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INVESTIGATING THE STRENGTH OF SELF COMPACTED CONCRETE BEAM REINFORCED WITH PLANTAIN BUNCH FIBRE

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UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

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A Dissertation in the Department of CONSTRUCTION AND WOOD TECHNOLOGY EDUCATION, Faculty of TECHNICAL EDUCATION, submitted to the School of Graduate Studies, University of Education, Winneba in partial fulfillment of the requirements for the award of the Master of Philosophy (Construction Technology) degree.

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DECLARATION

STUDENT'S DECLARATION

I, **James Yaw Afreh** declare that this Dissertation, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE: ....

DATE: ....

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Dissertation as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR: **DR. P. P-K YALLEY**

SIGNATURE: ....

DATE: ....

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DEDICATION

To my loving wife who supported me all the way; to my parents whose constant dedication and love enlightened me; to my sons whose innocent energy was and still is a source of inspiration; to all my friends and colleagues who stood beside me with great commitment; I dedicate my research, hoping that I made all of them proud.

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TABLE OF CONTENT

CONTENT **PAGES**

University of Education,Winneba http://ir.uew.edu.gh

University of Education,Winneba http://ir.uew.edu.gh

CHAPTER SIX

University of Education,Winneba http://ir.uew.edu.gh

LIST OF TABLES

TABLES

University of Education,Winneba http://ir.uew.edu.gh

LIST OF FIGURES

FIGURES

ABSTRACT

One of the ways to increase the strength properties of concrete is adding fibre material into the concrete. While to reduce a noise in construction project, a self compacting concrete was a good choice in the project. This thesis presents a study into the strength properties of self compacting beam concrete using plantain bunch fibre. Mix proportion of 1:1.82:1.27with different fractions of fibre namely: 0.00%, 0.25%, 0.50% and 0.75% by weight of cement with water cement ratio of 0.6, with an aspect ratio of 100was used for all the mixes. 40 beams and cylinders of size 150mm×150mm×600mm and100mm diameter of height 200mm respectively were cast. Tests conducted were density, flexural strength, splitting tensile strength and toughness. For density, the control specimen was 2405.6kg/m^3. There was reduction in density of 4.76% when 0.75%fibre content was added. Addition of fibres negatively affected the density. This may be attributed to the higher weight of fibre replaced the cement matrix of the concrete. Similar trend was recorded for flexural strength. Control specimen recorded the highest strength of 2.93MPa. There was reduction of 15% when 0.75%fibre content was added. Specimen with 0.50% fibre content recorded the highest flexural strength value. Though, there was an improvement of 5% in the splitting tensile strength when 0.50% of fibre is used in concrete when the tensile strength of the control specimen was 2.35MPa. The tensile strength increased up to 0.50% addition. This then started decreasing making 0.50% the optimum fibre content. For toughness, the control specimen was 33.67N/mm^2. However, an increase of 18% when 0.50% fibre content and 0.60 water-cement ratio were used to produce the highest toughness. The results support the conclusion that adding fibres improves the tensile strength and toughness of self compacting beam concrete. It is recommended that 0.50% fibre content and 0.60 water cement ratio could be used for lightweight concrete especially for low-cost structures.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

There is the need in developing the technology for using our locally available raw materials in the construction industry. The United Nations (UN) initiative of transforming the world by setting up targets for sustainable development has identified the need to make cities and human settlement safe, resilient and sustainable as much as possible (UNDP, 2015). Currently, shortage of adequate housing and declining infrastructure are among the major challenges that must be addressed. For instance, in Ghana, the annual deficit in the building industry is about 200,000 housing units (Adom-Asamoah &Afrifa, 2011). Beside the shortfalls, most formal housing units are beyond the affordability level of majority of the population. Extensive research efforts aimed at improving housing affordability have emphasized the need for construction materials and methods which will reduce total cost of structures as well as maintain sustainable construction industry.

In the construction industry, concrete has been the most widely used material because of its versatility and relative economy in meeting a wide range of needs. Nonetheless, a variety of concrete types have been developed to address strength, durability and constraints that can be met at construction sites. A typical example is the introduction of Self-compacting Concrete (SCC) in Japan when the availability of skilled labourers became a problem in the 1980s. An added advantage to the use of SCC is its ability to help reduce time and cost of construction since there is no need for mechanical vibration of the in-place concrete. For instance, construction of the anchorages of the Akashi Kaikyo suspension bridge took 2 years to complete when SCC was used. This would have taken 2.5 years for completion with the use of Normal Concrete (NC).

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In another case when SCC was used in the construction of a 2large liquefied natural gas (LNG) tank belonging to Osaka Gas Company, it led to a reduction in the number of workmen from 150 to 50 (Ouchi &Hibino, 2000). These benefits of using SCC in the construction industry have proven how it can help maintain sustainable development, particularly in rural and urban areas worldwide. Reinforced concrete beams appear as common structural elements in many structures ranging from tall buildings to offshore gravity structures. They are used as load-transferring elements, such as transfer girders, pile caps, tanks, folded plates, and foundation walls. In buildings, a beam or transfer girder is used when a lower column is to be removed. Sometimes the full depth of the floor-to-floor height is used to transfer the high axial forces of columns above to the supporting columns below (Kong, 2003).

An integral part of providing safe and resilient structures for human settlement is the selection of construction materials that give a great deal of reliability in terms of structural performance and durability under all forms of external loads. Basically, concrete has low tensile strength and as such, reinforcement (conventionally steel) is used to supplement region of structural components (beams, columns and slabs) that \are subjected to high tensile stresses. Apart from steel, other synthetic and natural materials such as fibre glass and others have been found to be good for resisting tensile stresses. One other natural material which is readily available and easy to use is plantain bunch fibre.

Natural fibres exist in reasonably large quantities all over the world and natural vegetable fibres are produced in most developing countries. Ghana is one the developing countries which mostly depend on foreign building materials to put up houses, such types of materials are cement, roofing sheet, asbestos, steel and any other materials which exert pressure on the country’s foreign exchange and also require a high degree of labour force.

The main reasons for the use of natural fibres are that they are abundantly available and comparatively cheap. Natural fibre composites are also claimed to offer environmental advantages such as reduced dependence on non-renewable energy/materials sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery and end of life biodegradability of components (Joshi, 2003; Majeed, 2011; Hamzah *et al*., 2010 as cited Hassan, et.al, 2012).

Many studies had been carried out on natural fibres like kenaf, bamboo, jute, hemp, coir, sugar, palm and oil palm (Arib et. al. , 2006; Khairiah&Khairul, 2006; Lee et. al. , 2005; Rozman et al. 2003; Sastra et. al. , 2005).The reported advantages of these natural resources includes low weight, low cost, low density, high toughness, acceptable specific strength, enhanced energy recovery, recyclability and biodegradability (Lee et al. , 2005; Myrtha et al. , 2008; Sastra et al. , 2005 as cited in Ihueze,et.al, 2012).

Vegetable fibres such as plantain bunch fibre are produced in developing countries like Ghana demand low degree of industrialization for their processing. Plantains (Musa spp., AAB genome) are plants producing fruits that remain starchy at maturity (Marriot and Lancaster, 1983; Robinson, 1996) and need processing before consumption. Plantain production in Africa is estimated at more than 50% of worldwide production (FAO, 1990; Swennen, 1990 as cited in Ihueze, et.al, 2012).

However, plantain is grown extensively in many regions, most especially Brong Ahafo, Ashanti, Eastern, and Western, for the purposes of harvesting its food. Plantain bunch fibre will be obtained from the farmers, market women, and most especially local women at Brong Ahafo, Ashanti, Eastern, and Western regions that engage in preparation of plantain chips.

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Currently, Ghana is the second largest producer of plantain in the world and in 2012, it was estimated that over 3,556,524 metric tons of plantain was produced annually in Ghana (FAO, 2012).

Plantain bunch fibre are agricultural waste products obtained in the processing of plantain and are available in large quantities in the tropical regions of the world, most especially in Africa, Asia and America. Plantain bunch fibres are not commonly used in the construction industry but are often dumped as agricultural wastes.

However, with the quest for affordable housing system for both rural and urban population in developing countries, various schemes focusing on cutting down conventional building material costs have been put forward. One of the suggestions in the forefront has been the sourcing, development and use of alternative, non-conventional local construction materials including the possibility of using some agricultural wastes and residues as partial or full replacement of conventional construction materials. Olanipekun *et al*.,(2006) and Nor *et al*., (2010) reported that in countries where abundant agricultural wastes are discharged, these wastes can be used as potential material or replacement material in construction industry (as cited in Hassan, et.al, 2012). One such alternative is plantain bunch fibre produced in abundance has the potentials of serving as reinforcement in self compacting beam concrete.

The huge amount of plantain bunch fibrous wastes, which are produced in our homes and markets centres in the country is normally done in an uncontrolled manner and contributes significantly to atmospheric pollution. Thus, these residues are becoming expensive to dispose by satisfying the requirements of environmental regulations. In such a situation, efforts are ongoing to improve the use of these by-products' through the development of value-added products. One of the ways of disposing these wastes would be the utilization of plantain bunch fibre into constructive construction material.

Although there are several reports in the literature which discuss the physical and mechanical properties of natural fibre reinforced concrete very limited work has been done on the mechanical and physical properties of self compacting concrete beam reinforced with plantain bunch fibre. Against this background, the present research work was undertaken, with an objective to investigate into the properties of self compacting concrete beam reinforced with plantain bunch fibre. This will surely help to come out with the use of locally available materials to cut down cost and also help in solving the environmental problems related to the disposal of plantain fibrous wastes.

1.2 Statement of the Problem

The high cost of construction materials is a dominating factor affecting housing system around the world. In Ghana, the annual deficit in the building industry is about 200,000 housing units (Adom-Asamoah &Afrifa, 2011). Beside the shortfalls, most formal housing units are beyond the affordability level of majority of the population. However, the cost of the material use in the construction industry cannot be projected in recent times, due to the fact that they are expensive and it is not easy to afford them. However, with the quest for affordable housing system for both the rural and urban population in the developing countries, various schemes focusing on cutting down conventional building material costs have been put forward. One of the suggestions in the forefront has been the sourcing, development and use of alternative, non-conventional local construction materials including the possibility of using some agricultural wastes and residues as partial or full replacement of conventional construction materials. Olanipekun *et al.*, 2006 and

Nor *et al*., 2010 reported, in countries where abundant agricultural wastes are discharged, these wastes can be used as potential material or replacement material in construction industry (as cited in Hassan, et. al., 2012).

On the other hand, solid waste disposal has become one of the major problems in our towns, and cities. Due to the huge amount of plantain bunch fibre wastes which are produced in our homes and market places in the country is normally done in an uncontrolled manner and contributes significantly to atmospheric pollution. Thus, these residues are becoming expensive to dispose by satisfying the requirements of environmental regulations. In such a situation, efforts are going on to improve the use of these by-products' through the development of value-added products. One of the ways of disposing these wastes would be the utilization of plantain bunch fibre into useful building materials. By considering these requirements, here an attempt is made to study the possibilities of reusing the plantain bunch fibre materials as fibre composites in self compacting beam concrete. Plantain bunch fibre are agricultural waste products obtained in the processing of plantain and are available in large quantities in the tropical regions of the world, most especially in Africa, Asia and America. Natural fibre from plantain bunch fibres was chosen in terms of its abundance availability and is not commonly used in the construction industry but is often dumped as agricultural waste in Ghana. The benefit of using plantain bunch fibre as a construction material is in two folds; firstly, it will solve environmental problem of disposal and secondly, reduce the cost of building materials. The use of self compacting concrete in large scale construction projects can be deemed to be beneficial due to a significant reduction in the cost of labor. Though, there are several reports in the literature which discuss the physical and mechanical properties of natural fibres, like coconut, jute, bamboo and raffia reinforced concrete and that plantain bunch fibre have not yet been studied as reinforcement in concrete. Thus, investigation into the properties of self compacting beam concrete reinforced with plantain bunch fibre is appropriate.

1.3 Aim of the Study

The aim of the study is to examine the effect of plantain bunch fibre on the properties of self compacting concrete beam.

1.4 Specific Objectives of the Study

- To determine the density of self compacting beam concrete reinforced with plantain bunch fibre.
- To assess the strength properties of self compacting beam concrete reinforced with plantain bunch fibre.
- To determine the optimum fibre content that will produce the highest toughness.
- To propose models for predicting the density, compressive strength, splitting tensile strength and toughness of self compacting beam concrete reinforced with` plantain bunch fibre.

1.5 Research Questions

- What will be the effects on density of self compacting beam concrete reinforced with plantain bunch fibre?
- What are the strength properties of self compacting beam concrete reinforced with plantain bunch fibre?
- What percentage will determine the optimum fibre content that will produce the highest toughness?

