UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

EFFECT OF FIBRE ASPECT RATIO OF PALM BUNCH FIBRE ON SOME PHYSICAL AND STRENGTH PROPERTIES OF CONCRETE

CHRISTIAN GAMETI

OCTOBER, 2018

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A Thesis 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 fulfilment of the requirements for the award of Master of Philosophy (Construction Technology) degree.

OCTOBER, 2018

DECLARATION

STUDENT'S DECLARATION

I, **CHRISTIAN GAMETI,** declare that this Thesis, 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 Thesis as laid down by the University of Education, Winneba.

NAME OF SUPERVISOR: **DR. PETER PAA-KOFI YALLEY**

SIGNATURE: ……………………………………………………………

DATE: ………………………………………………………………………

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DEDICATION

This research work is entirely dedicated to my late father, Mr. John Billy Yaw Gameti. He has always believed in me.

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ABSTRACT

The natural fibres, abundantly available in nature and also generated as agricultural waste, can be used advantageously in improving certain physical and strength properties of cement matrix and concrete. As compared to fibres widely used in construction activities viz. steel, glass carbon synthetic etc., these are advantageous in the sense that they are renewable, non-abrasive, cheaper, comparatively more flexible etc. Also, the health and safety concerns during their handling, processing and mixing are less. Several natural fibres have been used in experimental studies and construction activities to investigate and improve upon the mechanical properties of cement and concrete matrices which are brittle in nature. This research examines the effects of fibre aspect ratio of palm bunch fibre on the physical and strength properties of concrete. Experimental studies on compressive strength in accordance with BS 1881: Part 116 (1983), split tensile strength in accordance with BS1881, Part 117 (1983) and flexural strength in accordance with BS 1881: Part 118: (1983) were conducted with fibre aspect ratios of 75, 100, 125 and 150. The addition of palm bunch fibres significantly improved many of the engineering properties of the concrete, notably toughness, split tensile and flexural strengths. The ability to resist cracking and spalling were also enhanced. However, compressive strength was adversely affected. The toughness or energy-absorbing capacity increased, but there is an optimum aspect ratio (125), beyond which the toughness started to decrease. Overall the study has demonstrated that addition of palm bunch fibre to concrete leads to improvement of its engineering properties. Further work is however, required to assess the long term durability of concrete enhanced with palm bunch fibre.

CHAPTER ONE

INTRODUCTION

1.0 Background to the Study

Sustainability issues have become prevalent in the past years especially in sustainable construction practices. There has been some substantial effort to educate the public on its importance in both the long and short run. Sustainable construction practices are both ecologically friendly and are also cost efficient as they are often based on the use of locally available materials. Sustainable construction practices include the use of green materials such as compressed earth bricks. The rising demand in energy consumption coupled with concerns over the greenhouse effect has driven the construction industry to substitute conventional construction approaches through using alternative approaches, sources and structural systems (Silva *et al.,* 2010).

There is currently a great deal of interest in developing the technology for using locally available raw materials in the construction industry. Natural fibres exist in reasonably large quantities all over the world and natural vegetable fibres are produced in most developing countries. Ghana is one of 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.

Natural fibres have been used to reinforce inorganic materials for thousands of years. Examples include straw for bricks, mud and poles, plaster and reeds. During this century other fibres such as coconut, bamboo, wood cellulose fibres, wool or chips, bast fibres, leaf fibres, seed and fruits fibres have been used in cement-sand based products (Gram, 1983; Paramasivam *et al*., 1984; Sera *et al*., 1990; Duvaut *et al*., 20 00; Brahmakumar *et al*., 2005; Asasutjarit *et al*., 2007; Ismail, 2007; Zain *et al*., 2010; Zain *et al*., 2011; Mulinari *et al*., 2011). The use of natural fibre as reinforcement in concrete (cement-sand matrix) has been comprehensively investigated in many countries (Rehsi, 1991; Atnaw *et al*., 2011 as cited in Hassan, et al., 2012).

The main reasons for the use of natural fibres are that they are abundantly available and are 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, et al., 2003; Majeed, 2011; Hamzah *et al*., 2010 as cited in Hassan, et al., 2012).

Many studies have 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.* 2004; 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).

Mostly, palm tree is one of the most important agricultural and commercial plantation crops in Ghana. People recognized it as a tree of life because, every part of the palm tree such as fruits, trunks, leaves, shells of the fruits can be effectively utilized for living (Ahmad, et al., 2010; Eichhorn & Young, 2004). Palm bunch fibres obtained from palm bunch of palm fruit belonging to the family of palm fibres, are agricultural waste products obtained in the processing of palm oil, and are available in large quantities in the tropical regions of the world, most especially in Africa, Asia and Southern America. In Ghana, they are available in large quantities in the southern part of the country. Natural fibres have been used to enhance concrete and mortar, and have proven to improve the toughness of the concrete and mortar (Gram, 1983, and Ramakrishna, *et al.,* 2005). It has also been noticed that the degree of enhancement of concrete by natural fibres depended on the type of fibre species. The specific objective of experimenting on palm bunch fibre as an enhancement of concrete is two folds. Firstly, to assess if the fibres improve the mechanical properties of concrete like other natural fibres such as sisal, jute, coir, etc. Secondly, once it was proven that vital mechanical properties of concrete and mortar could be enhanced by palm bunch fibre then further investigation would be carried out on improving the long term durability of concrete and mortar with palm bunch fibres as an enhancement.

Palm bunch fibres are agricultural waste products obtained in the processing of oil palm and are available in large quantities in the tropical regions of the world, most especially in Africa, Asia and America. Palm bunch fibres are not commonly used in the construction industry. Rather, they are often dumped as agricultural wastes.

However, with the quest for affordable housing system for both the 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 material is Palm bunch fibre produced in abundance has the potentials of serving as reinforcement in concrete.

The huge amount of Palm bunch fibre wastes, which are produced in our homes and markets centres, the current waste disposal practice in the country is normally done to it 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 utilizing them into constructive building material. The benefits of using Palm bunch fibre as a construction material are in two folds; firstly, it will solve environmental problem of disposal and secondly, reduce the cost of building materials.

1.1 Statement of the Problem

Due to the high demand for housing facilities and the ever increasing cost of construction materials which has made building expensive, there has been various means of exploiting alternative building materials that have the potential to maintain adequate structural performance and at the same time reduce the cost of construction.

By considering these requirements, attempts have been made to study the possibilities of reusing some agricultural waste products as fibre composites in concrete to enhance their properties. The studies were not limited to concrete but also to soil blocks. Danso, et al., (2015a) studied the effect of fibre aspect ratio on the mechanical properties of soil building blocks. In their study, they concluded that generally, longer aspect ratios produce better mechanical properties of soil blocks.

Ali *et al.* (2012) analysed the properties of coir fibre depending on fibre length and content. They reported that addition of coir fibre in concrete could improve the compressive strength, modulus of rupture, toughness, and total toughness index of concrete. Similarly, Mahyuddin and Eathar (2010) made an experimental study on the compressive strength and concluded that incorporating a small amount of coconut fibre (0.6%) enhances the performance of concrete exposed to tropical climate by approximately 12%.

Tara and Ashim (2015) presented an experimental investigation of flexural strength of RC beams using sisal, artificial carbon and glass fabric reinforced composite system. Sisal fibre reinforced concrete (SFRC) in their experiment indicated a good increase in its flexural strength and improvement in toughness.

In an experiment, Udoeyo and Adetifa (2012) used water- retted kenaf fibres as reinforcement in mortar composites. The results of the experiment showed that although the bending capacity of kenaf fibre reinforced mortar sheet decreased with increase in fibre content, the flexural toughness and the impact resistance of the composite were enhanced with higher content of the fibre, compared with the control composites (composite without fibre). The water absorption and the fire resistance of the composite were also observed to be within acceptable limits specified by relevant standards.

Mahyuddin and Eethar (2010) investigated the effects of palm bunch fibre on the mechanical properties of lightweight concrete. Their result yielded an increase in the flexural strength and compressive strength with a maximum palm bunch fibre content of up to 0.8% in the mix. The density also increased slightly by the inclusion of palm fibre in the mix. Juárez *et al.* (2010) reported that the ultimate compressive strength of the fibre-reinforced composite value is dependent upon the aspect ratio of the fibre.

However, very limited work has been done on the effect of aspect ratio of fibre on the strength, physical and durability properties of palm bunch fibre reinforced concrete. Against this background, the present research work was undertaken.

1.2 Aim of the Study

The purpose of the study is to investigate the effect of fibre aspect ratio of palm bunch fibre (natural fibres) in concrete on its physical and strength properties.

1.3 Specific Objectives of the Study

- To establish the effect of fibre aspect ratio on the workability and density of concrete enhanced with palm bunch fibre.
- To determine the effect of fibre aspect ratio on the compressive, split tensile, toughness and flexural strengths of concrete enhanced with palm bunch fibre.

1.4 Scope of the Study

This research project involved the testing of Palm bunch fibre reinforced concrete cubes, beams and cylinders. For alkali treatment of fibre, NaOH was used for Palm bunch to improve the interfacial bonding, increase fibre surface charge and increasing the Young‘s Modulus of Elasticity. Alkali treatment will also decrease the residual Lignin content that cause improving composite strength. Since the materials chosen in this research work are locally available materials, a detailed characterization through various testing and analytical methods are essential. Multiple regression analyses will be used to propose models for predicting the density, compressive strength, flexural strength and toughness of Palm bunch fibre concrete. The results of the test were validated and conclusions drawn.

1.5 Significance of the Study

As an important study of interest in the construction industry, an alternative material has been found and used in the preparation of fiber-reinforced concrete that can also have more optimal properties. Consequently, it can promote sustainable development, where engineering design and construction is incorporated in the environmental sciences, particularly in the engineering design solution of a presently realistic problem that need to be addressed like climate change. It is practical and important that every resource should be put into use; though natural fibers have been widely used in the Philippine industry commonly for clothing and handicraft purposes, much of the unused fibers tend to be thrown away. The downside is the fatal effects of solid wastes, either domestic or agricultural, to humans, animals and even the environment, particularly the air and their health. Thus, a fiber reinforced composite has been designed and utilized to reduce the wastage brought about by the excessive use of fibers in the industry while making the environment a safe zone for humans and animals alike. It has also helped to evaluate the mechanical and physical properties which are of prime importance to the construction industry. Again it has proven whether aspect ratio has an influence on the properties of concrete reinforced with Palm bunch fibre.

1.6 Limitations of the Study

The study adopted a fibre aspect ratio of up to 150. However, engineering properties of fiber-reinforced concrete beyond aspect ratio of 150 was not taken into consideration. Comparison of the flexural strengths between Palm bunch fibre-reinforced and plain concretes was done on beams only through a graphical analysis of 28-days curing age strength base. However, it has not taken into consideration the other structural members of a concrete structure such as slabs, footings and columns. For flexural tests, loads are applied only at the mid span of the beam samples. It is assumed that the strength of concrete increases very slowly through time; thus, a logarithmic graph is adopted in this study to compare the flexural strengths between the plain and the Palm bunch fibre-reinforced concrete beams. The study has also disregarded the effect of shear or axial behavior. As structural application is concerned, it can hardly be used in buildings of at all levels, since it is reinforced with fiber but not steel, whose effect on strength by the loads it will carry is to be stressed most importantly.

1.7 Organisation of the Thesis

The thesis is presented in six chapters. Chapter one talks about the introduction section of the research work and is devoted principally to give an overview of the study. It comprises background of the study, statement of the problem, purpose and objectives of the study, research questions, significance of the study, limitations of the study, delimitations of the study and layout of the research report.

Chapter Two presents an exhaustive but incisive review of relevant literature related to the study. The literature review is geared towards justifying the specific objectives of the study, and the theoretical framework upon which the study is built. In addition, the identified gap in the related literature is highlighted in this chapter.

Chapter Three is based on the research methodology that was adopted for the study. It outlines the research design and approach that will be employed and their justification. The chapter further describes experimental studies on the use of Palm Bunch Fibre (vegetable fibre) as enhancement of concrete.

Chapter Four presents data and results of the study under suitable themes based on the pertinent research questions. The findings are also presented in the form of tables and figures as well as the analysis of the findings in the form of prose.

Chapter Five presents the discussion of major results from the experimentations. It also compares the results with literature, based on which conclusions are drawn.

Chapter six comes at the end of the study. It outlines the summary of the findings, draws conclusions drawn from the findings as well as necessary recommendations and suggestions for further research based on the findings.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents an exhaustive but incisive review of relevant literature related to the use of natural fibres in the construction industry. The literature review is geared towards justifying the specific objectives of the study, and the theoretical framework upon which the study is built. The chapter also provides an overview of literature on concrete as well as the properties of oil palm and palm fibre. It also provides experimental studies on the viability of natural and artificial fibres as reinforcement in concrete.

Moreover, information provided by other researchers with respect to the properties of concrete whereas concrete reinforced with natural fibres is also compared with that of artificial fibre reinforced concrete.

2.1 Concrete as a Construction Material

Concrete is the most common, man-made, building material that is being used for many applications including the construction of residential houses, high-rise buildings, bridges, streets, and dams. Aside from water, concrete is the most produced material in the world (WBCSD, 2009). It is a strong compound consisting of a mixture of cement, sand, coarse aggregates, water, and admixtures (McCormac, et al, 2006; Chudley & Greeno, 2008). It has been a prominent building material for over a century because of its availability as low cost materials, its high fire and weather resistance, and its high compressive strength. Its high compressive strength makes concrete suitable for structures like columns and arches that are primarily subjected to compressive stresses (Darwin et al., 2001). Concrete is the most widely used construction material in the world; its use far exceeds other materials. 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, 1993).

