EVALUATION OF THE MECHANICAL PROPERTIES OF KENAF BIO FIBROUS CONCRETE COMPOSITES CONTAINING SORGHUM HUSK ASH

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ABSTRACT

Fibrous Concrete Composite (FCC) is a high performance concrete that possesses an improved tensile strength and ductility under sustained load compared to Plain Concrete (PC). As a result of global search for sustainable, renewable and green materials to achieve a bio based economy and low carbon foot print environment, the use of fibre to produce fibrous concrete composite has continuously received significant research attention. Due to the growth amount of waste generation from agricultural product, there has been a developing interest in the utilization of waste in producing building materials to achieve potential benefits. This research evaluate the mechanical properties of kenaf bio fibrous concrete composites (KBFCC) containing sorghum husk ash (SHA) as partial replacement of Ordinary Portland Cement (OPC). Five volume fractions of kenaf fibre (KF) varying from 0% to 1.0% at an interval of 0.25% with a uniform length of 50mm was used with OPC concrete mixes. Another five mixes were made that replaced OPC with 10% SHA. Fresh properties of these mixes to evaluate the workability were measured using slump test, VeBe test, compacting factor test and fresh density test. It was observed that the combination of kenaf fibre and SHA decrease the slump values and increase the VeBe time of fresh concrete, the slump value of PC and the mix containing SHA were 160mm and 140mm respectively, also the mix containing fibre volume of 1% of OPC and one with SHA and fibre volume of 1% were 40mm and 25mm respectively. For the compacting factor and fresh density tests, it was observed that, as the fibre content increases there was decrease in both the compacting factor test and fresh density test. The decrease in fresh density and compacting factor was due to the density of the fibre (1200kg/m^3) and the lower specific gravity of SHA (2.32) to that of OPC (3.15). The addition of kenaf fibre to either OPC or SHA concrete mixes showed a positive interaction that led to high tensile and flexural strengths, thereby increasing the concrete ductility with higher energy absorption and improved crack distribution. The maximum increases in tensile and flexural strengths compared to those of plain concrete were achieved by the addition of 0.5% kenaf fibre at the age of 56 days for the mix with OPC alone and with the mix that has SHA which are 5.35N/mm^2,6.55N/mm^2 and 5.15N/mm^2, 5.90N/mm^2 respectively. For effective waste management, use of agro waste materials such as SHA and agricultural plant such as KF can be effectively put to use in the production of a sustainable concrete material and thus provide optimum economic benefit. It is recommended that SHA and KF should be incorporated into concrete mixes aimed at improving the splitting and flexural strength of concrete. The study showed that the use of KF and SHA in the production of sustainable green concrete is technical and environmentally achievable.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Concrete is a construction substance consist mainly of cement, coarse aggregates, smooth aggregates, as well as water in a fixed ratio. Concrete's utility in a variety of construction and structural engineering uses is undeniable. Offshore structures, shotcrete, Hydraulic structures, foundations in earthquake environments, graded slabs, thin/dense replacements, architectural panels, broken walls, precast materials, footings, worldwide transport infrastructural networks such as highway network, bridges, trains, airports, canals, and many other applications have all benefited from it over the years. The advantage of having the lowest quotient between the strength and the cost as compared to other usable products is not far-fetched from the cause for its general acceptance for use in various infrastructure productions. (Tejchman and Kozicki, 2010; Yatim *et al.*, 2011; Bicanic *et al.*, 2014).

Fibre reinforced concrete is a form of concrete that contains fibrous materials that are spread and oriented uniformly within the concrete matrix. The concept "fibre reinforced concrete" (FRC) was described by ACI 544 (1999) as "a concrete made of hydraulic cements comprising fine or fine and coarse aggregates and discontinuous distinct fibres." Synthetic fibres, steel fibres, natural fibres, and glass fibres are also widely found in concrete. After the introduction of fibre reinforced concrete, different research has been done on a variety of fibre materials to ascertain the true characteristics and benefits of the component. (Ogunbode *et al.*, 2016). For many, the high price rate of cement poses a significant barrier to sustainable housing. The government of Nigeria has initiated a mortgage repayment program in order to provide 10,000 homes for its citizens. (Andrews and Jonathan, 2014). Polozzonic materials are used to replace a portion of the cement in concrete made from agro wastes such as corncob ash, rice husk ash, sorghum husk ash, and palm kernel fuel ash, which are all inexpensive and readily available.