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1.6 Significance of the Study

The study is to explore the potential of plantain bunch fibre as a reinforcing material in self compacting concrete beam and to promote the use of locally available raw materials in the construction industry in order to cut down cost and also help in solving the environmental problems related to the disposal of plantain fibrous wastes. It will also help to evaluate the mechanical and physical properties which are of prime importance to the construction industry.

1.7 Organization of the Thesis

This thesis is in six chapters. Chapter 1 introduces self compacting concrete beam as another form of concrete technology and of plantain bunch fibre as a partial replacement of steel in structural concrete production. It also presents the objectives of the study. Chapter 2 presents a review of the related literature on self compacting concrete beam. Self compacting concrete beam and plantain bunch fibre in normal concrete and rationalizes the relevance of using self compacting concrete beam and plantain bunch fibre in structural concrete production. Chapter 3 gives an overview of the research programme methods and procedure for experimental investigation and highlights on concrete mix design as per different constituent materials applied in the study. Chapter 4 presents results and discussions of self compacting concrete beam reinforced with plantain bunch fibre and produced in the study and examines the suitability of the existing code provisions for the design of self compacting concrete beam reinforced with plantain bunch fibre. Chapter 5 presents the summary of findings of the study. Finally, chapter 6 deals with conclusions for the study and proffers recommendations for future studies in the content area.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the structure of vegetable fibres and how that structure contributes to their mechanical and physical properties. It also explains how the structure in vegetable fibres can be affected by certain substances, and presents ways of reducing those effects through the use of fibre pre-treatments. In addition, the use of vegetable fibres in concrete is reviewed, as well as the testing of self compacting fibre-reinforced concret beam.

Furthermore, it is also committed to the relevant literature review on the views required to connect to the research objectives on investigation into the properties of self compacting beam concrete reinforced with plantain bunch fibre; and for the purpose of orderly presentation; the study reviewed related literature such as those which impinged on the research problem, definition and properties of self compacting beam concrete reinforced with plantain bunch fibre.

2.2 Plantain

Plantain is known as *Musa paradisiaca* as its botanical name and was discovered by Alexander the Great at about 327 B.C. during his world conquest when he came in contact with this fruit and introduced it into Europe. Plantain found its way into Madagascar from Malaysia and India through trading Asian merchants and by Arabs during the Trans-Saharan trade boom. Plantain and banana trade along with yam and other food crops became a very important factor in the wealth, prosperity and rapid expansion of the Bantu Kingdom of central and southern Africa around 1500 AD. Up till date, plantain is still a major and popular staple meal across Uganda and the rest of the former Bantu region. Today, plantain is popular and eaten boiled or baked or fried or mashed in many parts of the world today like Florida, Spain, Mexico, Portugal, Japan, Malaysia, Egypt, Nigeria, Ghana, Brazil, to mention but a few places. Several varieties of plantain are cultivated in West Africa most especially Ghana. These are classified as French Horn Plantain, False Horn Plantain, or the True Horn Plantain (Ahiekpor, 1996; Hemeng et. al., 1996). The local names of the sub varieties of French horn plantain include Apempa, Oniaba and Nyeretia apem. Those of the False horn are Borodewuo, Apantu pa, Borodesebo and Osoboaso while the True Horn sub varieties comprise Asamienu and Aowin.

The fruit is extremely low in fat, high in dietary fibre and starch. It is very low in cholesterol and salt too. It is a good source of vitamins A, B6, and C which helps maintain vision, good skin, and build immunity against diseases. It is also rich in potassium, magnesium and phosphate (Scot et al, 2006).

2.3 Concrete

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glues them together. It is used in many different structures such as dam, pavement, building frame or bridge. Concrete is the most widely used construction material in the world. Its production exceeds that of steel by a factor of 10 in tonnage and by more than a factor of 30 in volume (Mehta &Monteiro, 2001).

Concrete is extensively used because of advantages it has over steel; Concrete is the most inexpensive and the most readily available material. The cost of production of concrete is low compared with other engineered construction materials. It is easy to cast into different shapes,

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hardens in water and can withstand the action of water without serious deterioration. It has low heat generate and low energy consumption for production (Mehta &Monteiro, 2001).

Concrete has the ability to work with other materials, additives and enhancers and is industrial waste consumer. Besides these immense benefits concrete has disadvantages concerning engineering properties such as being brittle, low tensile strength, low toughness and internal cracks under service load. Most of the mentioned limitations can be controlled by the introduction of fibres (Mehta &Monteiro, 2001).

2.3.1. Reinforced Concrete Beams

Reinforced concrete beams are structural members having depth much greater than normal in relation to their span, while the thickness in the perpendicular direction is much smaller than either span or depth(Nilson& Darwin, 1997). These members are used in many structural applications such as diaphragms, water tanks, foundations, bunkers, shear walls, girders used in multistory buildings to provide column offsets, and floor slabs under horizontal loads (Nilson &Darwin, 1997;Russo, Venir &Pauletta, 2005). Usually, beams have narrow width and contain congested shear reinforcement. Therefore, the conventional concrete does not flow well when it travels to the web and does not completely fill the bottom part. This results in many problems in concrete such as, voids, segregation, weak bond with reinforcement bars and holes in its surface. Therefore, the self compacting concrete is very appropriate type for casting these members.

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2.3.2Mix Design of Self Compacting Concrete

Many design approaches have been formulated for the design of SCC. Notable among these approaches are Ozawaet al (1993), Sedran et. al (1996), Petersson et al (1996), Hwang et al. (1996) and Hon et al. (1996). These approaches have been successfully implemented in different projects and all follow the same process of optimizing the constituent materials of concrete to attain the desired fresh and mechanical properties. The basis of the design procedures reduces the coarse aggregates content in a natural mix concrete and replaces it with an equal measure of fine aggregates proportion. This results in an unusual higher fine aggregate proportion and a smaller coarse aggregate proportion. Okamura and Ozawa (1994) stated that two main methods exist for the achievement of the self-compatibility of SCC but advised the use of the second method although the two could be combined. The first being the addition of a viscosity agent and the second is limiting the coarse aggregate volume and increasing the water/powder ratio which enhances the viscosity of the paste and helps prevent segregation (Hsi-Wen, 1998).

2.3.3 Experimental Study on Self Compacting Concrete beams

In reviewing existing literature on the mechanical behavior of SCC structural members under load, data was gathered from various research works and comparisons made on the respective parameters that were considered and varied to ascertain their contribution to structural behavior. Some of the parameters included the maximum size of coarse aggregate, shear span-effective depth ratio (a/d), coarse-to-fine aggregate ratio, beam depth, compressive strength of concrete, coarse aggregate content and type, percentage of longitudinal reinforcement, shear reinforcement ratio and spacing (beams with stirrups), number and characteristics of cracks and loading arrangement.

2.3.4 Shear behavior of beams

The shear behavior of concrete beams has received great attention from many researchers over the years in an attempt to establish probable means of enhancing their shear performance (Ahmad & Shaha, 2009; Ashor & Yang, 2008; Foster &Gilbert, 1998; Bakir & Boduroglu 2002, Hwang et al. 2000, Leong & Tan 2003, Russo et al.2004). It has been established that inadequate shear design of beams may result in failure at loads far below their flexural capacities and such failures are usually sudden and unexpected (Londhe, 2007). In most design codes, the shear strength of beams with shear reinforcement is taken as the sum of the shear resistance of concrete and the contribution from shear reinforcement (Adom, Asamoah & Afrifa, 2013).Mosley et al., (1999) established that reinforced concrete beams without transverse reinforcement possess some amount of shear strength that resists shear stresses before diagonal tension cracks develop. They considered a simply supported beam with a uniformly distributed load across its span (Fig. 2.1). As the load is applied, the principal compressive stresses assume the form of an arch and tensile stresses a suspended cable. In the region of the mid -span where bending stresses are high and shear low, the stresses tend to move in a direction parallel to the beam axis. At the support region where the shear stresses are dominant, the principal stresses are inclined at a steep angle such that the tensile stresses tend to cause diagonal cracking. If the diagonal tension exceeds the tensile strength of the concrete, then shear reinforcement must be provided.

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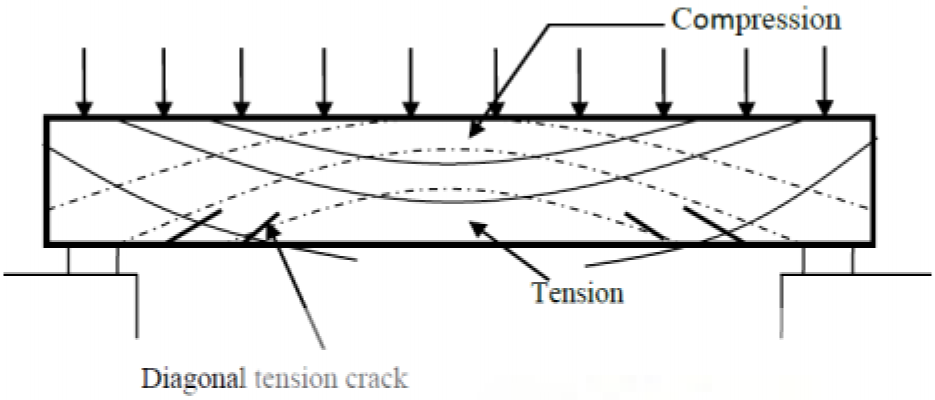

Figure 2.1: Principal stresses in a beam under bending (Mosley et al, 1999)

2.3.5 Development and General Characteristics of Self Compacting Concrete

Normal concrete is well-known for construction of concrete worldwide. However, in the construction of large structures where vibration of concrete to obtain a dense material with no voids is a requirement, the use of normal concrete becomes unfeasible due to the amount of vibration (labour) that would be done. In addition, in construction work where the reinforcements in the formwork are congested, it is difficult for coarse aggregates to occupy the required spaces in the formwork. Self compacting concrete, which does not require any vibration, can be used in such instances to save time, cost and ease of arrangement of coarse aggregates in the formwork. In 2000, the wall of a large liquefied natural gas (LNG) tank belonging to Osaka Gas Company in Japan adopted self compacting concrete in its construction. The concrete workers and construction time were reduced by 100 workers and 4 months, respectively. Self compacting concrete is prepared without the use of vibrators, thus achieves compaction under its own weight by flowing into place and also is cohesive enough to avoid segregation or bleeding. Hence, the important characteristics of self compacting concrete include its ability to fill formwork, pass through obstacles and resist segregation (Shi et al., 2015). The main constituents of self compacting concrete are cementitious material, water, aggregates (coarseand fine) and super plasticizer. The super plasticizer usually of high range water reducing agent is added to help obtain high flow ability. Also, mineral admixtures, in the form of supplementary cementitious materials (SCM), are added, in some cases, to improve segregation resistance which is vital to the defining property of self compacting concrete. Fly ash, metakaolin and silica fume as supplementary cementitious materials, have been adopted in self compacting concrete technology and metakaolin in particular was found to cause greater strength and durability of self compacting concrete (Hossain and Lachemi, 2009). The addition of mineral admixtures of the powder type as supplementary cementitious materials to self compacting concrete, causes an increase in slump flow of self compacting concrete and reduces the cost of concrete (Naik and Kumar 2001). Different SCM types (silica fume, metakaolin, Class F ash, Class C fly ash, and granulated blast furnace slag) in binary, ternary and quaternary cementitious blends were investigated for their permeability and results showed self compacting concrete with SCM had lower porous voids and absorbing water than self compacting concrete without SCM (Ahari et al., 2015).

The usage of mineral admixtures also helps improve the compressive strength of self compacting concrete. Limestone, silica fume and blast furnace slag were used as mineral admixtures and compared with ordinary self compacting concrete. The silica fume was found to improve the compressive strength by having the highest compressive strength than all other mixes (Abderahmane et al., 2013). In self compacting concrete, the proportion of coarse aggregates is decreased (minimizing coarse aggregates) and replaced with an increase in proportion of fine aggregates (maximizing fine aggregates). This is to allow adequate flow which is a basic requirement for self compacting concrete and also to avoid segregation (Lachemi et al., 2005).

2.3.6 Fresh Properties Tests of Self Compacting Concrete

Self compacting concrete in its fresh state is evaluated by various tests to determine the concrete's ability to conform to the defining characteristics that qualify it as self-compacting (Naik et al., 2001). The test methods help to judge self-compacting ability of concrete and also evaluate deformability. The fresh property tests developed to test for the major characteristics of self compacting concrete include slump flow test which measures the flow ability, T500 Slump Flow test that measures viscosity and L- Box test the passing ability (Hwang and Tran, 2015). In addition to the above mentioned tests, Thanh et al., (2015) conducted the sieve segregation test to measure the segregation resistance. The segregation resistance has also been measured by visual inspection during the slum flow test by Jalal et al., (2015).

