	0.54	99.46
2	3.45	1.38	4.79	1.92	98.08
1.18	20.22	8.09	25.01	10.01	89.99
0.6	30.46	12.19	55.47	22.20	77.80
0.425	69.10	27.66	124.57	49.86	50.14
0.3	50.32	20.14	174.89	70.00	30.00
0.212	33.01	13.21	207.90	83.21	16.79
0.15	22.14	8.86	230.04	92.07	7.93
0.075	12.46	4.99	242.50	97.06	2.94
Receiver	7.35	2.94	249.85	100.00	0.00
Total	249.85	100.00			

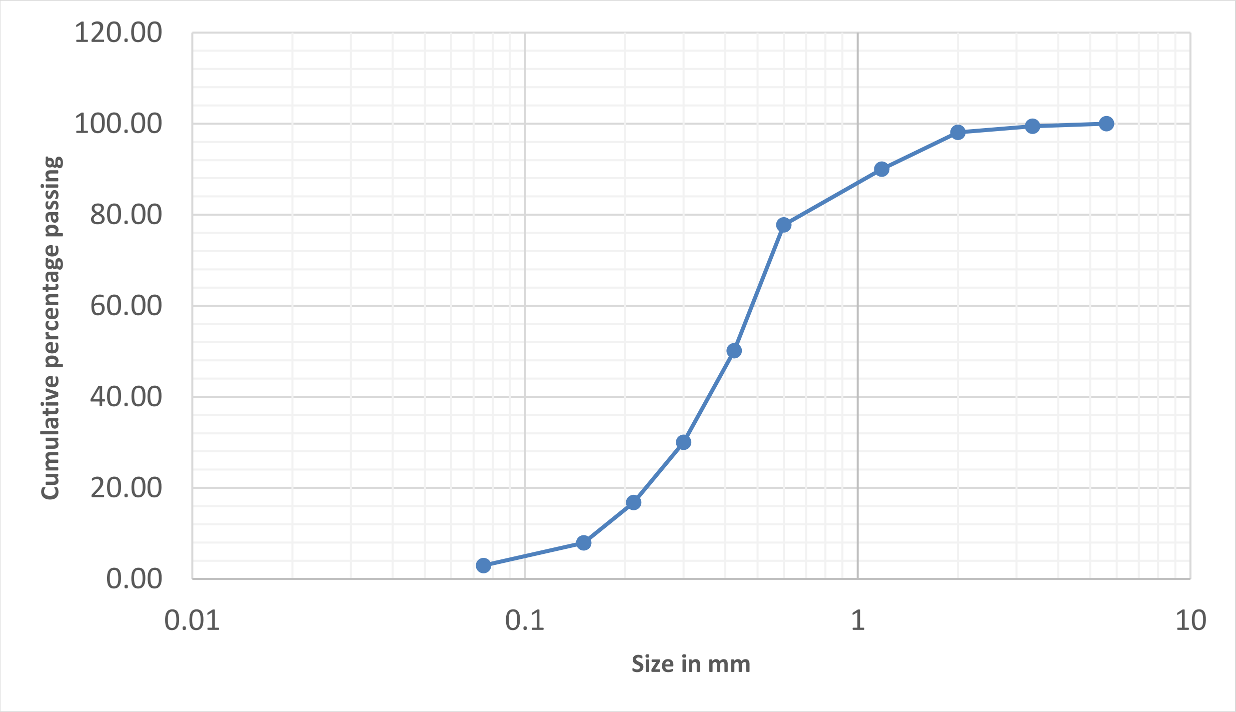


Fig A 1 Grading Curve of Sawdust

Total mass sieved was 250g. The percentage passing by mass was calculated using equation A1

$$\text{Percentage passing} = \frac{\text{mass of sand passing}}{\text{Total mass sieve}} * 100\% \qquad (A1)$$

From the grading curve shown in Fig B1 above, uniformity coefficient, Cu and curvature coefficients, Cc which are used as part of unified soil classification for sand was calculated using the equations: $\mathbf{C_u} = \frac{\mathbf{D_{60}}}{\mathbf{D_{10}}}$ and $\mathbf{C_C} = \frac{\mathbf{D_{30}}^2}{\mathbf{D_{10}xD_{60}}}$ **(A2)**

Where Cu = coefficient of uniformity

D60 = sieve size at 60% passing = 0.5

D10 = sieve size at 10% passing (effective size) = 0.18

D30 = sieve size at 30% passing =0.3

Cu on substitution equals 2.8 and Cc= 1.0.