As the developing world is becoming more industrialized and people are migrating to the cities, the need for infrastructure is growing quickly and concrete has become the primary construction material. Concrete has many advantageous properties including being inexpensive and the most readily available material, high compressive strength, easy to cast or moulded into shapes, durable, fire-resistance, harden in water and can withstand the action of water without serious deterioration, low maintenance and energy efficient (Darwin *et al*., 2001).

The strength and durability of concrete can be changed by making appropriate changes in its ingredients like cemetitious material, aggregate and water and by adding some special ingredients. Hence concrete is very well suitable for a wide range of applications. However, concrete has some deficiencies as listed below:

1) Low tensile strength
2) Low post cracking capacity
3) Brittleness and low ductility
4) Limited fatigue life
5) Incapable of accommodating large deformations
6) Low impact strength (McCormac et al., 2006).

The presence of micro cracks in the mortar-aggregate interface is responsible for the inherent weakness of plain concrete. For this reason, concrete must be reinforced with high tensile strength materials such as steel rebar. Civil structures made of steel reinforced concrete normally suffer from corrosion of the steel by salt, which results in the failure of those structures. Constant maintenance and repairing is needed to enhance the life cycle of those civil structures (ECCS-203, 2001).

These weaknesses can also be removed by inclusion of fibres in the mixture to carry some tensile stresses. Different types of fibres, such as those used in traditional composite materials can be introduced into the concrete mixture to increase its toughness, or ability to resist crack growth. The fibres help to transfer loads at the internal micro cracks. Such a concrete is called fibre-reinforced concrete (FRC) (Mehta & Monteiro, 2001).

2.1.1 Properties of Concrete

Concrete is a composite material consisting of mainly cement, water and stones (coarse aggregates) (McCormac, et al., 2006; Chudley & Greeno, 2008). The aggregates and the dry cement are mixed with water to form a fluid mass that is easily moulded into any shape by pouring them into concrete formwork erected on the field. On the other hand, concrete is sometimes mixed into dryer, non-fluid forms and used for the manufacturing of precast concrete products. In all cases, the mixture undergoes a process called hydration which is initiated by the cement to produce a hardened stone-like substance named concrete. Admixtures and chemical additives are sometimes added to the concrete or its binding constituent to reduce the cost of production or change or enhance its properties. These chemicals retard or increase the rate at which concrete may set or harden and also impart other mechanical and chemical properties (Chudley & Greeno, 2008). Concrete in its fresh state or hardened state exhibits various characteristics, depending on the properties of the constituent materials.

Concrete goes through a lot of physical and chemical processes during its production which have great impact on the quality and performance of the material under service loading. A good concrete must have its constituent materials remain uniformly distributed within the concrete mass even after placing and compaction. This calls for good quality control measures to ensure that the fresh concrete is thoroughly mixed and well compacted at placement (Neville & Brooks, 2002). Generally, concrete in its fresh state must be cohesive, consistent and workable to ensure its optimal performance (Shetty, 2005; Chudley & Greeno, 2008).

2.1.2 Hardened Concrete

Concrete in its hardened state must satisfy all usage requirements. The long term properties of hardened concrete is dependent on the degree of compaction and so it is important that the workability of fresh concrete is such that it can be well compacted, transported and placed without causing segregation (Neville & Brooks, 2002). It must be capable of withstanding against all forms of service loads it is subjected to. The properties of hardened concrete include strength, creep, durability, shrinkage, modulus of elasticity, deformation under load and permeability. The compressive strength of concrete is the most important property of concrete and predominantly controls its quality (Ozyildirim, 2011). The characteristic compressive strength of concrete is the compressive strength below which not more than 5% of the tested samples will fall. According to Jackson and Dhir (1996), as the strength of concrete increases, other properties of the material also improve. For this reason, 28 days cube or cylinder compressive strength as given by BS 8110 (1997) and ACI 318 (2002) respectively is commonly used in the construction industry for quality control measures.

2.2 Fibres

The term —fibre" covers materials whose length (L) is several times their diameter (d), and therefore, they have a high L/d or aspect ratio (Jayamol & Thomas, 1997). According to terminology adopted by American Concrete Institute (ACI) Committee 544 (1982), there are four categories of Fibre Reinforced Concrete (FRC) namely:

1. Steel Fibre Reinforced Concrete (SFRC);
2. Glass Fibre Reinforced concrete (GFRC);
3. Synthetic Fibre Reinforced Concrete (SNFRC);
4. Natural Fibre Reinforced Concrete (NFRC).

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

Naaman (2003) also reported that fibre reinforcement has been grouped into three main divisions considering its characteristics. These include:

1. 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);
2. Physical/chemical properties (density, surface roughness, chemical stability, non-reactivity with the cement matrix, fire resistance or flammability);
3. Mechanical properties (tensile strength, elastic modulus, stiffness, ductility, elongation to failure, and surface adhesion property as cited in Jansson, 2008).

2.2.1 Qualities of good Fibres in Hardened Concrete

For the effective use of fibres in hardened concrete:

- There must be a good fibre-matrix bond.
- 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.
- 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).*

2.2.2 Concrete with Fibres

Concrete made with Portland cement has certain characteristics: it is strong in compression but weak in tension and tends to be brittle. The weakness in tension can be overcome by the use of conventional steel bar reinforcement and to some extent by the inclusion of a sufficient volume of certain fibres. The use of fibres also alters the behaviour of the fibre-matrix composite after it has cracked, thereby improving its toughness (Yalley *et al.,* 2016). The combined use of regular concrete and steel reinforcing bars was able to overcome that disadvantage leading to a material with good compressive and tensile strengths but also with a long post-crack deformation (strain softening). Unfortunately, reinforced concrete has a high permeability that allows water and other aggressive elements to enter, leading to carbonation and chloride ion attack resulting in corrosion problems. Steel rebar corrosion is in fact the main reason for infrastructure deterioration. Due to this, in the early 1960s, a group published a paper about the mechanics of crack arrest in concrete by using very closely placed steel wires as reinforcement. They found that a smaller spacing meant an increase in tensile strength (Romualdi & Batson, 1963). Their successful research sparked an interest in fibre reinforced concrete around the world (Zollo, 1997). Since then, many types of fibres have been subjected to experimentation ranging from animal hair to synthetic polymers. Before that, in 1500 BC, ancient Egyptians introduced animal hairs and straw to reinforce mud bricks and walls in buildings. Straws were again used to strengthen sun-baked bricks of ‗AqarQuf‘ hill of a height 57metres near Baghdad (Balaguru and Shal, 1992 as cited in Sivaraja et al., 2010). Therefore, promoting the use of concrete reinforced with natural fibres could be a way to improve concrete durability and also sustainable construction.

2.3 Fibre Reinforced Concrete

Fibre reinforced concrete (FRC) is a concrete mix or a composite material that contains short discrete discontinuous fibres that are uniformly distributed and randomly oriented to enhance its structural performance (Bayasi & Soroushian, 1989). The idea of fibre reinforced concrete evolved even further in the early 1990s with the exploration of Engineered Cementitious Composites (ECC). ECCs is essentially highly ductile fibre reinforced concretes where the micromechanical interactions in the interfacial zone are engineered to produce desired properties including strain hardening behaviour (Li, 2003). Strain hardening is desirable because the composite material ends up with a post cracking tensile stress that is higher than its tensile strength as well as a larger area under the stress-strain curve. The area under a stress-strain curve represents the amount of energy required for failure (Van Mier, 1986). Conventional fibre reinforced concrete is strain softening, so the post-cracking tensile stress is lower than its tensile strength but its stress-strain curve still has a larger area under the curve than concrete without fibres. Therefore, more energy is required to reach failure in fibre reinforced concrete than with concrete without fibre reinforcement. The usefulness of fibre reinforced concrete (FRC) in various civil engineering applications is indisputable. Fibre reinforced concrete has so far been successfully used in slabs on grade, shotcrete, architectural panels, precast products, offshore structures, structures in seismic regions, thin and thick repairs, crash barriers, footings, hydraulic structures and many other applications. 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. (Tang et al, 2007). 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 (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 & 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 non-renewable; 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. As a result, the search for a suitable replacement has brought about the interest in studying natural fibres as reinforcement in cement composites (Castro & Naaman, 1981 as cited in Yaremko, 2012). The use of natural fibres to reinforce brittle building material can be traced back to Egyptian times when straws or horsehair were added to mud bricks. Aziz et al. (1984) reported that coconut coir, sisal, sugarcane bagasse, bamboo, jute and wood cement composites had already been investigated in more than 40 countries world-wide.

2.3.1 Mix Design of Fibre Reinforced Concrete

As with any other type of concrete, the mix proportions for FRC depend upon the requirements for a particular job, in terms of strength, workability, and so on. Several procedures for proportioning FRC mixes are available, which emphasize the workability of the resulting mix. Mix design therefore is the process of determining the relative quantities of the ingredients of concrete taking into account the availability of materials and their cost, requirements of placing and finishing the fresh concrete, and properties of the hardened concrete (Neville, 1995; Troxell, et al., 1968; Shah et al., 1993).

Test methods are available together with proposals for design methods for fibre-reinforced concrete (FRC), but none was completely accepted and agreed upon within the concrete community. Paper I, based on the state-of-the-art report by Jansson (2007), briefly describes some of the design proposals available at the time, e.g. the Italian proposal by Ascione et al. (2010), the proposal made by the Swedish Concrete Society (1997) and the Norwegian proposal made by Thorenfeldt et al. (2006). The interest in fibres as reinforcement can be seen in the numerous workshops and conferences specifically focusing on this topic, e.g. Workshop proceeding no 2 (2001), Workshop proceeding no 4 (2003) and the FRC workshop (2007) at the FRAMCOS 6 Conference in Catania, Italy and Model Code (2010) among others. For the continued work within the project, it was realized that most of the current literature on FRC concerns the effect of fibres on the load-bearing capacity and increased ductility: Barr and Hasso (1985), Gopalaratnam et al. (1991), Banthia and Sheng (1996), who also made an attempt to quantify crack growth resistance, Pereira et al. (2004), Song and Hwang (2004) and Barros et al. (2005).

2.4 Natural Fibres

Commonly, natural fibres are classified in three categories according to their origin: plant fibres, animal fibres and mineral fibres. Plant fibres are further divided in several main groups depending on the place they are extracted (stem, leaves, fruit, seeds, etc.). Fibres produced by plants (vegetable, leaves and wood), animals and geological processes are known as natural fibres (Jayamol, et al., 1997). Researchers have used plant fibres as an alternative source of steel and/or artificial fibres to be used in composites (such as cement paste, mortar and/or concrete) for increasing its strength properties. These plant fibres, herein referred to as natural fibres, include coir, sisal, jute, Hibiscus cannabinus, eucalyptus grandis pulp, malva, ramie bast, pineapple leaf, kenaf, bast, sansevieria leaf, abaca leaf, vakka, date, bamboo, palm, banana, hemp, flax, cotton, oil palm, coconut and sugarcane (Ramakrishna & Sundararajan, 2005a; Agopyan et al., 2005; Paramasivam et al., 1984; Li et al., 2007; Asasutjarita et al., 2007; Toledo Filho et al., 2005; Taj et al., 2007; Rao, et al., 2010; Fernandez, 2002; Reis, 2006; Aggarwal, 1992; Satyanarayana et al., 1990; Ghavami et al., 1999; Danso, 2017).

Natural fibres are cheap and locally available in many countries. So their use as a construction material for increasing properties of composites costs very little (almost nothing when compared to the total cost of the composites). Their use can lead to sustainable development (Ramakrishna & Sundararajan, 2005b). Another benefit may also include the easy usage/handling of fibres due to their flexibility, because the problem arises when high percentage of fibres is to be used as in case of steel fibres. But for use of very high percentage of fibres, there is a need to invent a methodology for casting. Volume fraction and fibre content are two terminologies used for expressing the quantities of fibres in a given composite (Ramakrishna & Sundararajan, 2005a; Agopyan et al., 2005; Paramasivam et al., 1984; Ramakrishna & Sundararajan, 2005b; Li et al., 2007; Asasutjarita et al., 2007; Toledo Filho et al., 2005; Reis, 2006; Aggarwal, 1992; Satyanarayana et al., 1990; Ghavami et al., 1999). Volume fraction can be the part of total volume of composite or the part of volume of any ingredient to be replaced. Fibre content can be part of total weight of composite or the part of weight of any ingredient to be replaced. Researchers have emphasized on the selection of optimum quantity of fibres along with the optimum fibre length (for example, matrix/composite with 3% volume fraction of fibres and 4 cm fibre length can achieve maximum strength, any further increase/decrease in volume fraction and/or fibre length may decrease strength of matrix/composite). Fibre reinforced composites can be used for many civil engineering applications including roofing tiles (Agopyan et al., 2005), corrugated slabs (Paramasivam et al., 1984), simple slab panels (Ramakrishna and Sundararajan, 2005a), boards (Li et al., 2007; Asasutjarita et al., 2007; Aggarwal, 1992) and mortar (Toledo Filho et al., 2005).