2.3.7 Application of Self Compacting Concrete

Self-compacting concrete has gained acceptance through its wide application in various forms that concrete is used for structural components. The forms of concrete include pre stressed (Choulli et al., 2008), and fibre reinforced concrete (Sable and Rathi. 2012). Over the years, since its inception, self compacting concrete has gained the attention of researchers to regarding its general behaviour and response to general circumstances and environments is done with normal or conventional concrete. Investigations have provided confidence in the use of self compacting concrete in place of normal concrete to reap the added benefits of self compacting concrete. Existing knowledge is key to developing better understanding of innovative developments which stems from creations. Self compacting concrete is developed by modifying the already existing constituents of normal or conventional concrete to achieve its self–compacting nature with no vibration which differentiates self compacting concrete from normal concrete which is always vibrated. Therefore, first understanding the general behaviour of normal concrete

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becomes necessary and key to a better understanding of self compacting concrete although there is an expectance of differences due to the modification of the constituents of self compacting concrete. Normal concrete's constituent materials are modified to obtain self compacting concrete. For concrete to be classified as self compacting concrete, the major characteristic that differentiates it from normal concrete(NC) is the absence of vibration in self compacting concrete. Since vibration in NC is done to achieve compaction of concrete to remove air voids and obtain a densely-packed material, self compacting concrete achieves compaction on its own by having materials flowing into place under its own weight. The concrete mix is made flowable usually by having high water – cement ratio which causes disadvantages in concrete strength. Therefore, super plasticizers are added with lower water–cement ratio for flowable concrete with no added disadvantage of too much water. The coarse aggregate content is reduced in place of the fine aggregates which contribute to the flow by eliminating the restrictions to flow produced by coarse aggregates. From self compacting concrete Guidelines (EFNARC, 2005), the fine aggregate content is made up of 48–55 % of the total aggregate weight. An increased content of paste and decreased coarse aggregate are therefore modifications to the normal concrete constituents to aid in the mix design of self compacting concrete.

2.4 Fibres

According to terminology adopted by American Concrete Institute (ACI) Committee 544, there are four categories of Fibre Reinforced Concrete namely 1) SFRC (Steel Fibre Reinforced Concrete), 2) GFRC (Glass Fibre Reinforced concrete), 3) SNFRC (Synthetic Fibre Reinforced Concrete) and 4) NFRC (Natural Fibre Reinforced Concrete). It also provides the information about various mechanical properties and design applications. Cement and Concrete Institute also published the classification of FRC in their website. Based on their classification, Fibres are

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classified into Glass, Steel, Synthetic (includes Acrylic, Aramid, Carbon, Nylon, Polyester, Polyethylene, Polypropylene) and Natural Fibres (Sivaraja, 2010).

2.4.1 Fibre Classification

Naaman (2003) reported that fibre reinforcement has been grouped into three main divisions considering its characteristics: fibre material (natural organic - cellulose, sisal, jute, bamboo, raffia, etc; natural mineral – asbestos, and rock-wool; and man-made – steel, titanium, glass, polymers or synthetic); physical/chemical properties (density, surface roughness, chemical stability, non-reactivity with the cement matrix, fire resistance or flammability); Mechanical properties (tensile strength, elastic modulus, stiffness, ductility, elongation to failure, and surface adhesion property Jansson, (2008).

2.4.2 Uses of Fibres in Concrete

For the effective use of fibres in hardened concrete:

- Fibres should be significantly stiffer than the matrix, i.e. have a higher modulus of elasticity than the matrix.
- Fibre content by volume must be adequate.
- There must be a good fibre-matrix bond.
- Fibre length must be sufficient.
- Fibres must have a high aspect ratio, i.e. they must be long relative to their diameter *(as cited by www.theconcreteinstitute.org.za).*

2.4.3 Concrete with Fibres

Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension. Due to that in early 1960's introduction of fibre reinforcement concrete started (Zollo, 1997 as cited in Sivaraja, 2010). Before that in 1500 BC, ancient Egyptians introduced animal hairs and straw to reinforce mud bricks and walls in building and straws were again used to strengthen sun-baked bricks of 'AqarQuf' hill of a height 57metres near Baghdad (Balaguruet. al., 1992as cited in Sivaraja, 2010).

2.4.4 Fibre Reinforced Self Compacting Concrete/Normal Concrete

The cracking characteristic of reinforced beams under loading is such that, in the early stages of loading of reinforced beams, fine vertical flexural cracks are first seen to form in the mid span of beams. As the load is increased, new flexural cracks are formed away from the mid span on both sides of the beam. Increasing the load is accompanied with flexural cracks formed at the previous stage away from the mid span. The cracks propagate diagonally into the loading zone while other diagonal cracks may form along the beam (Hassan et al., 2008; Hassan et al., 2010; Lachemi et al., 2005). For the cracking behaviour of self compacting concrete, it was found by Castel et al., (2010) to be the same for self compacting concrete and normal concrete both in ultimate and in service state at high loading and low loading values. Tension reinforcement is provided to arrest the extension of cracks in concrete beams under loading and fibre is added as tension reinforcement. Fibre is varied in proportion by weight of cement or percentage volume fraction to obtain optimum proportion at which the fibre reinforcement becomes beneficial to the self compacting concrete beams by reducing the crack openings. Artificial fibres such as steel, glass and polypropylene fibres and natural fibres such as sisal, jute, coconut palm and sugarcane have been used in various research works to investigate their benefit to concrete. In some instances, artificial and natural fibre are combined to form hybrid fibre reinforcement to investigate their effect on the performance of concrete and/or mortar (Dawood and Ramli, 2011).

2.4.5 Cracking and Fibre Reinforcement of Concrete

The differences and similarities in the cracking behaviour of self compacting concrete and normal concrete observed in previous researches where self compacting concrete beams were compared to normal concrete beams have been noted as follows. In these researches the beams made had similar characteristics such as the beam configuration and longitudinal steel reinforcement ratios and stirrups (where shear reinforcements were used). However, in spite of the similarities in the crack width of self compacting concrete and normal concrete there were differences observed in the load carrying capacity and ductility of self compacting concrete and normal concrete beams. The crack width was the same for self compacting concrete and normal concrete for the research work done by Hassan et al., (2008), Hassan et al., (2010), Biolzi et al., (2014), and Harkouss and Hamad, (2014). The number of cracks in normal concrete were more than in self compacting concrete for Hassan et al., (2008) and (Hassan, et al., 2010), this improved the shear resistance in normal concrete beams than in self compacting concrete beams. The increase in number of cracks here was due to the increase in coarse aggregate content. In other works by Abouhussien et al., (2014) and Sonebi et al., (2003), the number of cracks was more in the self compacting concrete than in the normal concrete. This slightly improved the shear strength of self compacting concrete than normal concrete with the increase in number of cracks of the self compacting concrete.

In addition to improving the cracking behaviour (crack width, number, length and spacing) of fibre-reinforced concrete, there is an added benefit of improving deflection, stiffness

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and ultimate load. From observations made by previous research the following conclusions are noted. For crack width, the crack width is reduced as the fibre prevents further crack propagation in self compacting concrete beams reinforced with fibre compared to ordinary self compacting beams as was observed by Shah and Modhera,(2010) and Fritih, et al., (2013). For crack spacing, with addition of steel fibre reinforcement, spacing between cracks are reduced such that closely spaced cracks were observed in steel fibre reinforced normal concrete and self compacting concrete beams as compared to ordinary normal concrete and self compacting concrete beams from Furlan et al.,(1997) and Fritih et al.,(2013). With the smaller crack spacing in fibre reinforced self compacting concrete beams in Fritih et al., (2013) denser crack network was also observed as stress transfer was improved through cracks and more cracks are developed hence the denser network. Shah et al. (2010) observed the same scenario of increase in number of cracks with the addition of steel fibre reinforcement at smaller crack width than fewer cracks with wider crack width.

The ductility of self compacting concrete beams with fibre reinforcement is found to be improved from experimental research by Bhalchandra and Bajirao (2012) and Shah et al. (2010). According to Shah et al. (2010) the improvement in the ductility was observed as fibre reinforced self compacting concrete beams compared to ordinary self compacting concrete beams sustained larger deflections due to the improved cracking behaviour with the reduced crack width and delay in the formation of flexural cracks at 60 % to 80% of ultimate loads. Contrary to the benefit to ductility observed by Bhalchandra and Bajirao (2012) and Shah et. al. (2010). Fritih et al. (2013) found that the ductility and load carrying capacity of fibre reinforced self compacting concrete and ordinary self compacting concrete beams were similar as fibre reinforcement did not have consequential effect on these properties. This was because fibres preventing crack widening and increasing stress transfer through crack and tension stiffening increases the number of cracks which offsets the increase in stiffness

2.4.6 Mix Design of Fibre Reinforced Concrete

Mix design is the process of determining the relative quantities of the ingredients of concrete taking into accounts the availability of materials and their cost, requirements of placing and finishing the fresh concrete, and properties of the hardened concrete (Neville, 1981; Troxell, et.al., 1968; Schrader, 1978 as cited by Bantie, 2010).

The mix design of FRC materials is quite similar to that of the conventional concrete except the inclusion of reinforcing fibres-the relative amount of which is governed by workability of the fresh concrete and the properties of the hardened concrete (Kuder et. al., 2007; ASTM E2002). The economic aspect of concrete mix in construction depends primarily on the cost of material other than on cost of labour and related factors as the latter two, although take larger part of the total cost, do not make differences between different concretes. Hence, concrete mix design aims at compromising between the costs of materials associated with the amount needed in the desired mix and the production of appropriate workability so as to keep placement and finishing costs at a minimum while securing quality in the finished product (Neville, 1981; Kuder et. al., 2007 as cited in Bantie, 2010).

In practice, proportions of cement, fine aggregate and coarse aggregate are expressed in terms of parts or ratios with cement as a reference-usually taken as unity. The content of water, fibre and other entrained air or admixtures is expressed in terms of water-cement ratio, fibre-matrix ratio and percentage ratio respectively. In any case, the basis of proportioning should be stated along with the parts or ratios: may be either by weight or by volume (absolute or bulk) (Holister and Thomas, 1966; Neville, 1981).

In ordinary concrete mix, it is reasonable to assume that concrete consists essentially of inert mineral aggregate and cement-water paste which is the active ingredient controlling workability, strength, permeability and drying shrinkage (Neville, 1981; Troxell, et. al., 1968; Schrader, 1978). However, this assumption is not always valid in FRC, as the content and anatomy of the fibre component would significantly affect properties of fresh and hardened concrete (Mark et. al., 1986; Soroushian and Marikunte, 1992as cited in Bantie, 2010).

Different methods of mix design of concrete have been investigated so far (Troxell, et.al, 1968): arbitrary proportions, proportioning by maximum density of aggregate, proportioning by surface area of aggregate, proportioning by fineness modulus of aggregate, proportioning by void content ratio and mortar voids, and proportioning by void contents of coarse aggregate. There are no separate methods of proportioning devised for the mix design of FRC. Instead, the relative amount of cement, aggregate and water is determined based on the usual methods of proportioning, then follows the determination of the fibre content based on the required workability and strength of the FRC. Many investigations (Holister and Thomas, 1966; Chatveera and Nimityongskul, 1992; Al-Feel and Al-Layla, 1992; and Kuder et. al., 2007) have been undertaken to determine the relative amount of fibre and the fibre aspect ratio to be added in FRC that would result a sound workability and desired properties of hardened concrete as cited in Bantie, (2010).

The amount of fibre to be added in a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibres) termed volume fraction (Vf), and the aspect ratio (l/d) is calculated by dividing fibre length (l) by its diameter (d). If the fibre in question has non-circular cross section, an equivalent diameter can be used to calculate aspect ratio. Generally, the fibre content and aspect ratio of the additive fibre should be lower in order to have a good workability Holister and Thomas, 1966; Kuder et. al., 2007 as cited in Bantie, (2010).

2.4.7 Fibre-Reinforced Concrete

Fibre Reinforced-Concrete (FRC) is one of the composite materials containing short discrete fibrous material uniformly distributed and randomly oriented, which increases its structural integrity. The concept of FRC technology dates back to the era of civilization. People used to employ mud reinforced with straw to construct houses, churches, mosques, utensils etc (Mark et. al, 1986). The recent trends in the technology of reinforcing concrete with fibres have been aiming at the improvement of physical properties, mechanical properties and to optimize cost of concrete production as (Mark et. al, 1986as cited in Bantie, 2010).