Pozzolanas are "siliceous or siliceous and aluminous materials that have little or no cementitious properties in themselves, but when finely divided and in the presence of moisture, they can react with calcium hydroxide (CaOH) liberated during the hydration of OPC at ordinary temperatures to form compounds with cementitious properties." (ASTM C 618, 1981). Pozzolanas are "siliceous or siliceous and aluminous materials that have little to no cementitious properties in themselves, but when finely separated and in the presence of moisture, they can react with calcium hydroxide (CaOH) liberated during the hydration of OPC at ordinary temperatures to form compounds with cementitious properties."

High production cost per ton of capital relative to cement, low cost promotion of waste disposal, decreased emissions by these wastes, and expanded famers' commercial foundation when the said waste is sold, thus promoting further production are some of the advantages to be benefited by the utilization of agro waste in the part substitution of cement. (Mahmoud *et al*., 2012).

One of the building industry's focuses has been on recycling, like the use of renewable biodegradable fibre and the use of industrial waste as a partial replacement for cement in concrete. (Ogunbode *et al.*, 2016), This is as a result of current worldwide challenge of carbon footprint or the effect of greenhouse due to the introduction of excess CO_2 into the air during the processing of cement and synthetic materials. This is due to the moment worldwide difficulty of carbon footprint or greenhouse effect due to the release of excess CO_2 into the atmosphere during the production of cement and synthetic materials (Olutoge *et al*., 2010; Nattapong *et al*., 2011; Rubenstein, 2012). In the last few years, research has been carried out to enhance the method of using fibre insulation to improve the performance of concrete sections of buildings. The majority of these projects, however, have focused on steel fibre and non-renewable resources (Abdul *et al*., 2015; Sarangi and Sinha, 2016). Both developing and developed countries are increasing their adoption and use of bio fibres in the building industry. Bio-degradable products, such as kenaf bio fibrous concrete, are becoming more common. (Ogunbode *et al.,* 2016).

1.2 Statement of the Research Problem

The growth in global population and income in the twenty-first century has increased the need for sustainable materials. These requirements occur as a result of landfills piling up due to massive depositions of accumulated garbage, the earth's environment shifting as a result of CO_2 emissions into the air during the production of new products and cement, and natural resources becoming extinct. (Olutoge *et al*., 2010; Nattapong *et al*., 2011).

Concrete's shortcomings, such as its low energy absorption and poor tensile strength, cause initial cracks and failure. (Ogunbode *et al*., 2016). These cracks in the concrete's surface provide a pathway for harmful species such as sulphates, moisture, chloride, and carbon dioxide to enter the concrete, causing the reinforcement to corrode and compromise the structure's durability. The two aforementioned problems, namely CO_2 emissions into the atmosphere during cement processing and poor tensile and energy absorption of concrete, necessitate the conduct of this study.

1.3 Aim and Objectives of the Study

The purpose of this study is to look into the mechanical properties of kenaf bio fibrous concrete composites incorporated with SHA in order to create a sustainable green concrete that is both technically and environmentally viable.

The following objectives were established in order to accomplish the above goal, to:

i Determine the effects of fibre volume fractions on the fresh characteristics of KBFCC containing SHA.

ii Evaluate the influence of varying fibre volumes fractions on strength properties of SHA based Nigeria kenaf bio fibrous concrete.

iii Investigate the relationships between compressive strength, tensile strength and flexural strength of Nigeria based kenaf bio fibrous concrete containing SHA.

1.4 Scope of the Study

The focus of the study is on the kenaf bio fibrous concrete composites with sorghum husk ash mechanical properties as a partial substitute for cement (compressive strength, separating flexural strength, and tensile strength). The thickness of the kenaf fiber geometry used in the study was 50 mm. The fibres used in the research were alkaline-treated kenaf fibre. The fibers were included at volume fractions of 0 per cent, 0.25 per cent, 0.5 per cent, 0.75 per cent, and 1 per cent. The amount of cement level substitution by weight of sorghum husk ash was 10%. Within 24 hours, many of the specimens included in this analysis were cast and demoulded. The mechanical properties research specimens were being cure in water for 7, 28, and 56 days.