According to Bledzki and Gassan (1999) and McKendry (2002), hemicellulose, cellulose and lignin are the three main components of biomass. In general, they cover respectively 20-40, 40-60 and 10-25 wt % for all natural fibres. Normally, all natural fibres, whether wood or non-wood types are cellulosic in nature. The major components of natural fibres are cellulose and lignin. Basically the natural fibre physical properties are influenced by the chemical structure such as cellulose content, degree of polymerization, orientation, and crystalline, which are affected by conditions during growth of plants as well as extraction method used. (Herrera-Franco & Valadez- Gonzalez, 2005).

2.4.1 Cellulose

According to Bismarck, et al., (2005) ~~c~~cellulose is a linear macromolecule consisting of D-anhydroglucose (C6H11O5) repeating units joined by β-1,4-glycosidic linkages with a degree polymerization (DP) of around 10,000. Each of the repeating unit contains three hydroxyl groups. These hydroxyl groups and their ability to hydrogen bond play a major role in directing the crystalline packing and also govern the physical properties of cellulose material”. In addition, all natural fibres are hydrophilic in nature and the mechanical properties of a fibre are significantly dependent on the DP (Mohanty et al., 2005).

2.4.2 Hemicellulose

As a matter of fact, hemicelluloses are polysaccharides composed by the combination of 5-and 6- ring carbon ring sugars and the polymer chains are much shorter (DP around 50 to 300) and branched, containing pendant side groups giving rise to its non-crystalline nature. Additionally, hemicelluloses are very hydrophilic and soluble in alkali and easily hydrolysed in acids (Bismarck, et al., 2005).

2.4.3 Lignin

Lignin is a high molecular-weight phenolic compound. Normally, it is resistant to microbial degradation and functions as structural support material in plants. In fact, the exact chemical structure of lignin still remains doubtful but most of the functional groups and units have been identified. Lignin is highly unsaturated or aromatic in nature because it has high carbon, low hydrogen content, amorphous and hydrophobic in nature. However, lignin is poly-functional that exist in combination with more than one neighbouring chain molecule of cellulose and/or hemicelluloses (Bismarck, et al., 2005; Mohanty et al., 2005).

2.5 Natural Fibres in Concrete

In their comprehensive summary of the use of natural fibres in cement composites, Aziz et al. (1984) reported that coconut coir, sisal, sugarcane bagasse, bamboo, jute and wood cement composites had already been investigated in more than 40 countries world-wide. Studies of other fibres such as pissava and henequey have since been reported by other authors including Agopyan (1988). Below are some examples of natural fibres in concrete;

2.5.1 Coir Fibre in Concrete

Sarikanat et al. (2014) have investigated the physical and mechanical properties of coir fibre cementious composites. In their study coir fibre incorporated composites were prepared by adding 0.4%, 0.6% and 0.75% coir fibre by weight of mixtures. From the experiments it was established that fibre incorporation affected water absorption capacity of mortars, improved their mechanical and thermal properties and decreased their unit weight. These effects became more important by increasing amount of fibres and when alkali treated coir fibres were replaced with untreated ones.

Ali et al. (2012) analysed the properties of coir fibre depending on fibre length and content. The coir fibre reinforced concrete (CFRC) strengths could be greater or smaller than that of plain concrete. It was reported that addition of coir fibre in concrete could improve the compressive strength, compressive toughness, modulus of rupture and total toughness index of concrete. CFRC with higher fibre content has a higher damping but lower dynamic and static modulus of elasticity.

Mahyuddin et al. (2013) made an experimental study on the compressive strength and concluded that incorporating a small amount of coconut fibre (0.6%) enhances the performance of concrete exposed to tropical climate by approximately 12%. The permeability of specimen increases with the fibre content in all types of exposure environments. It also recommended that the threshold value of the fibre content would benefit the long-term strength and durability of the concrete in all tested aggressive environments increases by 1.2%.

2.5.2 Oil Palm Fibre

Oil palm fibres are obtained from the oil palm tree. Oil palm (*Elaeis guineensis*) African tree in the palm family (Arecaceae), is cultivated as a source of oil. The oil palm is grown extensively in its native West and Central Africa, as well as in Malaysia and Indonesia (Corley et al., 1971). It is by far the most productive oil crop and alone is capable to fulfil the large and growing world demand for vegetable oils that is estimated to reach 240 million tons by 2050 (Corley, 2009). The genus *Elaeis* of the monocotyledonous palm family *Arecaceae* was formally introduced into botanical classification in 1763 by Nicholas Joseph Jacquin, who described *Elaeis guineensis*, known as African oil palm. The Greek word ―ελαιου”—oil, translated ―elaion,” gave the genus name (Hartley, 1977). The genus comprises two taxonomically well-defined species; the second is American oil palm, *Elaeis oleifera*. The well-known, phylogenetically closest relatives of oil palms are coconut palms, *Cocos nucifera*, which are also vegetable oil producing crops.

Oil palm or *Elaeis guineensis* originated from West Africa and the American oil palm, *Elaeis oleifera* is native to Central and South America. In other words, the oil palm tree is a native of tropical West Africa, and the other Palm Tree species of the genus is tropical American (Hartley, 1977). They are grown for their oil but only 10% is extracted to the oil and the rest (90%) is biomass. The biomass consists of palm kernel cake (59%), shell (5.5%), empty fruit bunch (22%), and fibre (13.5%) comes from the fresh fruit bunch (Rowell, 2008).

The world-wide grown crop is African oil palm naturally abundant in all the African rain forests. Both climate and humans shaped modern bio-geographic distribution. The late Holocene phase of dramatic forest decline, around 2500 years ago was favourable for the expansion of this sun-loving, pioneering species (Maley & Chepstow-Lusty, 2001). The oleaginous properties of the fruits were important in the subsistence economy in Africa for the past 5000 years (Sowunmi, 1999).

African oil palm trees can reach 15–18 meters in height, up to 30 meters in a dense forest. It is believed that some palm groves are more than 200 years old (Corley & Tinker, 2003). The leaves could be 8 meters in length. It takes about 2 years for the first leaf primordial to reach the fully expanded stage. To achieve maximal yield on commercial plantations, the leaf length is a critical trait that determines tree planting density.

In Eastern Asia the Palms, like other tropical families, extend along the coast reaching Korea and the south of Japan. In America a few small genera occur in the

Southern United States and California; and in South America the southern limit is reached in the Chilean genus *Juhaea* (the Chile coconut) at 37° S. latitude. The great centres of distribution for Palm Trees are tropical America and tropical Asia; tropical Africa contains only 2 genera, though some of the species, like the *Doum* Palm Tree, *Hyphaene thebaica*, and the *Deleb* or *Palmyra* palm tree, *Borassusfiabellifer*, have a wide distribution. With three exceptions Old and New World forms are distinct. The coconut, *Cocos nucifera*, is widely distributed on the coasts of tropical Africa, in India and the South Seas, the other species of the genus Palm are confined to the western hemisphere.

Mostly, palm tree is one of the most important agricultural and commercial plantation crops in Ghana. People recognize it as a tree of life because, every part of the palm tree such as fruits, trunks, leaves, shells of the fruits can be effectively utilized for living (Ahmad, et al., 2010; Eichhorn &Young, 2004).

2.5.3 Oil Palm 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 acceptable (as cited in Sivaraja et al., 2010).

2.5.4 Date Palm Fibre in Concrete

Ozerkan et al. (2013) presented an experimental work on mechanical performance and durability of treated palm fibre reinforced concretes. The experiments were concluded with four concrete mixes reinforced with varying percentages of treated natural date palm fibre up to 2.0%. The inclusion of fibre greater than 2.0% produced poor workability. Hence, it was suggested that such date palm fibre inclusion in mortars had to be limited to 2.0% by weight. Based on the experiment, it could be concluded that inclusion of treated palm fibres in cement matrix offers flexural strengths and durability performance improvements.

Kriker et al. (2005) tested and reported the mechanical properties of date palm fibres and concrete reinforced with date palm fibres in two different climates. They also studied continuity index, microstructure and toughness. The volume fraction and length of fibres chosen were 2-3% and 15-60mm respectively. It was concluded that male date palm fibre had 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.

2.5.5 Sisal Fibres in Concrete

Flavio de Andrade et al. (2011) have reported on the pull-out behaviour of sisal fibres from a cement matrix. Direct tension tests were performed on composites reinforced by 10% in volume of continuous aligned sisal fibre. From the experimental data the average adhesion bond strength 0.92MPa were reported for the fibre shape that promoted the best interfacial performance.

Sen and Reddy (2014) presented an experimental investigation of flexural strengthening of RC beams using sisal, artificial carbon and glass fabric reinforced composite system. Sisal fibre reinforced concrete (SFRC) strengthening of RC beams indicated good increase in its flexural strength and improvement in load deflection behaviour similar to carbon and glass fibre reinforced strengthening. The RC beam strengthened by SFRC showed highest amount of ductility, and also delayed the formation of cracks. Therefore, sisal fabric reinforced polymer composite system, with its various environmental benefits, being a natural fibre, could be used as alternative fabric reinforcement in fibre reinforced concrete, for flexural strengthening of RC beams.

2.5.6 Kenaf Fibre in Concrete

Udoeyo and Adetifa (2012) used water- retted kenaf fibres as reinforcement in mortar composites of size, 650 mm × 450 mm × 8 mm. Three fibre contents (0.5 %, 1.0 % and 1.5 %) and four fibre lengths (20 mm, 30 mm, 40 mm and 50 mm) were considered in the study. Physical and mechanical characteristics of the composites were evaluated according to ASTM and other appropriate standards. The results of the experimental program showed that although the bending capacity of kenaf fiber reinforced mortar sheet decreased with increase in fibre content, the flexural toughness and the impact resistance of the composite were enhanced with higher content of the fibre, compared with the control composites (composite without fibre). The water absorption and the fire resistance of the composite were also observed to be within acceptable limits specified by relevant standards.

2.5.7 Advantages and Disadvantages of Natural Fibres

There are several advantages in the use of natural fibres in concrete and mortar. Among others are:

- Low specific weight, which results in a higher specific strength and stiffness than synthetic fibres. This is a benefit especially in design for bending stiffness.
- It is a renewable resource; its production requires little energy, with no CO_2 emission while extracting the fibres.

Natural fibres have the following disadvantages:

- Lower strength properties, particularly its impact strength.
- Variable quality, depending on unpredictable influences such as weather.
- Moisture absorption, which causes swelling of the fibres.
- Lower durability, but fibre treatments can improve this considerably.
- Poor fire resistance.
- Price can fluctuate by harvest results or government policies on agriculture (Gram, 1983; Toledo Filho et al., 2000; Savastano Jr, et al., 2000)

2.6 Artificial Fibres in Concrete

Artificial fibres are tread-like materials invented by human researchers. Such fibres do not exist naturally. Below are some examples of artificial fibres in concrete;

2.6.1 Polymer Fibres

The earliest uses of polymer fibres in concrete were publicized by the burgeoning petrochemical industry following World War II (Bakis et al., 2002). Chemists and engineers from the early 1900‘s believed that the combination of polymer fibres and concrete composite materials with mechanical properties including crack resistance and impact resistance would result in a low cost concrete (Bakis et al., 2002). Since then, the idea of adding polymer fibres to concrete has attracted a wide variety of people in the construction industry. For every polymer fibre, there are three different diameters to choose from that are: 0.0002 in. (5 microns), 0.0006 in. (15 microns), and 0.0039 in. (100 microns) and for the length: 0.25 in. (0.64 cm), 0.3125 in. (0.79 cm), and 0.5 in. (1.27 cm). If the fibres have a small diameter, they are more effective than the larger diameter fibres because the smaller diameter fibre provide a larger surface area over which the fibres can bond. Additionally, if the smaller and larger length fibres have the same fibre-volume ratio, then the smaller diameter fibres would provide more fibres in a given mixture creating a stronger tensile strength.

Plastic shrinkage appears during the first few hours after casting while the concrete is still in a plastic state and has not attained any significant strength (Rahmani et al., 2012). Plastic shrinkage is a result from when water evaporates from a mixture, causing the concrete to weaken and eventually result in cracking. When polymer fibres are added to the mixture, the fibres are able to reduce the water evaporation by having the fibres control the bleeding channel (Cao, 2017). A bleeding channel is the process where all of the excess water is brought to the top surface through different paths. By incorporating polymer fibres into the mixture, the fibres are able to reduce the amount of water going to the top surface by reinforcing the concrete and disrupting the paths (Islam & Gutpa, 2016).

Impact resistance is the ability of concrete to consume energy. Seeing as how conventional concrete is brittle, the ability to take in energy under multiple impact loads is very low. Alhozaimy *et al*., (1996) explored how a polypropylene fibre, a type of polymer, interacts with pozzolans such as fly ash, silica fume, and slag to improve impact resistance when put in a mix together. They found that although the pozzolans form a stronger concrete, there is still a reduction in toughness. Pozzolans reduced the failure impact resistance of conventional concrete by 28% - 42%. When the fibres were added, the first-crack impact resistance of the concrete increased by 78% - 151% (Alhozaimy *et al*., 1996).