The first published papers studying the effects of fibre reinforcement in concrete date back to the early 1960's, when it was conceived that the strength of concrete would increase with the inclusion of small, closely spaced, fibres (Romualdi and Batson, 1963). Much of the fibre-reinforced concrete research has focused on the use of man-made or synthetic fibres, including steel, glass, and polymers, and their ability to prevent and control cracking in concrete systems. Synthetic fibres are manufactured and nonrenewable; however, the inclusion of vegetable fibres creates a market for naturally grown and renewable fibre reinforcement. The first naturally occurring fibre to be tested and widely used as reinforcement in concrete was the asbestos fibre, which later proved to be hazardous. In fact, the search for a suitable replacement has brought about the interest in studying natural fibres as reinforcement in cement composites (Castro and Naaman, 1981(as cited inYaremko, 2012).

2.4.8 Fibre-Reinforced Concrete Performance

Since fibre reinforcement is used to control cracking in a cement matrix, the performance of fibre-reinforced concrete is dependent on how well the cracks in the cement matrix are controlled. The performance of FRC system must therefore be partly attributed to the strength of the fibre-cement bond and type of fibre-cement failure mechanism. The two most common failure mechanisms in FRC are rupture and pull-out. Rupture involves the fibre breaking once a crack in the matrix is formed; whereas pullout involves the fibre continually bridging the crack as it grows (as cited in Yaremko, 2012).

The type of bond and failure in FRC system should then be considered before determining the appropriate type, size, and volume fraction of fibres. One study compared the performance of flax, polypropylene and glass fibres for reinforcing concrete, at varying sizes and volume fractions (Wang, 2003). This study has shown that each unique combination of type, size, and volume fraction of fibres, for the same cement mix, produces a unique bond and failure characteristic in the reinforced concrete (as cited in Yaremko, 2012).

2.5 ArtificialFibres in Concrete

An artificial fibre is a tread-like material invented by human researchers. Such fibres do not exist naturally. Some examples of artificial fibre include;

2.5.1 Steel Fibre in Concrete

Mechanical properties of high strength fibre reinforced concrete were studied by Wafa and Ashour (1992). A total of 504 test specimens were tested for different mechanical properties such as compressive strength, split tensile strength, flexural toughness and modulus of rupture. The mix was designed to achieve compressive strength of 94 N/mm^2. Three volume fractions of steel fibres such as 0.5%, 1.0% and 1.5% were selected. It was concluded that no real workability problem was encountered up to the addition of 1.5% volume fraction of fibres in concrete. Steel fibres enhanced the ductility and post cracking load carrying capacity of high strength concrete.

4.6%, 67%, 159.8% increase in compressive strength, modulus of rupture and split tensile strength were achieved by introducing hooked steel fibres as reinforcement in high strength concrete (as cited in Sivaraja 2010).

2.5.2 Hybrid Fibre in Concrete

Yao et. al (2003) examined the mechanical behaviour of hybrid fibre reinforced concrete at low fibre volume fraction. Three hybrid composites such as polypropylene and carbon, carbon and steel and steel and polypropylene fibres were chosen and the mechanical strength properties such as Compressive strength, split tensile strength, modulus of rupture and flexural toughness were ascertained. A statistical response surface method and three level full factorial experimental designs were used to study the effects of volume fraction and aspect ratio of fibre on fractional energy, compressive strength, splitting tensile strength, flexural strength and characteristic length of steel fibre reinforced concrete. When the mechanical properties alone considered, the optimal values of design variables such as 0.64% for volume fraction and 76.44 for aspect ratio were obtained. If both mechanical properties and cost optimization were considered, volume fraction of 0.558% and aspect ratio of 75.87 were obtained (as cited in Sivaraja, 2010).

2.5.3 Plastic Fibre in Concrete

Prahallada and Prakash (2013) studied on the effect of different aspect ratio of waste plastic fibres on the properties of fibre reinforced concrete and made some observations that an aspect ratio of 50 was a good aspect ratio from the workability point of view. Therefore, higher workability could be achieved for the aspect ratio of 50. This may be due to the fact that beyond an aspect ratio of 50, the waste plastic fibres may obstruct the flow with inconvenience of

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interlocking with the aggregates. Thus it can be concluded that aspect ratio 50 is a good aspect ratio for the production of waste plastic fibre reinforced concrete and it yield good workability to waste plastic fibre reinforced concrete. It was observed from the literature that the steel fibre reinforced concrete with an aspect ratio of 55 and percentage of steel fibre 0.5% results in 8%, 20% and 10% increase in the compressive strength, tensile strength and flexural strength as compared to 11%, 13% and 10% increase in the compressive strength, tensile strength and flexural strength for waste plastic fibre reinforced concrete respectively. Thus, waste plastic fibre reinforced concrete can be compared with that of steel fibre reinforced concrete. The study concluded that an aspect ratio of 50 is a good aspect ratio for the production of waste plastic fibre reinforced concrete and it yields maximum strength characteristics and good workability.

2.5.4 Comparison of Artificial Fibres

The mechanical properties of some artificial fibres commonly used for the purpose of reinforcement are stated in Table 2.1

Table 2.1: Comparison of Artificial Fibres (types and properties)

Fibre Type	Diameter, .001 in	Specific Gravity	E, ksi x 1000	Tensile Strength, ksi	Strain at Failure, %
Steel					
High Tensile	4-40	7.8	29	50-250	3.5
Stainless	.4-13	7.8	23.2	300	3
Glass	.4-.5	2.5-2.7	10.44-11.6	360-500	3.6-4.8
Polymeric					
Polypropylene	20-160	0.9	0.5	80-110	8
Polyethylene	1-40	0.96	0.725-25	29-435	3-80
Polyester	0.4-3	1.38	1.45-2.5	80-170	10-50
Amarid	0.4-.47	1.44	9-17	525	2.5-3.6
Asbestos	0.008-1.2	2.6-3.4	23.8-28.4	29-500	2-3
Carbon	0.3-.35	1.9	33.4-55.1	260-380	0.5-1.5

Source: PCA, 1991

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2.6 Vegetable Fibre

The rise in scientific research related to vegetable fibre is mainly attributed to two main factors. The first factor is the large amounts of naturally occurring vegetable fibre around the world which goes unused once vegetation is harvested. The second factor is the increasing knowledge of how well vegetable fibres perform when loaded in tension. An engineering material like vegetable fibre, which is economically feasible and can perform well in engineered applications, is of great interest and importance to design engineers.

2.6.1 Vegetable Fibre Structure

There are several types of vegetable fibres found in nature; these include sisal, jute, coconut, flax, wood and bamboo. The structure of these fibres is similar to the structure of the plantain bunch. The plantain bunch is made up of fibres of varying diameters and lengths.

Vegetable fibres contain three main components: lignin, hemi-cellulose and cellulose, all of which contribute to the structure of the fibre. All vegetable fibre is made up of these three components, in varied amounts. The cellulose component consists of long chains of glucose molecular units, extended along the length of the elementary fibre, while the hemi-cellulose and lignin act as binders to keep the fibre together (Gram, 1988). The mechanical properties of the fibre are governed by how the cellulose is oriented in the fibre and how much hemi-cellulose and lignin is present (Bos et. al., 1999, as cited inYaremko, 2012).

2.6.2 Vegetable Fibre Mechanics

Natural fibres derived from vegetation tend to exhibit high tensile strengths and relatively high stiffness, due to the orientation and bond strength between their main components. Table 2.2 shows the varying properties found in some vegetable fibres (Yaremko, 2012).

Table2.2: Selected Vegetable Fibre Types and Properties (Yaremko, 2012)

Fibre Type	Diameter (μm)	Density (10^3kg/m^3)	Young's Modulus (GPa)	Tensile Strength (MPa)	Strain at Failure (%)
Wood cellulose	20-120	1.5	10-40	300-900	-
Sisal	<200	0.75-1.05	13-26	280-565	3-5
Coir (coconut)	100-400	1.12-1.15	19-26	120-200	10-25
Bamboo	50-400	1.5	33-40	350-500	-
Jute	100-200	1.02-1.04	26-32	250-300	1.5-1.9

Source: PCA, 1991

The mechanical properties of vegetable fibres are thought to be influenced by how the plant is grown and harvested. The conditions of the ground and the climate may affect the orientation and amounts of each main fibre component. There are also several processes for extracting fibres from the plants, which involve exposing the plants to water or chemicals. Each process affects the components of the fibre which are later extracted from the plants (Olubayo, 2010, as cited inYaremko, 2012).

2.6.3 Vegetable Fibre Treatment

Vegetable fibres have the unique ability to absorb moisture from the surrounding atmosphere and retain water that they come into contact with. A fibre's abilities to both absorb and retain water are a function of how much hemi-cellulose and lignin are present in the fibre. One study found that hemp fibre had greater moisture absorption as the hemi-cellulose was reduced

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and less moisture absorption as lignin was reduced (Pejic et. al., 2007). Conversely, the hemp fibre retained less water as the hemi-cellulose was reduced and retained more water as the lignin was reduced.

Current research on vegetable fibres is focused on pre-treatments. These treatments manipulate the fibres' abilities to absorb and retain moisture, since those abilities promote the degradation of the fibres. Most of the vegetable fibre research is in the area of polymer-based composites, where small amounts of absorbed moisture into fibres can be detrimental to the composite's performance (as cited inYaremko, 2012).

The treatments used on vegetable fibres make use of various chemical and physical conditioning scenarios. All treatments aim to alter the main components of the fibre, in order to decrease its ability to absorb moisture, and improve the chemical bond between the vegetable fibres and the surrounding polymer matrix. Most of the treatments used on the vegetable fibre achieve a reduction in moisture absorption and create the desired bond characteristics by removing the hemi-cellulose and lignin components from the fibre. Unfortunately, the removal of any amount of these fibre components will result in reducing the fibre's tensile capacity. Invariably, most vegetable fibre treatments are damaging to the fibre's mechanical components, but help increase their resistance to degradation over time (Olubayo, 2010as cited inYaremko, 2012).

The mechanical properties of vegetable fibre are diminished when exposed to an alkaline solution. If fibres are able to stay relatively unsaturated, then they are not capable of losing any of their main components, and their mechanical properties will stay intact. Treated vegetable fibre has been successfully used in polymer-based composites, simply because the fibres are not embedded in a saturated matrix environment. However, the matrix environment of a cement-based

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composite like concrete may be saturated with pore water for most of its life span (as cited inYaremko, 2012).

A study conducted by Chimekwene, et.al.(2012),on the mechanical properties of plantain empty fruit bunch fibre reinforced composite. They concluded that, the effect of fibre treatment or chemical modification of fibre has been studied using a combined treatment of silane and Alkali treatment also examined was the effect of different fibre orientation as well as fibre loadings on the strength of the overall composite. From the study, they observed that Silane and Alkali treatment on plantain empty fruit bunch fibre lead to a higher tensile strength than that of untreated fibres. Also, from the results of the mechanical tests carried out on the samples, it was observed that fibre surface modifications of plantain empty fruit bunch fibre has achieved some degree of success in making a superior interface and mechanical properties.

2.6.4 Bonding between Vegetable Fibre and Cement Paste

The research pertaining to vegetable fibre bond in cement paste focuses on how the bonds are formed, maintained over time, and changed with respect to environmental conditions. An extensive early study on VFRC concluded that there are four variables which govern the bond between fibres and cement paste: water/cement ratio, porosity, fibre morphology, and compaction (Coutts, 1987b). This study states that these four variables determine the amount of cement particles present in the pore water, which come into contact with the fibres. This study also states that the bonding of cellulose fibres with cement paste is created both chemically and mechanically. The ingress of cement or hydration particles into the vegetable fibre, by way of the pore water, is referred to as mineralization. This ingress of pore water has been found to decrease the amount of hemi-cellulose and lignin components in the fibre (Bilba et. al., 2003). Various studies have reported that the mineralization of vegetable fibres like sisal, kraft, coconut, and eucalyptus, cause the fibre to create a stronger bond with the surrounding cement paste (Bentur and Akers, 1989; Silva et. al., 2009; Mohr et al. 2005; Rodrigues et. al., 2006; Savastano Jr. et. al., 2002 and 2009; Soroushian et. al., 1994 and 1996; Filho et. al., 2000; Tonoli et. al., 2010b and 2010c). These same studies also report that the ingress of cement particles causes the fibres to become stiff and brittle over time, lowering their mechanical performance and durability (as cited inYaremko, 2012).