1.5 Justification for the Study

Sorghum husk is a kind of agricultural waste that is abundant in Nigeria. Sorghum husk ash is a by-product of sorghum husk combustion which is not adequately disposed of, it would have a detrimental impact on the atmosphere and human health (Ogunbode *et al*., 2017). The amount of agro waste that is dumped into the landfills can be minimized by using SHA. Furthermore, by substituting SHA for cement and using kenaf fibre, contamination caused by carbon dioxide emissions from cement processing can be minimized. The formation of cracks is a big issue with concrete. As a result, a significant solution to reduce concrete brittleness is needed. In relation to the topic at hand, Toutanji (1999); Sun *et al*., (2001) reported that fibre reinforced cementitious composites can fix concrete brittleness.

Also, Beigi *et al*. (2013); Medina *et al*. (2014) stated that ductile material with pozzolanic mixture demonstrated remarkable ductility when passed through mechanical loading so also is the resilience under various environmental exposures, according to the report. The consequences of this research are important, particularly considering the recent trend of fibre reinforced concrete being a common building medium and the fact that environmental problems influence everybody in society. The need for this research work arises as a result of its positive impact on academics, who will contribute to researchers' knowledge, the construction industry, which will produce high-performance structures, and the economy, which will benefit from the use of waste to create wealth.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Fibre Reinforced Concrete

Fibre reinforced concrete is a form of concrete which contains fibre materials that are spread and oriented uniformly within the concrete matrix. ACI 544 (1993) defines fibre reinforced concrete (FRC) as a concrete composed of fine and coarse aggregates, hydraulic cements, and discontinuous discrete fibres. Steel fibres, glass fibres, natural fibres, and synthetic fibres are also widely found in concrete. After the introduction of fibre reinforced concrete, there has been a lot of research undertaken on a variety of fibrous materials to ascertain the true characteristics and benefits of each substance.

2.1.1 Steel Fibre

Steel fibres are the most researched and functional of the fibres listed. Steel fibre reinforced concrete is a form of concrete that involves distinct steel fibres that are randomly directed. Steel fibres in concrete are mostly used to monitor crack expansion and propagation after the concrete matrix has fractured. The mechanical properties of the reinforced material can be greatly enhanced as a result of crack management. Steel fibre reinforced concrete (SFRC) comes with downward slump in comparison with the usual concrete that has no fibres even with characteristics is the same (Johnston, 2001). Steel fibres have a tendency to entangle.

Vibration is used to maximize density, reduce the amount of air voids, and strengthen between reinforcement bars and the bond. Despite the presence of stiffness, pumping a well-adjusted fibre mixture is possible. (ACI 544, 1993). “The distribution of fibres is determined by their size in relation to the aggregates. To be functional in the hardened state, fibres need not be shorter than the full aggregate distance. The fibre length is typically 2-4 times the full aggregate size.” (Johnston, 2001 & Coetze, 1990). To make pumping easier, it is recommended that the amount of coarse aggregates be reduced by 10 per cent as compared to plain concrete. The original slump of plain concrete should be 50-75 mm higher than the ideal final slump; superplasticizer, rather than excess water, should be applied to the mixture to achieve the desired workability. (Johnston, 2001).

The workability of concrete is affected by the scale, the structure and volume fraction of steel fibres, as well as the size, form, and content of coarse aggregates. Compact ability is proportional to the aspect ratio of the fibres at a given fibre diameter and volume fraction. The overall potential quality of steel fibres is determined by the relative fibre to coarse aggregate amount and the ‘balling up' phenomenon. The following three metrics can be used to compare the output of various types of steel fibres.

- The aspect ratio (L/D), where the fibre length is represented by L and D denotes its diameter.
- The tensile quality of the material
- The relation between matrix and fibre (depending on the type of fibre)

2.1.2 Kenaf Fibre

Kenaf fibre is a non-woody fibre that grows in climate areas in the tropics and subtropics and has properties comparable to cotton and jute fibre. It is harvested from the stem of the Kenaf plant (Edeerozey *et al*., 2007). The mean diameter of the fibre is 67.6µm, It's similar to jute and cotton fibre in terms of properties. (Mahjoub *et al.,* 2014). Kenaf fibres are known as an agricultural fibre due to their use in the manufacture of a variety of industrial raw materials. Kenaf fibre is unusual in that it is commercially available at a low cost as opposed to other cellulose fibres and is available in large quantities. (Salleh *et al*., 2012).