Table A 2: Bulk density of Sawdust

Sample number	1	2	3
Mass of container W_1	2.55	2.60	2.60
Mass of soil +container,W_2	2.625	2.630	2.6295
Mass of soil (M)	0.025	0.030	0.0295
Volume occupied, V(m^3)	0.000035	0.00004	0.000047
Bulk Density =M/V(kg/m^3)	714.28	750	737.5
Average Bulk density(kg/m^3)		733.92	

The bulk densities of the sawdust were found to be 733.92Kg/m3.

Table A3: Specific Gravity of Sawdust

Trial Sample	1	2	3
Mass of empty pyncnometer bottle (A)g	443.00	443.00	443.00
Mass of bottle + dry sample (B)g	696.89	714.60	714.60
Mass of bottle + dry sample + water (C)g	953.39	969.84	977.00

Mass of bottle filled with water only (D)g	1471.00	1471.00	1471.00
Mass of dry sample (E)=(B)-(A)g	253.89	271.60	271.60
Mass of water occupying same volume as the sample (F) = (D)-(C-E) g	771.50	772.76	765.60
Specific Gravity = E/F	0.33	0.35	0.35
Average Specific Gravity =	0.35		

Water Absorption of Sawdust

$$\%\ of\ water\ absorption = \frac{Difference\ in\ weight}{Initial\ weight}\ x\ 100 \qquad (B3)$$

$$\%\ of\ water\ absorption = \frac{11.4-10}{10}\ x\ 100$$

$$\%\ of\ water\ absorption\ of\ sawdust = 14\%$$

APPENDIX B

Properties of palm kernel shell used for the project

Table B1: Bulk density of Palm Kernel Shell

Test run	1	2	3
Mass of soil, *M* (kg)	0.025687	0.029378	0.040371
Volume occupied, V (m^3)	0.000035	0.00004	0.000055
Bulk density = M/V (kg/m^3)	733.92	734.45	734.01
Average bulk density (kg/m^3)	734.1267		

The bulk densities of Palm kernel shell was found to be 734.1267 kg/m^3

Table B2: Specific gravity of Palm kernel shell

Trial run	Trial 1	Trial 2	Trial 3
Mass of empty pyncnometer bottle [A] , (g)	443	443	443
Mass of bottle + dry sample [B](g)	978	1006	986
Mass of bottle + dry sample + water [C], (g)	1820	1849	1834
Mass of bottle filled with water only [D], (g)	1471	1471	1471
Mass of dry sample [E] = [A] – [B], (g)	535	563	543
Mass of water occupying same volume as the sample , [F] = [D] – [C- E], (g)	194	205	200
Specific gravity = E/F	2.76	2.75	2.72
Average Specific gravity = 2.74			

APPENDIX C

Properties of steel used for the project

Table C1: Tensile test results for 10 mm diameter high yield reinforcement bar

Bars size(mm)	Area in mm2	Yield		Ultimate		Elongation mm
10	78.5	Load in (KN)	Stress (N/mm^2)	Load (KN)	Stress (N/mm^2)	
10	78.5	36.90	470.02	47.83	609.34	14.5
10	78.5	38.39	489.03	47.89	610.03	14.55
10	78.5	37.13	473.04	47.11	600.21	13.54
Average			477.36		606.52	14.20

APPENDIX D

Properties of plank used for the project

Table D: Characteristics of wood Used

Size of wood in mm	Extreme Fibre in Bending: face Parallel to Span In (N/mm^2)	Tension Parallel to face (N/mm^2)	Tension Perpendicular to face grain (N/mm^2)	Modulus of Elasticity in Bending (N/mm^2)
300 X 25	4.56	15.83	9.89	2500
300 X 25	4.70	15.75	9.20	2345
300 X 25	4.34	15.66	9.75	2445

APPENDIX E

Properties of cement used for the project

Table E: chemical composition of Dangote cement

S /No	Oxides	Mass Fraction(g)
1	Silicate (SiO_2)	20.39
2	Alumina (Al_2O_3)	6.03
3	Lime (CaO)	67.62
4	Magnisum Oxide (MgO)	1.31
5	Iron Oxide	2.29
6	Potassium Oxide (K_2O)	0.84
7	Sodium Oxides (Na_2O)	0.3
8	Titanium Oxide (TiO_2)	0.2
9	Loss on ignition	2.8
	Total	98.98

Note: LOI is loss of ignition