An extensive study on sisal and coconut fibre-reinforced cement-based composites looked at the interface between the fibre and cement matrix, also referred to as the transition zone (Savastano Jr. and Agopyan, 1999). It was observed that an increase in water-cement ratio caused an increase in the transition zone thickness and that there was a higher porosity in the cement matrix near the transition zone. This creation of porosity in the transition zone resulted in an insufficient fibre-cement bond. Some relationships between the transition zone characteristics and the overall properties of composites were also explored. When the concrete was mixed, fibres collected a large amount of the mix water and increased the size of the transition zones. Since the fibre degradation increased with the age of the specimens, the transition zones became weak points in the composite. In a related study investigating palm fibre-reinforced concrete, voids were found to have formed in the transition zone between the fibre and the cement matrix, when subjected to hot-dry curing conditions (Kriker et. al., 2005).

A few studies have concluded that the reduction in flexural toughness of a vegetable fibre-reinforced cement-based composite over time is due an increase in the fibre-matrix bond through mineralization, which causes the fibre to become brittle and fail in rupture (Kim et. al., 1999; Filho et. al., 2000, as cited inYaremko, 2012).

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2.6.5 Vegetable Fibre-Reinforced Concrete Performance

Vegetable fibre-reinforced cement-based composites (VFRC) area fairly new technology, and have seen an increase in research attention within the past three decades. The types of vegetable fibres that have been studied in VFRC include bamboo, cellulose, coconut, cotton, eucalyptus, flax, hemp, kraft, palm, and sisal. Many of these studies focused on measuring the mechanical properties of the VRFC in comparison to synthetic fibre-reinforced cement-based composites (SFRC) or unreinforced cement based composites, while making variations in fibre volume fraction, fibre lengths, cementitious materials, mixing procedures, and weather scenarios(as cited inYaremko, 2012). Another study has found that the inclusion of cellulose fibre as reinforcement in a cement-based composite created higher early strength than unreinforced composites (Soroushian & Ravanbakhsh, 1999).

Flexural toughness of concrete reinforced with flax fibre in amounts ranging from 0.1-0.5% by volume fraction was significant and comparable to that obtained with glass fibre (Wang, 2003). Flexural toughness was increased when concrete was reinforced with hemp fibre in the range of 0.18% to 0.84% by weight (Li et. al., 2004b). A recent study showed that larger flexural strength and toughness were gained in concrete reinforced with hemp fibre, in amounts ranging from0.18%-1.06% by weight, when fibres were saturated before mixing, as compared to fibres mixed in a dry state. (Li et.al., 2006). One study followed the performance of concrete reinforced with palm fibre at 0.6% and 0.8% by volume fraction, and found that over time the flexural toughness slightly decreased due to the ongoing reaction between the fibre and the alkaline pore water (Abdul, Razak, and Ferdiansyah, 2005, as cited inYaremko, 2012).

2.7Natural Fibres in Concrete

There are three types of natural fibre which are found in various forms on earth: animal, mineral and vegetable. Natural fibres have been used throughout history for one purpose or another, mainly because of their ability to be easily manipulated for use in different applications.

2.7.1 Advantages of Natural Fibres over Artificial Fibres

Though some artificial fibres are used more in the construction and building industry, vegetable fibres have also been tested and proven much better than artificial fibres. Table 2.3 shows the advantages of natural fibres over artificial fibres.

Table 2.3: Advantages of Natural Fibre over Artificial Fibre

Natural	Artificial
Abundantly available and are comparatively	prone to creep
Cheaper or cost effective material	It is expensive
Lower pollutant emissions	Higher pollutant emission
Lower greenhouse gas emissions	Increase country's foreign exchange
Enhanced energy recovery	Higher energy consumption
Low density with a high specific modulus	Weak in compression
High toughness	Corrosion effects
Acceptable specific strength	high cost of building component
Reduced dependence on non-renewable energy/materials sources.	
Recyclability, non-carcinogenic and bio-degradable nature	
Sisal has high tear resistance	
Fibres are soft and non-abrasive	
Reduce stress to the environment	

Sources: Jansson (2008); Sivaraja (2010);Verma et.al, (2013); FAO of the UN (2012).

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2.7.2 Coir and Sisal Fibre in Concrete

Ramakrishna et.al.(2002) as reported in Sivaraja, (2010) compared the theoretical and experimental investigations on the compressive strength and elastic modulus of coir and sisal fibre reinforced concretes for various volume fractions. It was observed that both the experimental and analytical values of elastic modulus had shown 15% discrepancy, which can be regarded as comparatively small.

Rheological properties of coir fibre reinforced cement mortar were carried out by Ramakrishna and Sundararajan (2002). Flow value, cohesion and angle of internal friction were determined for three different mix ratios and four different aspect ratios and fibre contents. Based on the rheological properties of fresh mortar, it was recommended to use shorter fibres with low fibre-content for achieving workability and higher fibre content for better cohesiveness in wet state (as cited in Sivaraja, 2010).

2.7.3 Date Palm Fibre in Concrete

Mechanical properties of date palm fibres and concrete reinforced with date palm fibres were tested and reported by Krikeret. al.al, (2005) in two different climates. In addition to the above properties, continuity index, microstructure and toughness were also studied. The volume fraction and length of fibres chosen were 2-3% and 15-60mm respectively. It was concluded that male date palm fibre possessed more tensile strength. Also it was stated that observing micro-structure of the fibre-matrix interface, cured in hot-dry and water environments. Based on the results and observations of that work, it was suggested that future research should be developed on the treatment of Male date palm surface fibre concretes to improve their mechanical properties using local industrial wastes, especially hot-dry climate.

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2.7.4 Palm Tree Fibre in Concrete

Mechanical characterization and impact behaviour of concrete reinforced with natural fibres were studied by Al-Oraimi and Seibi (1995). Experimentally they used glass and palm tree fibres on high strength concrete. Mechanical strength properties such as compressive, split tensile, flexural strengths and post cracking toughness were observed. It was concluded that natural fibres are comparable with glass fibres. A finite element analysis was also done using ANSYS software. Both analytical and experimental results were compared and found acceptable (as cited in Sivaraja, 2010).

2.7.5 Coir, Sisal, Jute and Hibiscus Fibre in Concrete

The capability to absorb energy, called toughness is important in actual service conditions. For that an experimental investigation was carried out by Ramakrishna and Sundararajan (2005) on impact strength of a few natural fibre reinforced cement mortar slabs .Four types of natural fibres such as coir, sisal, jute and hibiscus cannebinus with four different fibre contents such as 0.5%, 1.0%, 1.5% and 2.0% by weight of cement were used. The tests were carried using repeated projectile test apparatus and the performance of specimens was ascertained based on the parameters namely impact resistance, residual impact ratio, crack resistance ratio and the condition of fibre at ultimate. From this elaborative test results, it was concluded that coir fibres absorb more energy i.e. 253.5 J at 2% fibre content and fibre length of 40 mm. Coir fibre reinforced slab specimens exhibit fibre pull out failure, whereas all other types of fibre reinforced specimens exhibit fibre fracture at ultimate failure (as cited in Sivaraja, 2010).

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2.7.7 Review on Natural Fibres as a Reinforcing Material in Concrete.

Natural fibres are prospective reinforcing materials and their use until now has been more traditional than technical. They have long served many useful purposes but the application of materials technology for the utilization of natural fibres as the reinforcement in concrete has only taken place in comparatively recent years. The distinctive properties of natural fibre reinforced concretes are improved tensile and bending strength, greater ductility, and greater resistance to cracking and hence improved impact strength and toughness. Besides its ability to sustain loads, natural fibre reinforced concrete is also required to be durable.

Mechanical characterization and impact behaviour of concrete reinforced with natural fibres were studied by Al-Oraimi and Seibi (1995). Here an experimental study was conducted using glass and palm tree fibres on high strength concrete. Mechanical strength properties such as compressive, split tensile, flexural strengths and post cracking toughness were studied. It was concluded that natural fibres are comparable with glass fibres. A finite element analysis was also done using ANSYS software. Both the analytical and experimental results were compared and acceptable.

The mechanical properties of a natural fibre-reinforced composite depend on many parameters, such as fibre strength, modulus, fibre length and orientation, in addition to the fibre-matrix interfacial bond strength. A strong fibre-matrix interface bond is critical for high mechanical properties of composites. A good interfacial bond is required for effective stress transfer from the matrix to the fibre whereby maximum utilization of the fibre strength in the composite is achieved (Karnani, Krishnan, & Narayan 1997). In addition, factors like processing conditions/techniques have significant influence on the mechanical properties of fibre reinforced composites (George, Sreekala, & Thomas, 2001).

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Mechanical properties of natural fibres, especially flax, hemp, jute and sisal, are very good and may compete with glass fibre in specific strength and modulus (Van de Velde and Kiekens, 2002; Frederick & Norman, 2004). Mansur and Aziz (1983) studied bamboo-mesh reinforced cement composites, and found that this reinforcing material could enhance the ductility and toughness of the cement matrix, and increase significantly its tensile, flexural, and impact strengths.

On the other hand, jute fabric-reinforced polyester composites were tested for the evaluation of mechanical properties and compared with wood composite by Gowda, Naidu, and Chhaya (1999), and found that the jute fibre composite has better strengths than wood composites. A pulp fibre reinforced thermoplastic composite was investigated by Lundquist, Marque, Hagstrand, Leterrier, and Månson (2003), and found to have a combination of stiffness increased by a factor of 5.2 and strength increased by a factor of 2.3 relative to the virgin polymer. Information on the usage of banana fibres in reinforcing polymers is limited in the literature.

In dynamic mechanical analysis, Laly. (2003) have investigated banana fibre reinforced polyester composites and found that the optimum content of banana fibre is 40%. In addition, short banana fibre reinforced polyester composite was studied by Pothanet.al (1997); the study concentrated on the effect of fibre length and fibre content. The maximum tensile strength was observed at 30 mm fibre length while maximum impact strength was observed at 40 mm fibre length. Incorporation of 40% untreated fibres provides a 20% increase in the tensile strength and a 34% increase in impact strength. Luo and Netravali (1999) studied the tensile and flexural properties of the green composites with different pineapple fibre content and compared with the virgin resin. Sisal fibre is fairly coarse and inflexible. It has good strength, durability, ability to stretch, affinity for certain dyestuffs and resistance to deterioration in seawater. Sisal ropes and twines are widely used for marine, agricultural, shipping, and general industrial use.

Casaurang, Herrera, Gonzalez, and Aguilar (1991) carried out a systematic study on the properties of henequen fibre and pointed out that these fibres have mechanical properties suitable for reinforcing thermoplastic resins. Fuadet.al (1998) investigated the new type wood based filler derived from oil palm wood flour (OPWF) for bio-based thermoplastics composites by thermo gravimetric analysis and the results were very promising.

Schneider et.al (1996) developed composites using jute and kenaf fibre and polypropylene resins and they reported that jute fibre provides better mechanical properties than kenaf fibre. Sreekala et.al (2000) performed one of the pioneering studies on the mechanical performance of treated oil palm fibre-reinforced composites. They studied the tensile stress-stain behavior of composites having 40% by weight fibre loading. Isocyananate-, salane-, acrylated, latex coated and peroxide-treated composite withstood tensile stress to higher strain level. Isocyanate treated, salane treated, acrylated, acetylated and latex coated composites showed yielding and high extensibility. Tensile modulus of the composites at 2% elongation showed slight enhancement upon mercerization and permanganate treatment. The elongation at break of the composites with chemically modified fibre was attributed to the changes in the chemical structure and bond ability of the fibre. Alkali treated (5%) sisal-polyester bio composite showed about 22% increase in tensile strength (Mishraet.al 2002).

Aulia (2002) in testing a number of aggregates and mixes with polypropylene fibres found that “the use of 0.2% volume polypropylene fibres alone resulted in the low influence on both the compressive strength and modulus of elasticity of concrete….”Essentially, there was no difference between the compressive strength with and without fibres. Soroushian et al. (1992) found an interesting trend. With the addition of more fibres, the compressive strength significantly decreased. The plain concrete had strength of about 6700 psi, while the average strength with fibres decreased with higher dosage rates to about 5200 psi at a 0.1% by volume dosage. It must be noted that when Soroushian et al.(1992) added fibres they also added a small amount of super plasticizer. Kao (2005) also found a slight decrease in compressive strength at 28 days. However, at 1 day, the strength of the fibre-reinforced concrete was usually equal to or higher than the plain concrete control. Ismail (2006) carried out a study on the mechanical properties of Roselle fibre-reinforced cement composites. It was concluded that the tensile strength of composite increases, (this increase in strength is about 53%); while the compressive strength decreases as the fibre volume fraction is increased.