2.6.2 Steel Fibres

The study of steel fibre reinforced concrete started with experiments involving steel reinforcing materials like nails, pieces of cut wire and metal chips in 1910. Research was spearheaded by the United States in the early 1960s where the potential of steel fibres in concrete was evaluated. Since then, more research, development, and experimentation have led to an increase in the industrial application of steel fibre reinforced concrete (ACI Committee 554, 1982). Steel fibres are produced in many different forms ranging in length from 0.25 in. to 2.5 in. (0.6 cm to 6.4 cm) and in diameter from 0.02 in. to 0.04 in. (0.05 cm to 1.0 cm). These include straight and a variety of fibres deformations including hooked end, irregular, crimped, stranded, twisted, and paddled. In commercial use, about 67% of fibres used are hook-end fibres. This can be attributed to the fact that deformations help improve the bond between the matrix and the fibre. In the case of straight fibres, the lack of deformations creates a strain softening behaviour, which is similar to the response of concrete with no fibres. Fibres with deformations, however, display a strain hardening behaviour where the maximum load is much higher (Pająk & Ponikiewski, 2013).

There are two types of failure when it comes to fibre reinforced concrete. Either the fibres break or they are pulled out of the concrete. It takes less energy to pull a fibre out than to break it. Therefore, it is more desirable to ensure that the mode of failure with fibre reinforced concrete is to be bent and break. This mode of failure is desirable because steel has a high yield strength meaning it can take a lot of strain without much increase in stress. Steel fibres with deformations like hooks and crimps help with getting the steel embedded into the concrete where they can bend and yield. The most desirable mode of failure is a combination of a well embedded fibre that takes a lot of energy to debond with the concrete and for the fibre to bend and yield so it can reach maximum potential (Al-lami, 2015).

A study by You et al. (2010) explored the effects of replacing structural reinforcement, specifically stirrups, with steel fibre reinforced concrete. In a conventional reinforced concrete beam, stirrups are placed to counter shear cracks that occur when the tensile strength of the concrete is exceeded. Steel fibres are able to hold these cracks together before the cracks become bigger and cause failure. They experimented with completely replacing stirrups with steel fibres but this led to a lower ultimate load capacity. They then only partially replaced the stirrups with steel fibres and this hybrid had a higher load capacity. With this hybrid, they explored the effect that the amount of fibres had on the beam to find that an increase in shear strength had a linear relationship to the increase of fibres. This was because the number of fibres crossing the interface of the shear crack increased and there is a lot of energy absorption in both debonding the fibres with the concrete and the high yield strength of the steel fibres. This hybrid can help with relieving reinforcement congestion and increase the ability to use concrete in smaller spaces where it would be hard to fit a large number of stirrups (You et al., 2010).

Steel fibre reinforced concrete also helps with corrosion resistance (Wang et al., 2000). An oxide layer that forms during cement hydration protects the steel from reacting with oxygen and water, which causes rust. Corrosion that occurs at localized regions of steel is often due to the breakdown of this layer. Conventional concrete with rebar as the sole reinforcement usually shows signs of failure due to corrosion of the reinforcing rebar when rust pushes against the concrete creating large cracks (Wang et al., 2000). Galvanic corrosion is an accelerated type of corrosion caused by two metals in contact with each other in a corrosive electrolyte environment like sodium chloride. This type of corrosion can be avoided by using steel fibres in addition to reinforcing rebar rather than stirrups because there are fewer stirrups in contact with the reinforcing rebar. In cases where the fibres go through galvanic corrosion due to contact with the reinforcing structural rebar, the volume of the fibres is so small that the stresses they enact on the concrete are smaller compared to the bursting stresses created by larger diameter stirrups (Tang, 2017). Recent research suggests that steel fibres can also act as sacrificial anodes protecting the rebar and reducing or even topping corrosion through different processes (Berrocal et al., 2016).

2.6.3 Glass Fibres

Exploration of fibreglass reinforced concrete began in the late 1940s. However, the Eglass (which stands for ―electrical grade" glass) that was used because of its high strength could not resist the high alkalinity within the matrix, which resulted in the degradation of the glass fibres. Fibreglass has a high silica content that reacts with the sodium and potassium hydroxides in the mortar, which causes the deterioration of the fibres and formation of a gel which can create swelling within the concrete. Once the force created by the swelling is greater than the tensile strength of the concrete, cracks will form and allow water in that will freeze and thaw creating even bigger cracks. The water can also carry substances that will accelerate corrosion. Eventually, these processes will result in the reduction of strength and deterioration of the concrete as a whole. In the 1970s, a new type of glass was used that produced better results in concrete. The solution was the addition of zirconia to the glass formula and the use of low alkali cement. Zirconia resists the alkalis with the cement instead of chemically reacting like the silica. These alkali resistant (AR) glass fibres are still the type that is currently used. For the past 40 years, glass fibre reinforced concrete has been used with minimal chemical destruction of the fibres (Palmer, 2015).

In addition to increasing concrete in ductility and reducing crack widths, glass fibres specifically have very high tensile strength, are considerably economical, and very lightweight. In a study by Kiran and Rao, conventional concrete was compared with concrete that had 5%, 6%, and 7% glass fibre added. On average, the samples with the glass fibres had 19% higher strength than the samples without fibres (Kiran & Rao, 2015). A single glass fibre that is used in concrete can have anywhere from 50 to 200 strands, which means the cementitious bonds are not attached to every strand of glass which results in the ductility drastically increasing. As the outer strands of the glass fibre are pulled, the inner strands may stay put creating a greater ability to deform (Palmer, 2015).

It has also been found that the addition of glass fibres increases the peak compressive load. Samples of glass fibre reinforced ceramic concrete with up to 2% fibre content had up to 19% higher peak compressive strength compared to samples without glass fibres (Tassew & Lubell, 2014). Glass fibres are also more resistant to corrosion when compared to materials like steel because the iron in the steel corrodes when exposed to water and oxygen and glass does not. Corrosion is a key factor in the longevity of a concrete structure. As a material corrodes, a substance is produced (rust). That substance creates an excess volume that applies pressure to and debonds the concrete surrounding it. This leads to cracking that allows more environmental substances to permeate through the concrete. For example, once a crack forms, water can fill that crack and freeze, which widens the crack or salt, can spread through the cracks, which accelerates the corrosion of the rebar. Eventually, the concrete will completely deteriorate.

Previous researches about fibre reinforced concrete show that there is an opportunity for significant growth within this industry. They have also identified strength and corrosion resistance as benefits of fibre reinforced concrete.

2.7 Bonding between Natural Fibre and Cement Paste

The research pertaining to natural 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 FRC concluded that there are four variables which govern the bond between fibres and cement paste: water/cement ratio, porosity, fibre morphology, and compaction (Coutts, 1987). 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 natural 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 natural fibres like sisal, kraft, coconut, and eucalyptus, cause the fibre to create a stronger bond with the surrounding cement paste (Bentur & Akers, 1989; Silva *et al.,* 2010; Mohr *et al.* 2005; Savastano Jr. *et al.,* 2000; Soroushian & Marikunte, 1994; Toledo Filho *et al.,* 2000; Tonoli *et al.,* 2009). 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 (Yaremko, 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. & 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 natural fibre-reinforced cement-based composite over time is due to an increase in the fibre-matrix bond through mineralization, which causes the fibre to become brittle and fail in rupture (Toledo Filho *et al.,* 2000, as cited in Yaremko, 2012).

2.8 Comparison of Natural Fibres with Artificial Fibres

Natural fibres are abundantly available and are comparatively cheaper or cost effective materials. They have lower pollutant emissions and lower greenhouse gas emissions. They enhance energy recovery. They have low density with high specific modulus. They have high toughness and acceptable specific strength. They are recyclable, non-carcinogenic and bio-degradable in nature, soft and non-abrasive. Their uses also help to reduce over-dependence on non-renewable material sources and also reduce stress on the environment.

But artificial fibres are prone to creep, they are expensive, they have higher pollutant emission. They have higher energy consumption. Their use contributes to high cost of building component (Jansson, 2008; Sivaraja, 2010; Verma et al., 2013).

CHAPTER THREE

EXPERIMENTAL DESIGN AND PROCEDURE

3.0 Introduction

This chapter dealt with the methodology that was used to find answers to the research objectives. The objective of this chapter was to experiment on the use of natural fibres as an enhancement of concrete. The chapter further describes experimental studies on the use of palm bunch fibre (vegetable fibre) as enhancement of concrete. The study focused on the effects of aspect ratio of natural fibres (palm bunch fibre) on the properties of concrete.

The chapter has four sections namely; Materials, Experimental Methods and Procedures, Preparation of specimens (Cubes, Cylinders and Beams) and Testing methods.

3.1 Materials

The materials used to prepare the specimens for the study were Ordinary Portland Cement (OPC), fine aggregates, coarse aggregates, palm bunch fibers and water.

3.1.1 Cement

Ordinary Portland cement produced from Ghana cement (GHACEM), was used for the experiment. It was purchased from a retailing shop prior to the experiment date and was kept in the laboratory, very dry place in order to do away with any premature hydration which could lead to caking of the cement. In all 265.42kg of cement was used for the experiment. The cement composition was obtained through literature review from manufacturer‘s text. Figure 3.1 shows a bag of cement that was used for the study.

Figure 3.1: A bag of cement

3.1.2 Fine Aggregates (Sand)

The fine aggregate was obtained from Buoku, a sand winning site at Sunyani. The sand was air dried to saturated surface dry in order not to alter the chosen water-cement ratio. The drying of the sand was done in a room temperature condition for 24 hours. The sand was sieved to expel any foreign material such as roots, stones etc. that might be present in it and might have adverse effect on the performance of the concrete. This was achieved by using BS 5mm sieve to sieve the sand. The total quantity of sand used for the experiment was 477.75 kg. In addition, a silt test was performed on the sand to ascertain the silt content. Sample of the fine aggregate is shown in Figure 3.2.

Figure 3.2: Sample of fine aggregate

3.1.3 Coarse Aggregate (Gravels)

Crushed aggregates from Gasto Chipping and Quarry production at Sunyani was used. The aggregate was mixed aggregate of different sizes, up to 19.05mm. Sieve analysis test was performed to know the particle distribution of the aggregate. Sample of the crushed aggregate is shown in figure 3.3**.** The total quantity of crushed aggregates used for the experiment was 800.07 kg.

Figure 3.3: Sample of crushed granite

3.1.4 Fibres

The fibres were palm bunch fibres with average diameter of 0.3mm and lengths of 25mm, 30mm, 40mm and 50mm, corresponding to approximate aspect ratios of 75, 100, 125 and 150, respectively. Sample of the fibres are shown in Figure 3.4.

Figure 3.4 Sample of palm bunch fibre

3.1.5 Water

Water used for this research was tap water from Ghana Water Company Limited, obtained from Sunyani Technical University campus.

3.2 Experimental Methods and Procedure

3.2.1 Fibre Extraction

To facilitate the extraction of fibres, palm bunches were soaked in water as shown in Figure 4.5 for one month and later placed in 10% concentration of sodium hydroxide (NaOH) for seven days. Careful Physical extraction of the fibres by hand as shown in Figure 3.6 then followed after the seven days. Fibres were separated while minimising structural damages during the extraction process. The fresh water was meant to remove the pith particles and the lignin from the surface of the fibres (Nanayakkaza, 2005). Studies conducted by Ramakrishna and Sundararajan (2005b) on the durability of natural fibres, indicated that NaOH is also a good solvent for both lignin and hemicelluloses, and also palm bunch fibre retained about 73% of its initial tensile strength when placed in NaOH for up to 60 days. Based on this knowledge, the palm bunches were further placed in NaOH for seven days to dissolve the lignin and hemicelluloses to facilitate extraction of fibres.

Figure 3.5: Palm bunches soaked in water

Figure 3.6: Physical extraction of fibres by hand

3.2.2 Determination of Average Diameter of Fibres

Hundred pieces of fibres were randomly selected from the prepared palm bunch fibres. The diameter of each of the selected fibres was measured using a micrometre screw gauge as shown in Figure 3.7.

Figure 3.7: Measuring of diameters of fibres with micrometre screw gauge

The diameters of the selected fibres ranged between 0.27mm and 0.32mm. The average diameter was determined by dividing the sum of the total diameter by the number of fibres selected. The aspect ratio was then determined using the formula; $FAR = \frac{l}{d}$, Where;

FAR = Fibre Aspect Ratio,

l = length of fibre,

d = dimeter of fibre.

3.2.3 Silt and Clay Test

This test was carried out in accordance with BS 882:1992. Sample of sand to be used was taken to the laboratory for silt and clay test. The following materials and tools were used for the test: sand, salt, water, measuring cylinder - 250ml and 500ml, and stirring rod. To start, a saline solution was prepared by taking 2.5g of fine salt and dissolving it into 250ml of water in the 500ml measuring cylinder. The purpose of the saline solution was to accelerate the rate of settling of the various particles of the sand. 50ml of saline solution was poured into the 250ml cylinder (glass). The sand was then added into the same cylinder with the 50ml saline solution till the water level in the same cylinder reached the 100ml reading level. An additional saline solution was added till the water read 150ml. The additional water was to facilitate the ease of stirring. The stirring rod was used to stir the mixture thoroughly. The cylinder was then placed on a flat surface for three hours for sedimentation. The height of sand and silt were measured and expressed in percentage:

$$\text{Silt and clay content (\%)} = \frac{\text{Height of silt and clay} \times 100}{\text{Height of sand}}$$

3.2.4 Sieve Analysis Test on Coarse Aggregates

This test was done in accordance with BS 812: Part 103.1 1985. The apparatus used for the test were: Quartering machine, Automatic sieve shaker, Trays, Set of BS Sieves and Beam balance. The samples were air dried and quartered to get a statistically convenient sample for the test. The quartered sample was weighed and recorded. The weighed sand was poured into the arranged BS sieves and covered. The sieves containing the material were subjected to five minutes shaking using the automatic shaker. The remained sample on each sieve was weighed and recorded. Aggregate sizes from12.5mm and below was used. Figure 3.4 shows the automatic shaker. The quantity of the aggregate used for the whole research was 800.07 kg.