Studied on the mechanical properties of plantain empty fruit bunch fibre reinforced composite. The study concluded that, the effect of fibre treatment or chemical modification of fibre has been studied using a combined treatment of salane and Alkali treatment also examined. From the study, they concluded that Salane and Alkali treatment on plantain empty fruit bunch fibre lead to a higher tensile strength than that of untreated fibres. Also, from the results of the mechanical tests carried out on the samples, it is quite evident that empty plantain fruit bunch has a very promising future and can be used as a substitute for artificial/glass fibres. Yalley and Kwan (2009) carried an experimental study on the use of coconut fibre as enhancement of concrete. The study concluded that the addition of coconut-fibres significantly improved many of the engineering properties of the concrete, notably torsion, toughness and tensile strength. The ability to resist cracking and spalling were also enhanced. However, the addition of fibres adversely affected the compressive strength. When coconut fibre was added to plain concrete, the torsional strength increased (by up to about 25%) as well as the energy-absorbing capacity, but there was an optimum weight fraction (0.5% by weight of cement) beyond which the torsional strength started to decrease again. Similar results were also obtained for different fibre aspect ratios, where again results showed there was an optimum aspect ratio (125). An increase in fibre weight fraction provided a consistent increase in ductility up to the optimum content (0.5%) with corresponding fibre aspect ratio of 125. Overall the study has demonstrated that addition of coconut fibre to concrete leads to improvement of concrete the toughness, torsion and the tensile stress.

Hasan et.al (2012) carried some experimental investigation on the use of coconut fibre in the production of structural lightweight concrete. It was concluded that the density of plain concrete was more than the fibre reinforced concrete. It was also observed that the density of concrete decreased with increase in the volume of coconut fibre in the conventional coarse aggregate. Conventional concrete specimens were fully crushed when their ultimate failure load was reached but the specimens in the case of 1% and 3% of coconut fibre by the total volume did not crush when their ultimate failure load was reached. Thus, coconut fibre reinforced concrete can enhance higher toughness. From these results, it is apparent that the usual fibre treatments reported so far did not significantly change the physical and mechanical performance of plantain bunch fibre composites.

Though, there are several reports in the literature which discuss the physical and mechanical behavior of natural fibre reinforced composites. However, very limited work has been done on the effect of different fibre weight fraction and water cement ratio on physical and mechanical properties of self compacting beam concrete reinforced plantain bunch fibre composites. Against this background, the present research work was undertaken, with an objective to explore the potential of plantain bunch fibre as a reinforcing material in concrete composites

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and to investigate its effect on the mechanical and physical properties of the resulting composites. The present work thus aimed to develop plantain bunch fibre composites with different fibre weight fraction and water-cement ratio respectively and to analyse their strength properties by experimentation.

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The experimental design was aimed at examining the effect of plantain bunch fibre on the properties of self compacted concrete beams, using one aspect ratio of plantain bunch fibre. The experimental procedures included the selection of materials, concrete mix design as well as preparation and testing of concrete. A total of 40 beams were tested to achieve the objective of the research.

3.2. Concrete mix design

A basic mix ratio of 1:1.82:1.27 (cement; fine; coarse aggregates,) with water/cement ratio of 0.6 was used for the study. The mix ratio was obtained through preliminary trial mixes to achieve target strength of 30MPa.

3.3Materials

The raw materials used in producing the concrete beams include: cement, crushed granite stones, river sand, 16mm mild steel, plantain bunch fibre and potable water, with the coarse aggregate and fine aggregates conforming to BS EN12620:2013 and the Portland cement satisfying the requirements of BS EN197-1:2000

3.3.1 Fine Aggregates

The fine aggregate (Sand) used in the studies conforming to the requirements of BS EN12620:2013, and was river sand obtained from Sunyani in the Brong Ahafo region of Ghana.

3.3.2 Coarse Aggregates

The coarse aggregate used was within the requirements of BS EN12620:2013, and was obtained from a quarry located at Buoho in the Afigya Kwabre District of the Ashanti region of Ghana. Coarse aggregate used had a maximum size of 10 mm.

3.3.3 Mild Steel Bars

Mild steel bars as per IS: 432, part-1-1982 was used for the beams in reinforced concrete work. These steel bars are plain in surface with a diameter of 16mm.

3.3.4 Cement and Water

Ordinary Portland cement type whose properties conform to the requirement of BS EN 197-1:2000was used for mixing of concrete and the water was treated from Ghana Water Company.

3.3.5 Extraction and Treatment of Plantain bunch Fibres

An alkali treatment which is chemical method was used to extract the fibres. The fibres were soaked in a 5% NaOH solution for 4hours. The fibres were further treated with a solution of water and methanol (Saline treatment) in the ratio of 4:6 and then neutralized with 1% acetic acid solution and finally washed with water. The resultant fibres were dried at room temperature at 30^{o}C for 72 hrs before the examination of the test as cited in Ihuezet.al.(2012). The diameters of the fibres were measured using a micrometre screw gauge with an average diameter 0.15mm with an aspect ratio of 100. The fibres were cut with sharp scissors maintaining a length of 15 mm.

Figure 3.1: Micrometre screw gauge

Figure 3.2 Fibres in NaOH solution Fibre out of solution Dried Fibre

Extractions and Treatment of Fibre

3.4 Mix Proportion of Materials Used in the Concrete

Based on the results of the control concrete of 0.00% of fibre and 0.60 water cement ratio (plain concrete), the various fibre composites were prepared with fibre compositions of 0.25%, 0.50% and 0.75%, of the weight of the cement and water cement ratio of 0.60 with 30MPa as the target strength. The proportions of the constituents of the fibre composites by weight are given in Table3.1. The results are presented and discussed in detail in chapter 4.

Table 3.1: Weight Proportion of Materials used for Beams Specimen

Specimen	Weight of cement (Kg)	Weight of fine agg. (Kg)	Weight of coarse agg. (Kg)	Weight of fibre (Kg)	Weight of water (Kg)
A 0.00%/0.60	41.589	72.088	50.303	0.000	24.953
B 0.25%/0.60	41.589	72.088	50.303	0.1039	24.953
C 0.50%/0.60	41.589	72.088	50.303	0.2079	24.953
D 0.75%/0.60	41.589	72.088	50.303	0.3119	24.953

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3.4.1 Mixing Procedure

Mixing was done manually in the laboratory on a mixing platform using aspade. For the plain concrete (Control sample), the fine aggregate was first weighed and poured on the metal sheet, followed by cement and then mixed thoroughly after which coarse aggregate was added. They were mixed thoroughly after which water was added. The total component was then mixed until a uniform mix was obtained. In the case of the various mixes with the fibre contents, the fine aggregate was first batched, followed by the cement, plantain bunch fibre and coarse aggregate. Mixing was done thoroughly to ensure that the fibres were uniformly distributed before water was added and finally mixed. The concrete samples were taken and the slump checked in accordance with BS EN 12350 – 2: 2000, for the consistency of the fresh concrete before the beams and cylinders were prepared.

3.4.2Preparation of Specimens

The test samples were prepared as per the requirements of BS EN 12390, 2002. Five beams were prepared from each mix (plain concrete, 0.25%, 0.50% and 0.75% fibre content concrete).

3.4.3 Casting of the Concrete

The beams and cylinders were prepared by placing each mix sample in a rectangular and cylindrical mould of size 150mm×150mm×600mm and 100mm diameter with height200mm respectively and filled to one third and then shacked, self compaction. The remaining portions were filled two times and the same procedures were followed. In figure 3slump values of100mm and 50mm were achieved for plain and fibre reinforced concrete respectively, which represented high and medium workability. Figure. 3.3 shows the slump test and figure. 3.4 shows the arrangement of mind steel and casting of concrete.

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Figure 3.3: Testing of concrete workability beams using slump test

Figure 3.4: Casting of concrete

3.4.4 Demoulding

The specimens were left in the moulds for 24 hours to set under ambient temperature before the specimen was removed from the mould.

3.4.5 Curing of Test Samples

The specimens were submerged in a curing tank for 28 days before testing. The specimens were prepared in accordance with the provisions of ASTMC330 (2009), ASTMC469 (1987) and BS8110-1 standards. The curing of the specimen is shown in a submerged curing tank in the figure 3.5.

Figure 3.5: Specimen in Curing Tank

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3.4.6 Testing of the Samples

Five samples each of the various mixes were tested after twenty eight days to determine the final strength of each mix using the strength testing machine at Sunyani Technical University which satisfies the requirements. BS EN 12390 – 4: 2002. The beams and cylinders were tested as required by BS EN 12390 – 3: 2002. The specimens were first weighed to calculate the average densities as per BS EN 12390 – 7: 2002 after which the beams and cylinders were subjected to strength test, in accordance with BS 1881-127-1990; additional plywood packing strips were used at point of load contact to prevent stress concentration. Beams and cylinders from each mix were tested for flexural and splitting tensile test at day 28 until they failed by crushing. A total of forty (40) specimens were prepared with five (5) each made for the control specimen and five each for the various fibre contents for beams and cylinders respectively. Five specimens each were tested for the control and five specimens each were tested for the various categories of the concrete beams and cylinders respectively at twenty – eight days maturity. Before the specimens were tested, they were marked with to facilitate the observation of the cracks as they progress across the beams and cylinders respectively.

Regression analysis method will be used to analysed the data. The details will be seen in chapter four. Figure 3.6 and figure 3.7 shows how the testing and crushing is done.

Figure 3.6: Testing Machine Setup

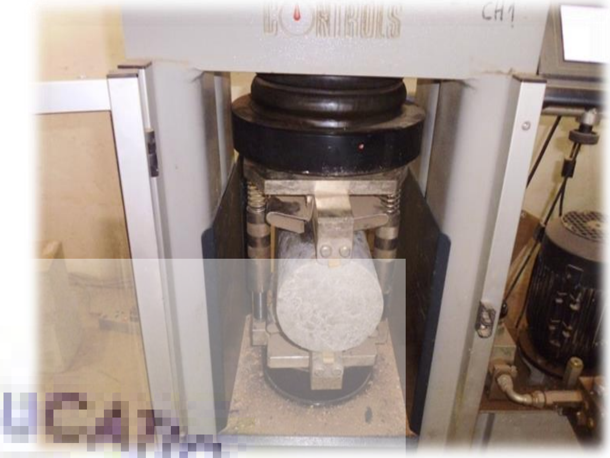

Figure 3.7: Split Tensile Testing Machine Setup

3.5 Data Analysis

The raw data was captured using the Statistical Package for Social Sciences (SPSS), presented and analyzed using descriptive statistics such as frequency distribution and percentages. The researcher used these methods because they provided better explanation and analysis of the study.

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CHAPTER FOUR

RESULTS/FINDINGS

4.1Introduction

This chapter presents the results with particular reference to the established objectives. The behavior of the specimens in the experimental program was evaluated in terms of their strength properties of self compacted beam concrete reinforced with plantain bunch fibre in order to establish physical and mechanical properties of concrete. Comparison was made between the control sample results and the fibre composites to establish the effects of fibre on the strength properties of concrete. The raw data is recorded in the Appendix for referencing where necessary.

4.2 Density

The table 4.1 gives the average densities of self compacting concrete beam with plantain bunch fibre.

Table 4.1: Average Densities of Plantain Bunch Fibre Concrete

Specimen	Number of specimen	Fibre content	Water cement	Average Density
		(%)	Ratio	(Kg/m^3)
A0	5	0.00	0.60	2405.6
B1	5	0.25	0.60	2222.2
B2	5	0.50	0.60	2303.7
B3	5	0.75	0.60	2296.3

From Table 4.1, it could be seen that the density of the control specimen was 2405.6Kg/m^3, and is higher than the density of self compacting plantain bunch fibre. There was a reduction of 4.76% when 0.75% of plantain bunch fibre was added to the concrete using water cement ratio.

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Again it could be observed that, at a constant water cement ratio, the specimen with 0.00% as control recorded the highest density followed by specimen with plantain bunch fibre of 0.50%, 0.75% and 0.25% respectively. Statistical analysis was conducted to validate the experiment results. Table 4.2 gives the details of the result.

4.4 Statistical Analysis of Density.

Table 4.2: Model Summary for Density Tests Results

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.422[a]	.178	-.233	83.764141

a. Predictors: (Constant), Fibre content.

Table 4.3: ANOVA[b] for Density Tests Results

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3035.648	1	3035.648	.434	.578[a]
	Residual	14002.772	2	7001.361		
	Total	17038.370	3			

a. Predictors: (Constant), Fibre content

b. Dependent Variable: Density

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Table4.4: Coefficients^a for Density Tests Results

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2405.6	70.007		33.481	.001
	Fibre content	-98.650	149.681	-.422	-.658	.578

a. Dependent Variable: Density

Regression models were fit using the average densities of the data. The density, D_s was taken as the dependent variable whereas the fibre content, f_c was taken as the independent variable. The result is presented in Table 4.4. The regression equation is given by: **D_s (kg/m^3) = 2405.6 – 98.650f_c (%)**

This implies that, at a constant water cement ratio, a (%) increase in fibre content would decrease the density of self compacting plantain bunch fiber concrete by about 99kg/m^3. Therefore the independent variable has a negative effect on the density of self compacting plantain bunch fiber concrete.

From Table 4.2, It could be seen that R^2= 0.178 indicate that, 17.8% of the variations in the density can be explained by the predictor, that is fibre content. In Table 4.3, the F value (1, 2) = .434, p>0.05. This implies that the overall model is not statistically significant at 0.05. However, 82.2% of the variations may be attributed to other factors such as curing time, compaction etc.

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4.5 Flexural Strength

Table 4.5: Average Flexural Strength of Plantain Fibre Concrete

Specimen	Number of specimen	Fibre content (%)	Water cement ratio	Average Flexural strength (MPa)
A0	5	0.00	0.60	2.93
B1	5	0.25	0.60	2.49
B2	5	0.50	0.60	2.65
B3	5	0.75	0.60	2.56

From Table 4.5, the flexural strength of the control specimen was 2.93MPa, and is higher than the specimens with flexural strength of self compacting plantain bunch fiber concrete. There was a reduction of 15% when 0.75% of plantain bunch fiber was added to the concrete using water cement ratio of 0.60. It could be observed that at a constant water cement ratio, the spacemen with 0.50% plantain bunch fiber content had the highest flexural strength among the fibre enhanced concrete. However, it can be concluded that the optimum fibre content of self compacting plantain bunch fiber concrete is 0.50%.

4.6 Statistical Analysis of Flexural Strength.

Table 4.6: Model Summary for Flexural Strength Tests Results

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.635[a]	.403	.105	.18269

a. Predictors: (Constant),Fibre content, Water cement ratio(constant)

Table 4.7: ANOVA^b for Flexural Strength Tests Results

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.045	1	.045	1.325	.365^a
	Residual	.067	2	-033		
	Total	.112	3			

a. Predictors: (Constant), Fibre content

b. Dependent Variable: Flexural strength

Table 4.8: Coefficients^a for Flexural Strength Tests Results

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.93	.153		18.319	.003
	Fibre content	-.380	.327	-.635	-1.163	.365

a. Dependent Variable: Flexural strength

Regression models were fit using the flexural strength data. The flexural strength, F_s was taken as the dependent variable whiles the fibre content, f_c was also taken as the independent variables. The result is presented in Table 4.8. The regression equation is given by: **F_s (MPa) = 2.93 – .380f_c (%).**

This shows that, at constant water cement ratio, a (%) increase in plantain bunch fibre would decrease the flexural strength of self compacting concrete by about 0.40MPa. Therefore the independent variables have a negative influence on the flexural strength of self compacting plantain bunch fiber concrete.

From Table 4.6, it could be seen that R^2= 0.403 and it implies that, about 40.3% of the variations in the flexural strength of concrete can be explained by the factor, that is fibre content.

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From Table 4.7, the F value (1, 2) =1.352, p>0.05. This indicates that the overall model is not significant at 0.05. However, 59.7% of the variations may be attributed to other factors which are not part of my objectives such as curing time, compaction, curing type etc.

4.7 Splitting Tensile Strength

Table 4.9: Average Tensile Strength of Plantain Bunch Fibre Concrete

Specimen	**Number of specimen**	**Fibre content** (%)	**Water cement** Ratio	**Average Tensile strength** (MPa)
A0	5	0.00	0.60	2.35
B1	5	0.25	0.60	2.44
B2	5	0.50	0.60	2.47
B3	5	0.75	0.60	2.45

From Table 4.9, the splitting tensile strength of the control specimen was 2.35MPa, and is lower than the tensile strength of specimens with plantain bunch fiber concrete. There was an improvement of 5% when 0.50% plantain bunch fiber was added to the concrete using water cement ratio of 0.50. It could be observed that at a constant water cement ratio, the spacemen with 0.25% plantain bunch fiber content had the lowest tensile strength among the fibres used in the concrete. Again it could be concluded that the inclusion of 0.50% weight fraction of fibre and water cement ratio of 0.60 improve the tensile strength of the plain concrete.

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4.8 Statistical Analysis of Tensile Strength.

Table4.10: Model Summary for Tensile Strength Tests Results

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.802[a]	.642	.464	.03892

a. **Predictors: (Constant), Fibre content**

Table4.11: ANOVA[b] for Tensile Strength Tests Results

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	.005	1	.005	3.594	.198[a]
	Residual	.003	2	.002		
	Total	.008	3			

a. Predictors: (Constant), Fibre content

b. Dependent Variable: Tensile strength

Table 4.12: Coefficients[a] for Tensile Strength Tests Results

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.35	0.033		73.022	.000
	Fibre content	.132	0.070	.802	1.896	.198

a. Dependent Variable: Tensile strength

Regression models were fit using the splitting tensile strength data. The tensile strength, T_s was taken as the dependent variable whiles the fibre content f_c was taken as the independent variable. The result is presented in Table 4.12. The regression equation is given by: **T_s (MPa) = 2.35 + 0.132f_c (%).**

This implies that, a (%) increase in plantain bunch fibre would increase the tensile strength of the concrete by about 0.5MPa. Therefore the independent variable has a positive influence on the tensile strength.

From Table 4.10, it could be noted that R^2= 0.642, and it shows that about 64.2% of the variations in the tensile strength can be explain by the predictor, that is fibre content. In Table 4.11, the F value (1, 2) =3.594, $p>0.05$. This implies that the overall model is not significant at 0.05. However, 35.8% of the variations may be attributed to other factors such as curing time, compaction, etc.

4.9 Toughness

Table 4.13: Toughness

Strain	A0	B1	B2	B3
0	0	0	0	0
0.2	1.48	1.5	1.45	2.01
0.4	4.185	5.8	4.72	5.98
0.6	6.85	8.71	7.06	7.88
0.8	9.75	9.28	8.61	8.87
1	10.87	9.89	9.02	8.98
1.2	0	0.1	9.08	0.12
TOTAL	**33.67**	**34.98**	**39.94**	**33.92**

Fibre content % and water-cement for the specimen are represented as follows: A0=0.00/0.60, B1=0.25/0.60, B2=0.50/0.60 and B3=0.75/0.60 respectively.

Generally, from Table 4.13 the addition of plantain bunch fibres up to certain fibre content would improve the toughness of self compacting plantain bunch fiber concrete. The toughness of the concrete was calculated as area under the stress-strain curve under compression up to a strain of 1.2mm. However, it could be seen that the modulus of toughness for the control specimen was 33.67N/mm^2, and is lower than the modulus of toughness of the specimens with plantain bunch fibre. There was an increase of 19% when 0.50% plantain bunch fiber concrete was added to the concrete using water-cement ratio of 0.60. Again it could be noted that looking at the percentage of fibre content, the specimens with fibre content of 0.50% recorded the highest modulus of toughness followed by those with fibre content of 0.25% and 0.75% respectively. It could be concluded that the optimum fibre content and that produces the highest toughness of self compacting plantain bunch fiber concrete are 0.50%.

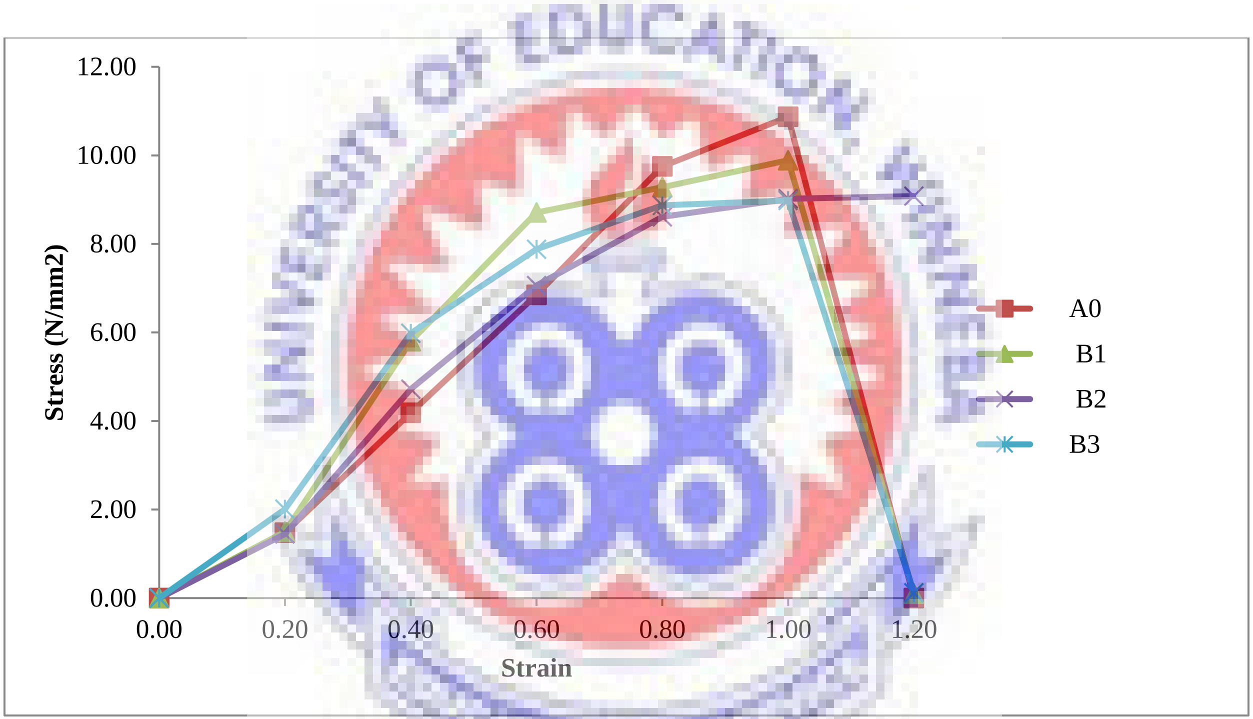

Figure 4.8: Stress – Strain Curve for Self Compacting Beam Concrete with Different Percentage of Plantain Bunch Fibre with Water Cement Ratio.

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From figure 4.8, it is clearly noted that when looking at the percentage of fibre content, the specimens with fibre content of 0.50% recorded the highest modulus of toughness followed by those with fibre content of 0.25% and 0.75% respectively. It is also affirm the conclusion that the optimum fibre content and water cement ratio that produces the highest toughness of self compacting plantain bunch fiber concrete are 0.50% and 0.60 respectively.

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CHAPTER FIVE

DISCUSSIONS OF RESULTS

5.1 Introduction

This chapter presents discussions from the analysis of the results in the previous chapter. The chapter is set to connect the findings of this present research to perspectives in theory. The idea is to establish the level of consistency among authors in this field.

5.2 Density

From the analysis of the study, it could be seen that the density of the control specimen was 2405.6Kg/m^2, and is higher than the density of the specimens with self compacting plantain bunch fiber concrete. There was a reduction of 4.76% when 0.75% plantain bunch fiber was added to the concrete using water cement ratio of 0.60. Again it could be observed that, at a constant water cement ratio, the spacemen with 0.50%plantain bunch fiber content had the highest density of self compacting plantain bunch fiber concrete followed by those with 0.75% and 0.25%respectively.This is similar to studies conducted by (Hasan, et.al, 2012;Ismail, 2007) for a reduction in density of about 8.5% for every 0.5% fibre volume increase occurred. Such reduction in density may be attributed to increasing porosity and air void which brought about insufficient compaction of the high fibre content mixture, therefore, the density of the concrete is a function of the fibre content.

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5.3 Flexural Strength

In analyzing the result, it could be seen that the flexural strength of the control specimen was 2.93MPa, and is higher than the flexural strength of specimens with self compacting plantain bunch fiber concrete. There was a reduction of 15% when 0.75% plantain bunch fiber was added to the concrete using water cement ratio of 0.60. It could be observed that at a constant water cement ratio, the specimen with 0.50% plantain bunch fiber content had the highest flexural strength among the fibre enhanced concrete. However, it can be concluded that the optimum fibre content and water cement ratio of self compacting plantain bunch fiber concrete are 0.50% and 0.60 respectively. This is very similar to Soroushian et al., 1992 and Kao, 2005). The increase in flexural strength of the control specimen may be due to the good homogeneity of the concrete. However, the flexural strength of specimens decreased with the increase in plantain bunch fibre, this can be explained by the fact that the composites have lower strength and this might be due to the increase in air void and high porosity in the concrete composite.