Figure 3.8: The automatic shaker set up

3.3 Specimens Preparation (Cubes, Beams and Cylinders)

The preparation of the cubes, cylinders and beams were in accordance with British Standard (BS 1881: Part 108: 1983).

3.3.1 Mix Proportion

A strength target of 30MPa was to be achieved. Trial mixes were conducted and a mix ratio of (1:1.8:2.8/0.5, 1 part of cement: 1.8 parts of fine aggregate: 2.8 parts of gravels and water/cement ratio of 0.5) yielded the targeted strength of 30MPa. All the concrete mixes were prepared with a water-to-cement ratio of 0.5 and a mix ratio of 1:1.8:2.8 for cement: fine aggregate: coarse aggregate. Fibre content of 0.5% by weight of cement was used with various aspect ratios of 75, 100, 125 and 150. The concrete mixes were in accordance with the provision of BS 1881, Part 108, 1983.

3.3.2 Batching

For reliability of result, the study adopted batching by weight. Sufficient moulds in accordance with BS 1881 were available to enable simultaneous casting of all specimens. This eliminated discrepancies such as variation in mix proportion, water content etc., which might have arisen if more than one mix was required per casting.

Figure 3.9: Batching of materials with a digital scale

3.3.3 Mixing Procedure

According to literature, to ensure complete distribution of fibres throughout a concrete mix, sometimes it becomes necessary to stop the mixer, remove the mixing paddles, sprinkled a layer of fibres onto the concrete surface and reactivated the machine for approximately five revolutions after each addition. In an endeavour to ensure that the fibres were well distributed and randomly orientated, and thus prevent balling or interlocking, the concrete together with the fibres were mixed by hand in this research the mixes were in small quantities.

The dry cement and sand were mixed by hand till a grey colour was achieved. The coarse aggregate was added and the mixing continued. About 80% of the water was added while mixing. To ensure a complete distribution of fibres throughout the concrete mix, fibres were fed continuously in smaller quantities to the concrete while stirring. Finally, the remaining water was added and the mixing continued until a homogeneous paste was obtained. The mixing procedure is shown in Figure 3.6.

Figure 3.10: Hand mixing of materials

3.3.4 Testing of Fresh Concrete

The slump test was used to test the workability of the concrete. A slump cone frustum mould (diameters 200mm and 100mm, and height 300mm) was filled with concrete in three layers of equal volume. Each layer was compacted with 25 strokes of a tamping rod of length 600mm long and 16mm diameter with a hemispherical tip. The rodding was uniformly distributed and full depth for the first layer and just penetrating previous layers for the second and third layers. The concrete was struck off by a screeding motion and by rolling the rod across the top of the cone. Immediately, after screeding off, the cone was lifted up straight. The slump cone was then set next to the concrete and the difference in height between the slum cone and the original center of the specimen was noted. With the rod set on the cone, the slump measurement was taken using tape measure. Figure 3.7 is the set up for the slump test. The test was performed for all samples. The slump test was performed in accordance with BS 1881: Part 102:1983.

Figure 3.11: Slump Test set up

3.3.5 Casting of Concrete

Twenty-five cubes of size 150mm were cast to be used for compression test. For split tensile test, 25 cylindrical specimens of diameter 150mm with 300mm length were cast. Again, 25 number of 150×150×600 beams were cast for flexural test.

In all cases, the moulds were filled in 3 layers. At each fill, the moulds with the contents were compacted on a vibration table. This method of compaction was to align the fibres normal to the direction of vibration (Parameswaran & Rajagopalan 1975).

3.3.6 Curing of Specimens

The specimens were stripped from the moulds 24 hours after casting and submerged in water until testing. The specimens were left in the water to cure about 55°F for 28 days before testing. Figure 3.8 shows specimens being cured in a bath at the laboratory. Curing was in accordance with BS 1881: Part 111: 1983.

Figure 3.12: Specimens being cured in a bath

3.4 Testing Methods

For this study, the following tests were performed: Visual Inspection of Hardened Specimens, Compressive Strength, Flexural strength, Split Tensile strength and Density. All the tests were executed after 28 days of curing at the Sunyani Technical University Building Construction laboratory.

3.4.1 Visual Inspection of Hardened Specimens (Cubes, Beams and Cylinders)

Visual inspection on specimens was conducted to determine any physical changes on the specimens. To achieve this, all the specimens were arranged on a platform and a special observation was made on each category. Figure 3.9 shows samples of specimens arranged for visual inspection.

Cubes **Cylinders** **Beams**

Figure 3.13: Samples of specimen arranged for visual inspection

3.4.2 Compressive Strength Test

This test was done in accordance with BS 1881: Part 116 (1983). Cubes were tested on the 28th day of curing. The compressive strength test was conducted using digital compressive strength testing machine manufactured by Controls Milano, Italy.

The testing took place at Sunyani Technical University Building Construction laboratory. The compressive strength was measured by breaking the concrete cube specimens in the compression machine. The cubes were first weighed to ascertain their weights. Cubes were loaded into the machine as shown in Figure 3.10. An increasing compressive load was applied to the specimen until failure occurred to obtain the maximum compressive load. The dimensions of the cubes, weight of the cubes and the number of days of curing were captured by the machine before the compressive loads were applied on specimens in the machine. These parameters were to help the machine calculate the appropriate strength of the specimen.

Figure 3.14: Compressive Strength test set up

3.4.3 Flexural Strength Test

This test was in accordance with BS 1881: Part 118: 1983. The flexural strength was conducted on the beam of size 150mm × 150mm × 600mm at the end of 28 days of curing. The determination of the flexural strength was done using the digital flexural strength machine manufactured by Controls Milano, Italy. These parameters were recorded before loading the beam: days of curing, specimen dimension and weight. The specimens were placed in a 3-point load machine as shown in Figure 3.11. The specimens were then subjected to a load. The load was gradually increased to break the specimen. The maximum applied load by the testing machine at failure of the specimens was recorded as well as their strengths.

Figure 3.15: Flexural Strength Test set up

3.4.4 Split Tensile Strength Test

This test was done in accordance with BS1881, Part 117, 1983 which is similar to IS 5816 (1999). The specimens were placed in the machine such that the longitudinal axis is perpendicular to the load as shown in Figure 3.12. The specimens were then subjected to a load. The load was continuously increased without shock to break the specimen. The maximum applied load which broke the specimen was recorded as well as the strength. The method for the determination of tensile strength according to BS1881, Part 117, 1983 is given by

$$\sigma_t = \frac{2F}{\pi Ld}, \quad \text{where,}$$

F = Applied force

L =Height of cylinder

D =Diameter of cylinder

However, in this study a digital split tensile strength machine which gives a direct reading was used.

Figure 3.16: Split Tensile Strength Test set up

3.4.5 Density of Specimens

This test was carried out in accordance with BS 1881: Part 114: 1983. The specimens were weighed before crushing. This data including the dimensions of specimen were used to calculate for the densities of specimen.

Densities of specimen were calculated as:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

The specimens were placed on the scale as shown in Figure 3.17 for weighing.

Figure 3.17: Specimens being weighed

The results of the laboratory experimentation are analysed in the next chapter. The raw data is in the appendix for cross examination.

3.4.6 Toughness

The toughness was calculated as the area under the stress-strain curve of up to a strain of 1.4mm, which was calculated by interpolation from the flexural test results figures.

CHAPTER FOUR

PRESENTATION OF RESULTS

4.0 Introduction

This chapter presents the results from the study. It includes results from all experiments that were carried out during the study.

4.1 Silt and Clay Test

This test was conducted to establish the suitability of the fine aggregate for concrete production. The experiment recorded these measurements:

Height of sand = 115ml

Height of clay and silt = 8.6ml

The clay and silt content was calculated as: $S_c = \frac{HSC}{HS} \chi 100\%$

$$S_c = \frac{8.6}{115} \chi 100\%$$

$$= 7.48\%.$$

Where;

S_c = clay and silt content per cent,

HSC = height of clay and silt (fines),

HS = height of sand.

4.2 Sieve Analysis of Crushed Granite

The sizes of the crushed granite ranged between 0.075mm and 19.05mm. The study used particles between 0.075mm and 12.7mm. Figure 4.1 shows the particles distribution of granite used for the cubes, cylinders and beams. Particles of size 12.7mm was approximately 90% in the distribution. However, there were substantial amount of various particles in the distribution ranging from 0.075mm to 12.7mm.

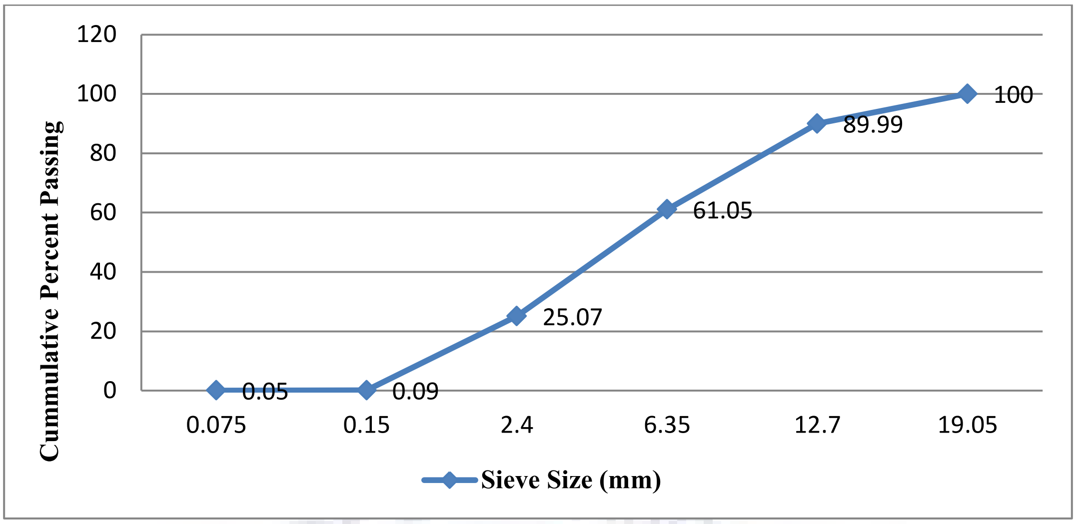

Figure: 4.1: Particles distribution of crushed granite

4.3 Determination of Average Diameter of Fibres

Hundred pieces of fibres were randomly selected from the prepared Palm Bunch Fibres. The diameter of each of the selected fibres was measured using a micrometre screw gauge. The average diameter was then determined. Table 4.1 shows the result of average fibre diameter which was 0.3mm.

Table 4.1: Diameter of Palm Bunch Fibre

Fibre	Average Diameter (mm)	Average Diameter (mm)
1 - 10	0.31	0.30
11 – 20	0.29	
21 – 30	0.28	
31 – 40	0.32	
41 – 50	0.30	
51 – 60	0.31	
61 – 70	0.29	
71 – 80	0.27	
81 – 90	0.33	
91 – 100	0.30	

Source: Field data 2018

4.4 Workability/Slump Test

The slump test is prescribed by BS 1881: Part 108:1983 and was used to test the workability of the concrete. The slump test result is shown in Figure 4.2. The slump was measured in millimetres. The slump results ranged from 46 to 58. The aspect ratio of 75 recorded 54mm, 100 was 51mm, 125 was 50mm and 150 also recorded 46mm, while the zero fibre (control) measured 58mm.