5.4 Splitting Tensile Strength

From the analysis it was indicated that the splitting tensile strength of the control specimen was 2.35MPa, and is lower than the tensile strength of specimens with self compacting plantain bunch fiber concrete. There was an improvement of 5% when 0.50% of plantain bunch fiber was added to the concrete using water cement ratio of 0.50. It could be observed that at a constant water cement ratio, the specimen with 0.25% plantain bunch fiber content had the lowest tensile strength among the fibres used in self compacting plantain bunch fiber concrete. Again it could be concluded that the addition of 0.50% weight fraction of fibre and water cement ratio of 0.60 improved the tensile strength of the plain concrete. Although, the typical relationship between the fibre cement-ratio and tensile strength produce quite a low increase in strength, the general tendency shows enhancement in strength at 28 days age, and indicates a marked increase of about 5% in the tensile strength of self compacting plantain bunch fiber concrete. This is very similar to an increase of about 15% and 3.2% for concrete with fibre content of 0.5% and 0.75% respectively, which was reported by Yalley and Kwan, (2009). Again is very similar to the 53% in the ultimate tensile strength reported by Ismail, (2007).Such an increase may be attributed to the good homogeny between the fibre and the cement and high compaction of the concrete.

5.5 Toughness

In summary, the inclusion of plantain bunch fibres up to certain fibre content would enhance the toughness of self compacting plantain bunch fiber concrete. The toughness of the concrete was calculated as area under the stress-strain curve under compression up to a strain of 1.2mm. However, it could be seen that the modulus of toughness for the control specimen was 33.67N/mm^2, and is lower than the modulus of toughness of the specimens with plantain bunch fibre. There was an increase of 18% when 0.50% of plantain bunch fiber was added to the concrete using water cement ratio of 0.60. Again it could be noted that, looking at the percentage of fibre content, the specimens with fibre content of 0.50% recorded the highest modulus of toughness of self compacting plantain bunch fiber concrete followed by those with fibre content of 0.25% and 0.75% respectively. It could be concluded that the optimum fibre content and water cement ratio that produces the highest toughness self compacting plantain bunch fiber concrete are 0.50%. This is very similar to the addition of bamboo-mesh, coconut-fibres in concrete which improved the toughness properties of the concrete, which was reported by Mansur and Aziz, (1983),Yalley and Kwan, (2009) and Hasan, et,al, (2012). The increase in toughness may be attributed to the fact

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that, the fibre presence in the concrete contributed greatly in offering restraint to strain in the concrete.

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CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the summary of the major findings from the interpretations and discussions in the previous chapters, from which conclusion and recommendation are drawn.

6.2 Summary of Findings

In general, it clearly indicates that the density of the control specimen was 2405.6Kg/m^2, and is higher than the density of specimens with plantain bunch fibre. There was a reduction of 4.76% when 0.75% plantain bunch fiber was added to the concrete using water-cement ratio of 0.60. Again it could be observed that at a constant water-cement ratio, the specimen with 0.50% plantain bunch fiber content had the highest density of self compacting plantain bunch fiber concrete followed by those with 0.75% and 0.25%respectively.

From one of the major findings, it could be seen that, the flexural strength of the control specimen of self compacting beam concrete was 2.93MPa, and is higher than the flexural strength of specimens with plantain bunch fibre. There was a reduction of 15% when 0.75% of plantain bunch fiber was added to the self compacting beam concrete using water-cement ratio of 0.60. It could be observed that at a constant water-cement ratio, the specimen with 0.50% plantain bunch fiber content had the highest flexural strength of self compacting beam concrete among the fibre enhanced concrete.

The inclusion of plantain bunch fibre in self compacting beam concrete increased the tensile strength of concrete. However, there was an improvement of 5% when 0.50% of plantain

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bunch fiber was added to the concrete using water-cement ratio of 0.50. It could be observed that at a constant water cement ratio, the specimen with 0.25%plantain bunch fiber content had the lowest tensile strength among the fibres used in the concrete. Again it could be concluded that the addition of 0.50% weight fraction of fibre and water-cement ratio of 0.60 improve the tensile strength of self compacting beam concrete.

The addition of plantain bunch fibre in self compacting beam concrete enhanced the toughness properties of concrete to some extent. There was an increase of 19% when 0.50% of plantain bunch fiber was added to the concrete using water-cement ratio of 0.60. Again it could be noted that, looking at the percentages of fibre content, the specimens with fibre content of 0.50% recorded the highest modulus of toughness. It could be concluded that the optimum fibre content that produce the highest toughness of self compacting beam concrete is 0.50%.

6.3 Conclusion

This study has presented the outcome of the results of an experimental program investigating the strength of self compacting beam reinforced concrete incorporating different weight percentage of plantain bunch fibre and water cement ratio. Based on the experimental results and observations, the following conclusions can be drawn;

In all cases, the addition of plantain bunch fibre in concrete adversely affected the density of the concrete and hence decreased the density of self compacting beam concrete.

The inclusion of fibres in self compacting beam concrete adversely has a negative effect on the flexural strength; increase in the percentage weight fraction of plantain bunch fibres in the concrete mix decreased the flexural strength of the concrete. This may be attributed to difficulties in poor homogeny between the fibre and the cement which consequently lead to an increase in voids. However, the inclusion of plantain bunch fibres in concrete has a significant influence on many of the engineering properties like toughness and tensile strength.

When plantain bunch fibre was added to plain concrete, it increased the amount of energy-absorbing capacity of the concrete and makes it tougher. However, the optimum weight fractions of plantain bunch fibre that produces the highest toughness of self compacting beam concrete is 0.5%. It was concluded that plantain bunch fibre has the potential to be used in the conventional concrete for the production of structural lightweight concrete.

6.4 Recommendations

The following were the elements which play a critical role in the preparation of self compacting beam reinforced concrete with percentages of fibre inclusion. Therefore they must be seriously taken into consideration when working and planning on construction. These include; Density, flexural strength, tensile strength and toughness.

- The mix proportion used in this study can be used for both plain and reinforced concretes beam, which requires fibre incorporation. It is recommended that an intensive education should be embarked on the use of plantain bunch fibre in the construction industry.
- Self compacting beam reinforced concrete with 0.5% fibre and 0.60 water cement ratio should be adopted to be used in the production of structural lightweight concrete.
- More research work should be carried out to determine the optimality of the fibre content in range of 0.25% to 0.50% to know the validity of the conclusion.
- A study should be carried out by means of monitoring manual compaction, curing time of plantain bunch fibre reinforced concrete, which may improve the experimental result and allow a more conclusion to be drawn.

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6.5 Scope for Future Work

There is a very wide scope for future scholars to explore this area of research. This work can be further extended to study other aspects of such composites like effect of various fibre lengths and volume, loading pattern, fiber treatment on physical and mechanical behavior of plantain bunch fibre reinforced composites and the resulting experimental findings can be equally analyzed.

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APPENDIX A

CALCULATION OF MIX PROPORTION FOR CONCRETE REINFORCED BEAMS

BEAMS

Volume of beam = length x Breath x Thickness = .150 x .150 x 0.60

= 0.0135m3

Density of concrete $=\frac{m}{v}$ = 0.0135kg x 2400kg/m^3

= 32,4kg

Add 5% for waste = 34.02 kg

Multiply by 5= 170.1kg

Mix ratio: 1:1.27:1.8 = 4.07

Cement content for 5 beams = $\frac{1}{4.07}\ x\ 170.1kg = 41.79kg$

Sand content for 5 beams = $\frac{1.27}{4.07} x\ 170.1kg = 53.08kg$

Stone content for 5 beams $=\frac{1.8}{4.07} x\ 170.1kg = 75.23kg$

Water cement ratio of 0.6= 0.6 x 170.1kg = 102.1kg

Fibre content of = 0.25% = 0.0025 x 170.1kg = 0.4253kg

0.50% =0.0050 x 170.1kg = .8505kg

0.75% = 0.0075 x 170.1kg= 1.2758kg

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APPENDIX B

Average Values of the Flexural strength (MPa)

Specimen	Number of specimen	Stress N/mm^2	av N/mm^2	fibre %	w/c
A0	5	2.93			
A0	5	2.96			
A0	5	2.93	2.93	0.00%	0.6
A0	5	2.91			
A0	5	2.94			
B1	5	2.49			
B1	5	2.51			
B1	5	2.46	2.49	0.25%	0.6
B1	5	2.45			
B1	5	2.53			
B2	5	2.65			
B2	5	2.63			
B2	5	2.67	2.65	0.50%	0.6
B2	5	2.64			
B2	5	2.66			
B3	5	2.56			
B3	5	2.58			
B3	5	2.54	2.56	0.75%	0.6
B3	5	2.53			
B3	5	2.59			

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APPENDIX C

Average Values of Density of the beam (kg/m^3)

Specimen	Number of specimen	kg/m^3	av kg/m^3	fibre %	w/c
A0	5	2403.5			
A0	5	2407.6			
A0	5	2405.7	2405.6	0.00%	0.6
A0	5	2404.7			
A0	5	2409.5			
B1	5	2220.2			
B1	5	2224.2			
B1	5	2202	2222.2	0.25%	0.6
B1	5	2222.4			
B1	5	2224.2			
B2	5	2300.6			
B2	5	2306.7			
B2	5	2302.8	2303.7	0.50%	0.6
B2	5	2304.9			
B2	5	2303.5			
B3	5	2298.3			
B3	5	2299			
B3	5	2293.6	2296.3	0.75%	0.6
B3	5	2296.2			
B3	5	2294.4			

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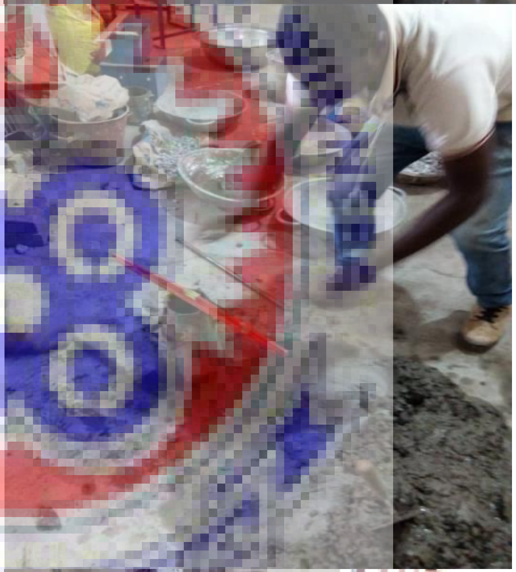
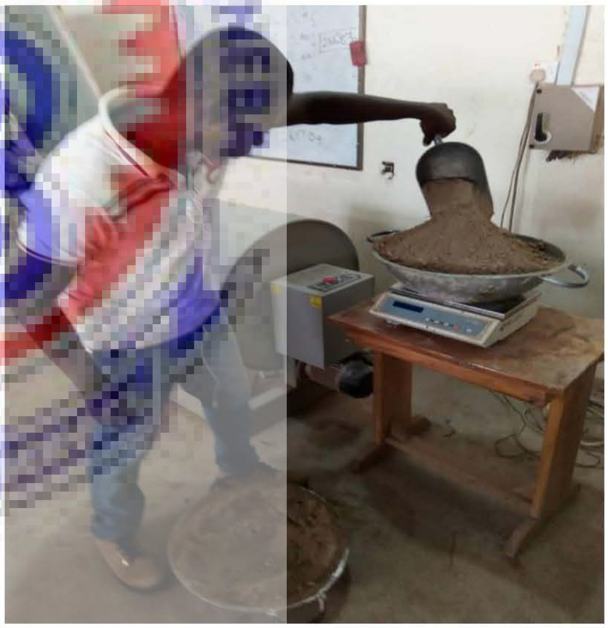
APPENDIX D

Average Values of the splitting Tensile Strength(MPa)

Specimen	Number of specimen	N/mm^2	av N/mm^2	fibre %	w/c
A0	5	2.35	2.35	0.00%	0.6
A0	5	2.36			
A0	5	2.34			
A0	5	2.35			
A0	5	2.33			
B1	5	2.46	2.44	0.25%	0.6
B1	5	2.42			
B1	5	2.44			
B1	5	2.41			
B1	5	2.47			
B2	5	2.46	2.47	0.50%	0.6
B2	5	2.48			
B2	5	2.46			
B2	5	2.49			
B2	5	2.47			
B3	5	2.43	2.45	0.75%	0.6
B3	5	2.47			
B3	5	2.45			
B3	5	2.46			
B3	5	2.44			

APPENDIX E
IMAGES SHOWING THE PREPARATION OF LABORATORY WORK





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