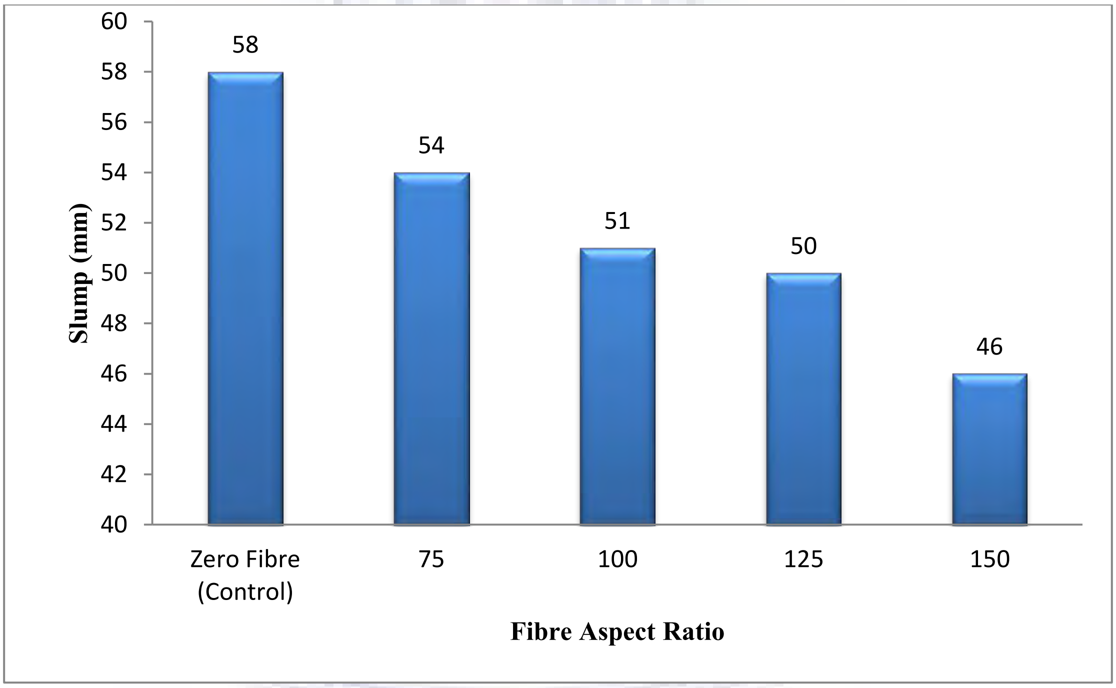

Figure 4.2: Aspect ratio versus Slump

4.5 Visual Inspection of Hardened Specimens (Cubes, Cylinders and Beams)

Visual inspection of specimens was carried out to find out if there were any physical changes in the specimens. In general, there was not much difference in the physical appearance of all the specimens in terms of size, shape and colour. Specimens maintained their sizes, shapes and had the normal grey colour of concrete. However, grey solid particles were found at the bottom of the bath most likely to come from the broken edges of specimens.

4.6 Compressive Strength

Compressive strength test result is shown in Table 4.2. The zero fibre (control) yielded the highest compressive strength value of 31.15 N/mm^2 for the 28 days curing age, followed by aspect ratio 75 yielding 29.41N/mm^2. Aspect ratio‘s 100, 125 and 150 yielded compressive strengths of 28.76N/mm^2, 28.43N/mm^2 and 27.02N/mm^2 respectively for the 28 days curing period. From the table, specimens from the four aspect ratios decreased in strength compared with the specimen without fibres.

Table 4.2: Compressive Strength of Concrete made from Different Aspect Ratios of fibre.

Aspect Ratio	N	Mean	Std Dev
Zero Fibre (control)	5	31.15	0.78837
75	5	29.41	0.15353
100	5	28.76	0.11597
125	5	28.43	0.34838
150	5	27.02	0.50463

Source: Field data 2018

4.6.1 Effect of FAR on CS at Constant FC and W/C = 0.5

Regression analysis was performed using Microsoft Excel to assess the relative contribution of Fibre Aspect Ratio (FAR) in the prediction of compressive strength of concrete enhanced with Palm Bunch Fibre at constant Fibre Content (CF) and Water/Cement ratio (W/C). From the regression equation in Figure 4.3, it was realised that there is a negative correlation between the two variables. This means that a percentage increase in the FAR would decrease the compressive strength by about 0.03 N/mm^2. The R^2 which is equal to 0.92 indicates that 92% of the variation in the compressive strength can be explained by the value of the fibre aspect ratio in the concrete. The value 31.78 represents the compressive strength for zero FAR.

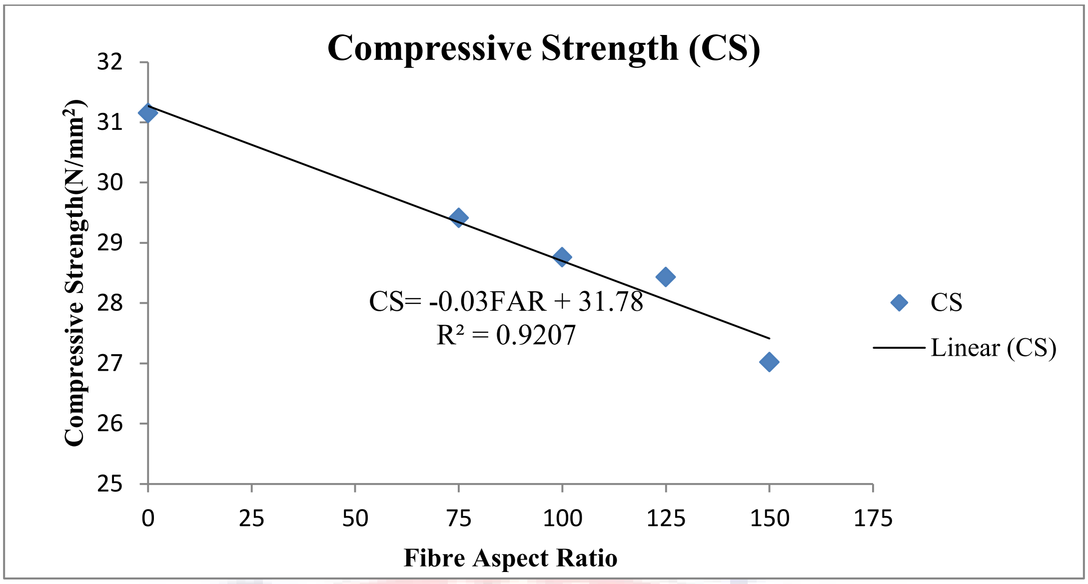

Figure 4.3: Effect of FAR on Compressive Strength (CS)

4.7 Flexural Strength

The summarised results of tests for Flexural strength carried out on the samples in the experiments are shown in Table 4.3. The flexural strength also took a different pattern. Aspect ratio 150 recorded the highest strength value of 2.65N/mm^2 followed by 125, 100, and 75 recording strength values of 2.50 N/mm^2, 2.42 N/mm^2, and 2.28 N/mm^2 respectively. Zero fibre or plain concrete (control) recorded the lowest strength value of 2.19N/mm^2.

Table 4.3: Flexural Strength of Concrete made from different aspect ratios of fibre

Aspect Ratio	N	Mean	Std Dev
Zero Fibre	5	2.19	0.08204
75	5	2.28	0.08204
100	5	2.42	0.11597
125	5	2.50	0.07596
150	5	2.65	0.15852

Source: Field data 2018

4.7.1 Effect of FAR on FS at Constant FC and W/C = 0.5

Figure 4.4 shows the relationship between Flexural Strength and FAR in concrete mix. It can be observed that there is a positive correlation between the two variables. The R^2 value, 0.8938 indicates that 89.38% of the variation in flexural strength can be explained by the FAR in the concrete. It can also be noticed from the equation, FS = 0.003FAR+2.1404, that the value 2.1404 represents flexural strength without the influence of FAR. The value 0.003 is the co-efficient of FAR in the mix which means that if the FAR is increased by one unit, the flexural strength will also increase averagely by 0.003 N/mm^2.

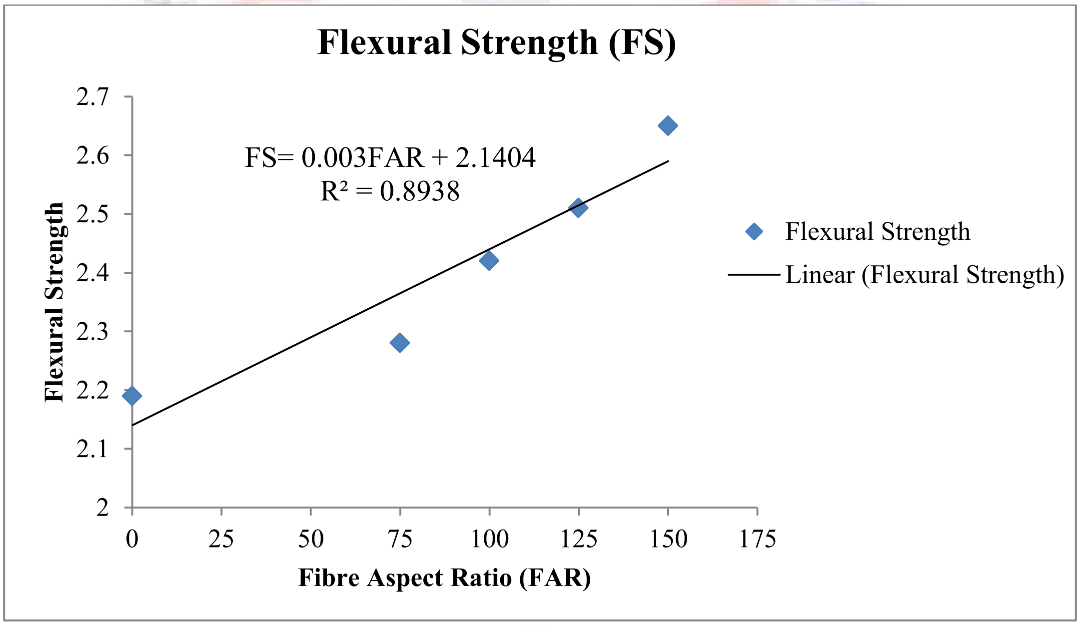

Figure 4.4: Effect of FAR on Flexural Strength (FS)

4.8 Split Tensile Strength

The splitting tensile strength test was used to determine the tensile strengths of the plain concrete and concrete with the various aspect ratios of fibre inclusions at the 28-day curing age. Unlike the plain concrete cylinders, the two halves for mixes with various aspect ratios of fibres were held together by the fibre after splitting, Fig. 4.5A. However, for the plain concrete, the cylinders split down the centre as expected as shown in figure 4.5B below.

A B

Figure 4.5: Condition of concrete cylinder after splitting

The summarised results of the splitting tensile strength in Table 4.4 indicate that there was an increase in tensile strength for the 28 days of curing for all the mixes. Aspect ratio 150 yielded the highest percentage increase by 15.8%, followed by 125, 100 and 75 which increased by 13.7%, 12.0%, and 3.3% respectively.

Table 4.4: Split Tensile Strength of Concrete made from different aspect ratios of fibre.

Aspect Ratio	N	Mean	Std Dev
Zero Fibre	5	1.83	0.12748
75	5	1.89	0. 07791
100	5	2.05	0.02588
125	5	2.08	0.07470
150	5	2.12	0.01924

Source: Field data, 2018

4.8.1 Effect of FAR on STS at Constant FC and W/C = 0.5

To ascertain the relationship between Flexural Strength and FAR in concrete mix, a regression analysis was performed using Microsoft Excel. It can be observed from the formula in Figure 4.5 that there is a positive correlation between the two variables. The $R^2 = 0.8869$ indicates that 88.69% of the variation in Split Tensile Strength can be explained by the FAR in the concrete. It can also be noticed from the figure that from the equation, STS = 0.0021FAR+1.8075, the value 1.8075 is the Split Tensile Strength of concrete with zero fibre. The value 0.0021 is the co-efficient of FAR in the mix which means that if the FAR is increased by one unit, the split tensile strength also increases averagely by 0.0021 N/mm^2.

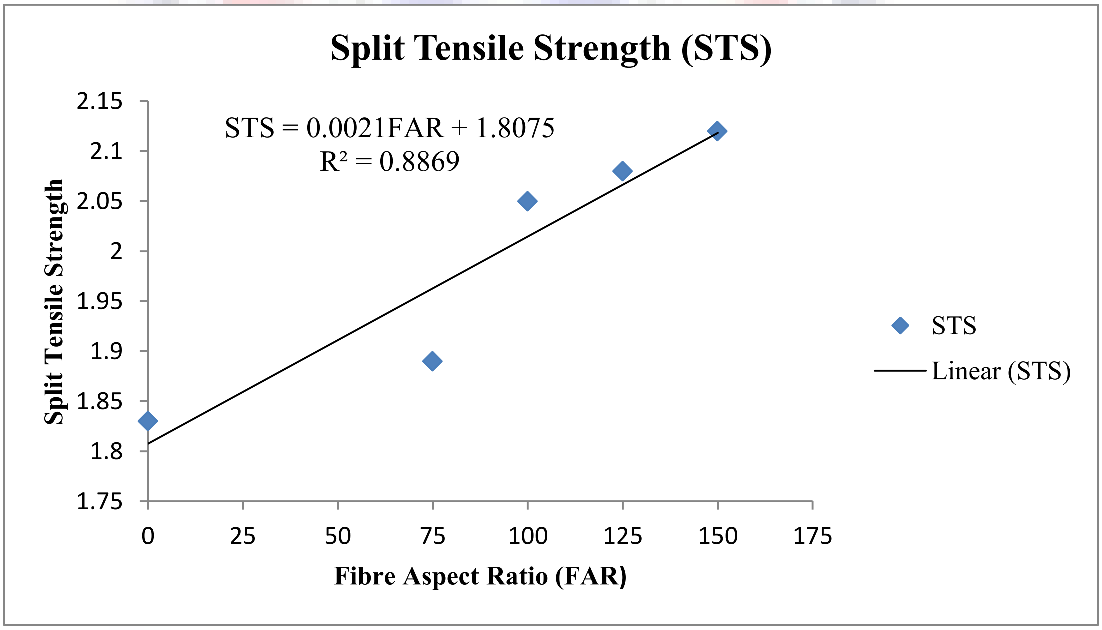

Figure 4.6: Effect of FAR on Split Tensile Strength (STS)

4.9 Density

The density of the concrete produced decreased with the inclusion of fibre. As shown in Figure 4.7, with no fibres (control), the density of the concrete was 2524kg/m. With 75, 100, 125 and 150 aspect ratios, the average densities recorded were, 2430kg/m^3, 2415kg/m^3, 2379kg/m^{3}and 2352kg/m^3 respectively (3.72%, 4.32 %, 5.75% and 6.81% lower than plain concrete or concrete with zero fibre respectively).

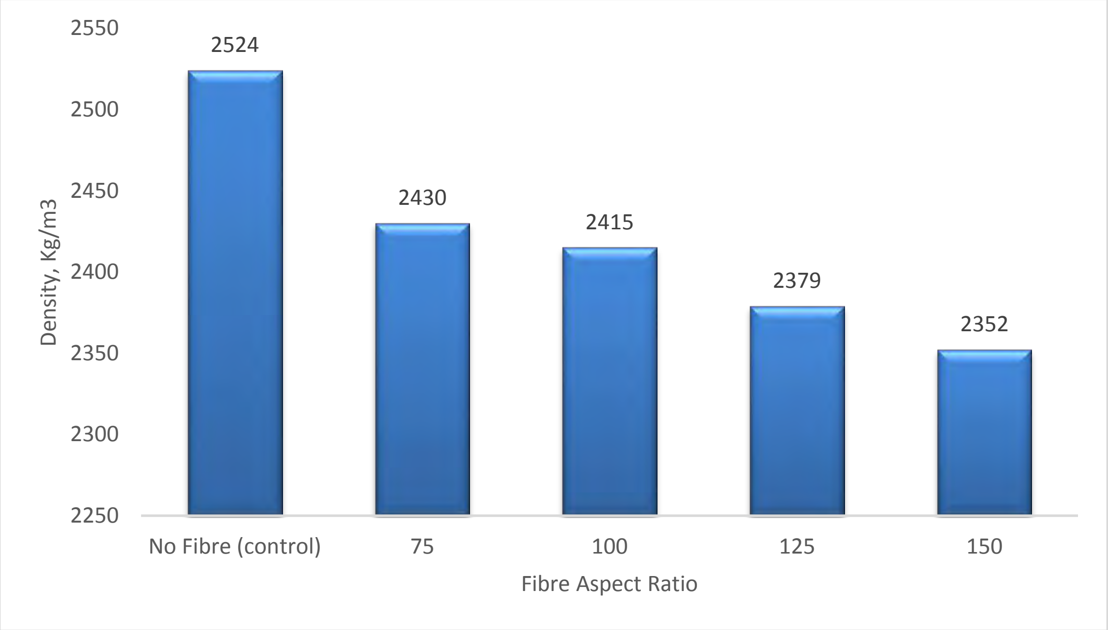

Figure 4.7: Aspect Ratio versus Density

4.10 Toughness

Toughness is the absorbing capacity of concrete. It expresses the ductility of concrete. Generally, from Table 4.5, the inclusion of Palm bunch fibres up to a certain fibre aspect ratio at constant fibre content would increase the toughness of concrete. The toughness was calculated as the area under the stress-strain curve under flexure which was deduced by interpolation up to a strain of 1.4mm. It could be observed that the toughness for the control specimen was 2.7 N/mm^2, and is lower than the toughness of the specimens with Palm bunch fibre. It can also be noticed that the toughness increased proportionally with increase in aspect ratio and reached a maximum of 4.40 N/mm^2 at aspect ratio 125, then falls to 3.68 N/mm^2 at aspect ratio 150. The toughness of the various aspect ratios is schematically presented in a stress strain curve in Figure 4.8.

Table 4.5: Toughness

Strain	Flexural Strength					Toughness				
	Zero Fibre	**FAR 75**	**FAR 100**	**FAR 125**	**FAR 150**	**Zero Fibre**	**FAR 75**	**FAR 100**	**FAR 125**	**FAR 150**
0	0	0	0	0	0	0.01	0.02	0.02	0.02	0.02
0.2	0.1	0.2	0.2	0.2	0.2	0.05	0.07	0.08	0.08	0.07
0.4	0.4	0.5	0.6	0.6	0.5	0.11	0.13	0.15	0.18	0.15
0.6	0.7	0.8	0.9	1.2	1	0.17	0.2	0.22	0.3	0.25
0.8	1	1.2	1.3	1.8	1.5	0.24	0.29	0.31	0.42	0.36
1	1.4	1.7	1.8	2.4	2.1	0.33	0.39	0.41	0.53	0.48
1.2	1.9	2.2	2.3	2.9	2.7	0.39	0.43	0.47	0.59	0.53
1.4	2	2.1	2.4	3	2.6	1.4	1.47	1.68	2.1	1.82
		Total				**2.7**	**3.0**	**3.32**	**4.4**	**3.68**

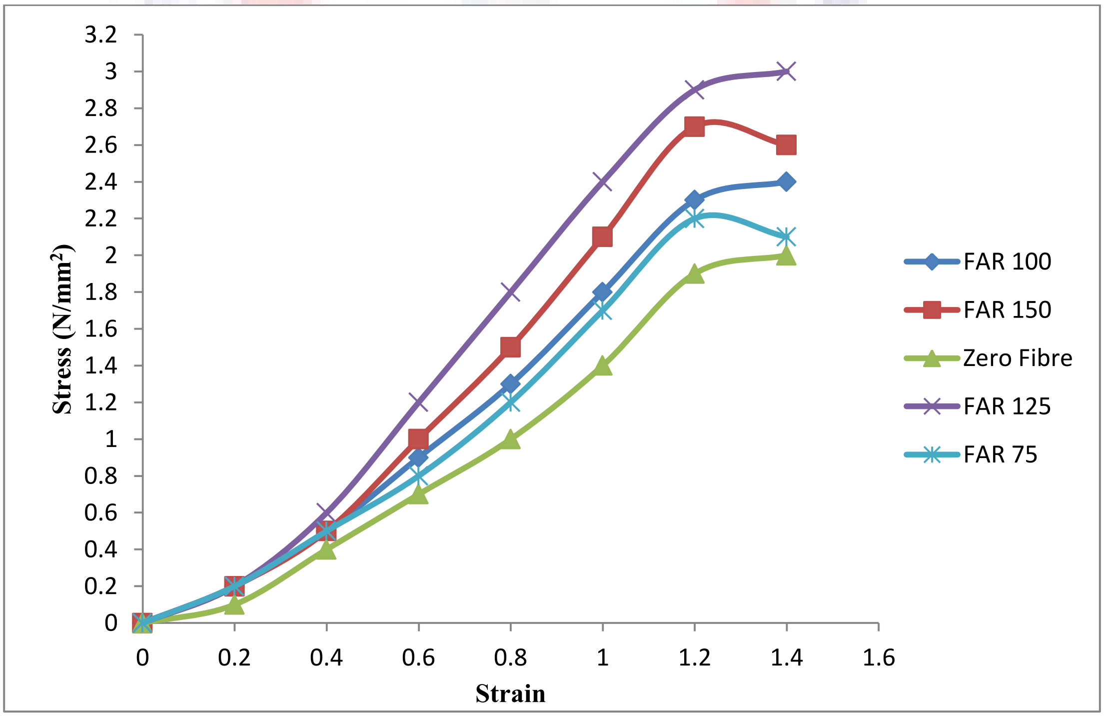

Figure 4.8: Stress Strain Curve for Concrete with Different Aspect Ratio of Fibres

CHAPTER FIVE

DISCUSSION OF RESULTS

5.0 Introduction

This chapter gives explanations to the results in the previous chapter. It also compares the results to literature in order for conclusions to be drawn.

5.1 Silt and Clay Analysis

This test was conducted to establish the suitability of the fine aggregate to be used for the concrete. The experiment recorded 7.48%. The value falls within the standards of ASTM‘s allowable silt and clay content of 10% by weight in sand used for concrete production (ASTM C117, 1995). Therefore, the sand is suitable for concrete.

5.2 Workability Test (Slump)

Workability is the ability of a fresh (plastic) concrete mix to fill the form/mould properly with the desired work (vibration) and without reducing the concrete's quality (Neville, 1995).

The degree of workability ranges from very low to high: 0-25 very low, 25-50 low, 25-100 medium, and 100-172 high (Neville, 1995). The slump results from the study were within the range of 46 to 58 which fall within the medium range. However, the slump reduced with increase in aspect ratio. This is in line with a report by Siddiqui (2004) that slump decreases with an increase in the percentage of san fibres and fibre length. Felekoglu *et al.,* (2007) also confirmed that the most disadvantage of incorporating a fibre in a mix is the workability. Thus, it leads to high volumes of entrapped air in concrete mixes.

5.3 Visual Inspection of Hardened Specimens (Cubes, Cylinders and Beams)

Visual inspection of specimens was carried out to find out if there are any physical changes in the specimens. In general, there were not much difference in the physical appearance of all the specimens in terms of size, shape and colour. Specimens maintained their sizes, shapes and had the normal grey colour of concrete. However, grey solid particles were found at the bottom of the bath most likely to come from the broken edges of specimens.

5.4 Compressive Strength

Compressive strength test result is shown in Table 4.2. For this investigation the best aspect ratio was about 75 though if a smaller aspect ratio had been tried, a higher compressive strength (closer to plain concrete) might have been obtained.

The aspect ratio 75 yielded the highest compressive strength value of 29.41N/mm^2 for the 28 days with the zero fibre (control) yielding the lowest strength of 22.88N/mm^2 for the 28days curing age. The 100 aspect ratio‘s strength was 28.76N/mm^2, 125 and 150 aspect ratios also yielded 28.43N/mm^2 and 27.02N/mm^2 respectively for the 28 days curing period. From the table, specimens from the four aspect ratios decreased in strength compared with the specimen with zero fibre. In ranking the four aspect ratios in terms of performance, the zero fibre (control) was ranked first place.

The targeted strength for the concrete design for the study was 30MPa. None of the four aspect ratios exactly hit the targeted strength but the differences were not so significant. This confirms a report by Yalley and Kwan (2009) that, the addition of fibres adversely affected the compressive strength as expected, which might be due to difficulties in compaction which consequently led to creation and increasing of voids. This is reflected in the increase in the air content with increase in the fibre length.

Again from the result, the compressive strength decreased as the fibre aspect ratio increased. This is also in line with a report by Yetgin *et al.* (2008) that a lower fibre aspect ratio leads to a higher compressive strength in masonry pieces, but a higher addition of fibre decreases the value of compressive strength. Similarly, Asasutjarit *et al.* (2007) claimed that the effect of fibre length is inversely proportional to the mechanical properties. This opinion advocates that the short fibre become mineralised earlier than long fibres. It is also known that fibres can reduce density, create voids, result in micro fractures fibre concrete matrix, and reduce compressive strength (Rigassi, 1995; Khedari *et al.,* 2005; Namango, 2006; Morton, 2008).

5.5 Flexural Strength

Flexural strength is the measurement of strength of an unreinforced concrete beam or slab to resist failure in bending. The summarised results of tests for Flexural strength carried out on the samples in the experiments are shown in Table 4.3. The flexural strength also took a different pattern. Aspect ratio 150 recorded the highest strength value of 2.65N/mm^2 followed by 125, 100, and 75 recording strength values of 2.50 N/mm^2, 2.42 N/mm^2, and 2.28 N/mm^2 respectively. Zero fibre or plain concrete (control) recorded the lowest strength value of 2.19N/mm^2.

Similar to the observations made in this study, Bagherzadeh *et al.* (2012) reported a flexural strength increase in PP fibre reinforced lightweight cement composites compared to the unreinforced composites. They also observed longer PP fibres (12 mm) to perform better in flexural strength compared to shorter fibres (6mm).

In a similar report the flexural strength and modulus of composites increased proportionally with fibre length reaching a maximum of 90 MPa and 2.7 GPa respectively at 25mm fibre length. This result is in agreement with that obtained by Jang & Han (1999) in functionally graded glass fibre mat reinforced poly (methyl methacrylate) compounds. Joseph *et al,* (1999) attributed the increase in the flexural strength and modulus to the increasing fibre-to-fibre contact when the fibres were impregnated. This suggests that for applications where the flexural rigidity is required, composite fabricated from longer fibre length is desirable.

5.6 Split Tensile Strength

Split tensile strength of concrete specimen is the tensile stresses developed due to the application of compressive load at which the concrete may crack. The summarised results of the splitting tensile strength in Table 4.4 indicate that there was an increase in tensile strength for the 28 days of curing for all the mixes. Aspect ratio 150 yielded the highest percentage increase by 15.8%, followed by 125, 100 and 75 which increased by 13.7%, 12.0%, and 3.3% respectively.

From the results it was observed that the tensile strength of the mixes increased as the aspect ratio was increased. This confirms the position of Shao-Yun Fu and Bernd (1996) who studied the effect of length and fibre orientation distributions on tensile strength of short fibre reinforced polymers using an analytical method for predicting the tensile strength of short-fibre-reinforced polymers (SFRP). The results showed that the strength of SFRP increased rapidly with the increase of the mean fibre length at small mean fibre lengths. The inclined tensile strength of fibres has a great effect on the strength of composites (Shao-Yun Fu & Bernd, 1996). Shorter fibre lengths will create more fibre ends, which eventually act as stress concentration points where failure often occurs at these sites. This possibly clarifies the reduction of tensile strength with shorter aspect ratios (Phua, et al., 2010). It is expected that, at the same fibre content, composites with the highest fibre aspect ratio of 150 would have higher tensile strength than those with smaller fibre aspect ratios (Silva *et al.,* 2010).

Comparable to the observations made in this study, Danso et al. (2015b) asserted in a study to investigate the physical, mechanical and durability properties of soil building blocks reinforced with natural fibres that even after splitting, the fibres still held the two halves of the blocks together as shown in Figure 4.5A.

5.7 Density

The density of the concrete produced decreased with the inclusion of fibre. As shown in Figure 4.8, with no fibres (control), the density of the concrete was 2524kg/m. With 75, 100, 125 and 150 aspect ratios, the average densities recorded were, 2430kg/m^3, 2415kg/m^3, 2379kg/m^{3}and 2352kg/m^3 respectively (3.72%, 4.32 %, 5.75% and 6.81% lower than plain concrete or concrete with zero fibre respectively). As mentioned by Khedari *et al.* (2001), short fibres are aligned and pack densely than the longer ones. This suggested that the inclusion of fibres into plain cement composites become less dense with increase fibre length. This may be due to the tendency of longer fibre to entangle and agglomerate and increased fibre-fibre interaction leading to inefficient wetting (Faca *et al*., 2007). Also the fibres are less dense than the concrete they replace.

5.8 Toughness

The summarised results from Table 4.5 and figure 4.9 indicate that the inclusion of Palm bunch fibres up to a certain fibre aspect ratio at constant fibre content would increase the toughness of concrete. The toughness was calculated as the area under the stress-strain curve under flexure up to a strain of 1.4mm. Aspect ratio 125 yielded the maximum toughness of 4.40 N/mm^2, which is about 63% higher than the control specimen without fibre. Aspect ratios 150, 100 and 75 followed with percentage increases of 36.3%, 23% and 11% respectively higher than the control specimen. It could be seen that the modulus of toughness increased as the aspect ratio of Palm bunch fibre also increased up to 125 and started to decrease. The result was in line with reports from Shibata *et al.* (2005) and Abdelmouleh *et al.* (2007) who posited in a research work to examine the effect of fibre length on the properties of concrete that toughness increases as the fibre length is increased and reached a certain fibre length, then falls. They concluded that this may be attributed to the strong stress fields developed at the ends of the fibres in the composite beyond the maximum fibre length which made the composite samples less tough. They added that shorter fibres are said to move to optimised position in a composite than longer fibres.

Yalley *et al*., (2016) reported that the above phenomenon could be explained by suggesting that there is a better alignment of fibres with a certain critical fibre length. Beyond the critical length, any increase in fibre length, or fibre aspect ratio, would worsen fibre-fibre interactions thus reducing toughness, strength and modulus. The use of fibres also alters the behaviour of the fibre-matrix composite after it has cracked, thereby improving its toughness (Yalley *et al*., 2016).

The increase in toughness of the concrete could be attributed to the probable increase of fibre-cement contact of the fibres due to higher lignin content of the fibres (about 30%) which stiffened the cell-wall of the fibre, thereby preventing brittleness of the fibres (Nanayakkaza *et al*., 2005).

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.0 Introduction

This chapter comes at the end of the study. It outlines the summary of the findings, draws conclusions and makes recommendations based on the findings.

6.1 Summary of Findings

From the study, the following findings were discovered:

Concrete slump measures the workability of concrete. From the study, slump measurements of concretes from the four aspect ratios indicate that as the fibre aspect ratio is increased, the workability of concrete also decreases. However, the differences in the slump among the aspect ratios were plus or minus one, therefore insignificant.

In general, there were not many differences in the physical appearance of all the specimens in terms of size, shape and colour after the 28 days curing age. Specimens maintained their normal grey colour of concrete.

From the study, the compressive strength decreased with the inclusion of Palm Bunch Fibre to the mixes. Also, as the fibre aspect ratio increased the compressive strength decreased. None of the specimens from the four aspect ratios exactly hit the targeted compressive strength.

The summarised results of tests for Flexural strength, which is the measurement of strength of an unreinforced concrete beam or slab to resist failure in bending carried out on the samples in the experiment, indicated that the addition of Palm Bunch Fibre to concrete increases the flexural strength of concrete. The increase in flexural strength is also proportional to increase in fibre aspect ratio.

It was observed from the results of the study that the split tensile strength of the mixes increased as the aspect ratio was increased. Generally, the incorporation of Palm Bunch Fibre to concrete affected the tensile strength positively.

From the study, the density of concrete produced decreased with the inclusion of Palm Bunch fibre. The decline in the density of the specimens was also proportional to increase in fibre aspect ratio.

Again from the study, the inclusion of Palm bunch fibres up to a certain fibre aspect ratio (125) at constant fibre content would increase the toughness of concrete.

The study reviewed a strong positive relationship between density and compressive strength. The sample which performed better in strength also performed better in density and it followed in that order.

6.2 Conclusions

Following the findings that were unearthed from the study, these conclusions were drawn;

Palm Bunch Fibre has the potential to be used in conventional concrete for the production of structural lightweight concrete.

The fibre addition to composites improves crack resistance spalling.

The addition of palm bunch-fibres improved the tensile strength of concrete.

The addition of palm bunch-fibres to concrete increased the flexural strength of concrete.

The incorporation of palm bunch-fibres enhanced the toughness of concrete drastically with utmost FAR 125.

However, the addition of fibres adversely affected the compressive strength, as expected. The failure in compression may be due to difficulties in compaction which consequently led to increase of voids.

Also the inclusion of fibres decreased the density of concrete and increase in FAR is inversely proportional to density.

6.3 Recommendations

Based on the result of this study, the following recommendations would be useful:

1. Economic methods of natural fibre extraction, handling, and economical and automated methods of dispersing fibres at a batching plant is needed if large quantities of fibres are going to be used in construction.
2. The construction of reinforced concrete specimens can be time-consuming and labour-intensive due to the complicated detailing of reinforcing bars in contrast to the fibre reinforced concrete specimens. The current findings represent a good encouragement for engineers towards the use of fibre reinforced concrete.
3. Palm bunch waste disposal problems will be minimised if they are utilised well in the construction industry.
4. Further research is required to find out the durability properties such as water absorption, abrasion etc. of Natural Fibre Reinforced Concrete.
5. Further research is required to ascertain what will happen to the flexural and split tensile strength of concrete beyond aspect ratio of 150.

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APPENDICES

APPENDIX A

SUMMARY OF EXPERIMENT MATERIALS

A1 Quantity of cubes, cylinder and beams used for the experiment

Aspect Ratio	Cubes	Cylinders	Beams
Zero Fibre	5	5	5
75	5	5	5
100	5	5	5
125	5	5	5
150	5	5	5
Total	25	25	25

A2 Measurement of Materials for Preparation of Specimen

Parameters:

Mix ratio 1:1.8:2.8, which represents:

1 part of cement in weight;

1.8 parts of sand in weight;

2.8 parts of gravels in weight.

Cube size 150 × 150 × 150, all in millimeters

Volume of one concrete cube $= 150^3$

$= 3375000\text{mm}^3 = 0.003375\text{m}^3$

Total volume of concrete cubes $= 0.003375\text{m}^3 \times 25$

$= 0.084\text{m}^3$

Beam Size 150 × 150 × 600, all in millimeters

Volume of one concrete beam = $13500000mm^3 = 0.0135m^3$

Total volume of concrete beams = $0.0135m^3 \times 25$

= $0.3375m^3$

Cylinder Size 150 × 300, all in millimeters

Volume of one concrete cylinder = $21205750.41mm^3 = 0.021206m^3$

Total volume of concrete beams = $0.0212m^3 \times 25$

= $0.5301m^3$

Total volume of concrete for experiment = Total volume of concrete for cubes + Total volume of concrete for beams + Total volume of concrete for cylinders

= $0.084m^3 + 0.338m^3+0.530m^3$

= $0.952m^3$

Allowing 3% wastage, volume of concrete = $5/100 \times 0.952m^3 = 0.029m^3$

= $0.981m^3$

In this study, all the concrete materials were batched by weight; therefore, measurements in volumes were converted to weight in order to batch materials using the digital weighing scale. In the conversion, ratio and proportion method was used.

Converting volume to weight;

If a bag of cement weighs 50kg and has a volume of $0.033m^3$

Therefore, Total weight of concrete = $0.981m^3/ 0.033 \times 50$ kg

= 1486.36 kg

A3 Water/Cement Ratio

The water cement ratio (W/C) chosen for the research was 0.5. It was calculated as:

W/C = Weight of Water/Weight of Cement

Therefore, Weight of Water = W/C × Weight of Cement

= 0.5×265.418

In all, the total weight of water for the preparation of the concrete was 132.71 kg

A4 Weight and Volume of Concrete Materials

Constituent	Volume (m^3)	Weight (kg)
Cement	1/5.6 × 0.981	1/5.6 × 1486.34
	= 0.1752	= 265.42
Sand	1.8/5.6 × 0.981	1.8/5.6 × 1486.34
	= 0.3153	= 477.75
Stone	2.8/5.56× 0.981	2.8/5.6 × 1486.34
	= 0.4905	= 743.17
Water		0.5 × 265.418
		= 132.71
Fibre		0.5/100 × 265.42
		= 1.33

Appendix "B" Test Results

B1 Grading Test Results on Crushed Granite Sample

NAME: CRUSHED GRANITE Lab. Ref. No: DATE: 20 /07/2018

STATION: SUNYANI TECHNICAL UNIVERSITY

B. S. Sieve	Wt. Retained	% Retained	% Passing	Riffled Wt.
76.20mm (3 in)				
63.50mm (2 ½ in)				
50.80mm (2 in)				
38.10mm (1 ½ in)				
25.40mm (1 in)				
19.05mm(3/4 in)	-	-	100	-
12.70mm (1/2 in)	2994	10.01	89.99	90
9.52mm (3/8 in)	-	-	-	-
6.35mm (1/1 in)	324	28.94	61.05	61
4.76mm (3/16 in)	-	-	-	-
3.18mm (1/8 in)	-	-	-	-
2.40mm (7 mesh)	3	35.98	25.07	25
1.80mm (14 mesh)	-	-	-	-
600um (25 mesh)	-	-	-	-
400um (36 mesh)	-	-	-	-
3000um (52 mesh)	-	-	-	-
210um (72 mesh)	-	-	-	-
150um (100 mesh)	3	24.17	0.09	01
75um (200 mesh)	3	0.85	0.05	
.75um (...200 mesh)	3	0.09	0	0
TOTAL............	3324			

B2 Compressive Test Results

Aspect	Compressive Strength (N/mm^2)						Load (KN)					
Ratio	1	2	3	4	5	Mean	1	2	3	4	5	Mean
No Fibre	31.86	30.38	31.15	30.96	31.32	31.15	736.9	703.6	720.2	691.2	722.5	714.88
75	29.60	29.22	29.41	29.30	29.51	29.41	666.0	657.5	661.7	659.3	663.9	661.68
100	28.89	28.63	28.76	28.66	28.68	28.76	650.0	644.2	647.1	644.9	649.4	647.12
125	28.90	28.10	28.07	28.49	28.58	28.43	650.3	632.2	631.6	641.0	643.1	639.64
150	26.14	27.80	27.10	26.91	26.88	27.22	594.2	652.5	609.8	605.5	604.8	613.36

B3 Flexural Strength Test Results

Aspect	Flexural Strength (N/mm^2)						Load (KN)					
Ratio	1	2	3	4	5	Mean	1	2	3	4	5	Mean
No Fibre	2.11	2.21	2.31	2.22	2.12	2.19	11.042	10.536	11.547	11.142	11.242	11.102
75	2.16	2.39	2.28	2.26	2.29	2.28	10.801	11.964	11.382	10.916	11.638	11.340
100	2.29	2.55	2.42	2.32	2.52	2.42	11.467	12.752	12.109	12.096	12.212	12.127
125	2.61	2.42	2.44	2.50	2.53	2.50	13.031	11.122	12.176	12.071	12.246	12.129
150	2.41	3.04	2.73	2.63	2.84	2.65	12.017	15.193	13.605	13.712	12.170	13.339

B4 Split Tensile Strength Test Results

Aspect Ratio	Split Tensile Strength (N/mm^2) 1	2	3	4	5	Mean	Load (KN) 1	2	3	4	5	Mean
No Fibre	1.98	1.68	1.83	1.73	1.93	1.83	139.9	118.7	129.3	122.3	136.4	129.32
75	1.78	1.96	1.89	1.97	1.86	1.89	126.2	138.7	132.2	125.1	130.1	130.48
100	2.01	2.08	2.05	2.04	2.06	2.05	142.1	146.9	144.9	144.2	145.6	147.74
125	1.97	2.14	2.05	2.15	2.11	2.08	139.2	151.2	144.8	151.9	141.3	145.68
150	2.11	2.14	2.12	2.09	2.13	2.12	149.1	151.2	149.8	147.7	150.5	149.68

B5 Weight and Volume of specimen

Aspect Ratio	Volume (m^3)	Weight (Kg) 1	2	3	4	5	Mean
Zero Fibre	0.15^3	8.38	8.78	8.61	8.43	8.41	8.52
75	0.15^3	8.08	7.98	8.01	8.11	7.99	8.20
100	0.15^3	8.22	8.01	8.16	8.22	8.17	8.15
125	0.15^3	8.03	8.17	8.18	8.27	8.12	8.03
150	0.15^3	7.91	7.97	8.00	7.92	7.90	7.94