Kenaf fibre's superior qualities and properties, such as its high mechanical tensile strength and hardness, make it a preferred fibre over others. (Aji *et al*., 2009), strong tolerance to effects (Sydenstricker *et al*., 2003; Toriz *et al.*, 2002; Wambua *et al.*, 2003) found that they have excellent stability (Nair *et al*., 1996; Toriz *et al.*, 2002), low density (Sotoudeh *et al.*, 2013), high aspect ratio (Akil *et al.,* 2011), and high modulus (Huda *et al.,* 2006). They are biodegradable and reusable (Nishino *et al.,* 2003), cause less skin and respiratory problems, dampen vibration (Sydenstricker *et al.,* 2003), and have a better energy recovery (Sydenstricker *et al*., 2003; Mohanty *et al.,* 2000) They are suitable for use as a strengthening agent in cement, concrete, and polymer composites due to their mechanical properties (Sanadi *et al*., 1995).

Kenaf fibre, on the other hand, is a cellulose fibre with a negative property of high water soptivity. When used as reinforcement in hydrophobic matrices, this negative property causes weak fibre surface matrix bonding and fibre degradation. (Coutinho *et al*., 1997; Rowel *et al*., 1999). Several studies have been conducted to address the hydrophilicity deficiency of Kenaf fibre used in cement and concrete composites. Mercerization (alkalinisation) was found to be the most effective process. This is accomplished by treating the fibre's surface with sodium hydroxide. Kenaf fibre's moisture soptivity is reduced, and its mechanical bonding property is improved, thanks to a chemical process.

After passing through the retting procedure, kenaf fibre becomes a curled long fibre. It is chopped into smaller lengths as required for use in concrete composites.

2.2 Ordinary Portland Cement

Ordinary Portland cement, also known as Portland cement, is cement made by mixing argillaceous and calcareous, among other alumina, silica, and iron oxide bearing materials and burning them at a clinkering temperature of up to 14000 degrees Celsius (25500F), and then grinding them (Neville and Brooks, 2010). According to Akers (2000), the raw materials used to make Portland cement includes four main compounds: lime (CaO), iron (Fe_2O_3), silica (SiO_2), and alumina (Al_2O_3), as well as two small compounds: gypsum ($CaSO_4$ $2H_2O$) and magnesia (MgO). Limestone, calcite, marl, and shale are examples of calcareous (CaO) materials, while clay, shale, and sand are examples of argillaceous (SiO_2 and Al_2O_3) materials. The global rate of manufacturing of this commodity (OPC) is currently around 2.1 billion tonnes in a year, with expectations of increasing to around 3.5 billion tonnes in a year by 2015 (Fernanda *et al.*, 2008).

Portland cement is described by ASTM C 150 (2012), as hydraulic cement made by pulverizing clinker that is primarily made up of hydraulic calcium silicates and typically contains different types of calcium sulphate as an inter-ground addition. Cement pulverizing clinkers, according to Mehta and Monteiro (2014), are sintered nodules with a diameter of 5 to 25 mm that form when a natural mixture with a high temperature are applied to a predetermined composition.

2.2.1 Properties of Portland cement

Paste of cement is an essential component of mortar/concrete; Rasa *et al.* (2009) reported that the density and compressive strength of concrete paste of cement have a significant impact on the properties of concrete. Nonetheless, approval assessments or, more often, examinations of the properties of a cement to be used for a specific use may be performed by the purchaser or an impartial laboratory. The European Standard BS EN 196-1 (2016) specifies chemical composition and fineness standards, while BS EN 196-6 (2010) specifies additional tests for Portland cements, both ordinary and rapid-hardening.

2.2.1.1 Fineness

Compared to coarsely ground cement, finely ground cement has a larger exposed surface area; one of the characteristics of cement determines the rate of reaction with water. The grinding of clinker mixed with gypsum is one of the final steps in the cement manufacturing process. The overall surface area of cement reflects the substance required for hydration since hydration begins at the exposed area of the particles of the cement. Thus, hydration rate is determined by the fineness of the particles of the cement, and although a high fineness is required for rapid strength growth, long-term strength is unaffected. Of note, a faster rate of early hydration often means a faster early heat evolution rate. (Neville, 2012). This cement property can be calculated by measuring in an air permeability apparatus, the precise surface of the cement, with a standard value of 300kg/m^2 for OPC specific surface.

2.2.1.2 Chemical composition

This is the foundation of cement characterization, and it influences every properties of cement except the fineness. (Neville & Brooks, 2010). Since a high content of some constituents of cement compounded in contrast to others will cause the pace of setting and hardening to be slowed or accelerated, the constituents must meet standard specifications. Excess of any compound will influence the heat evolution rate as the cement hydrates, so the concentrations of lime, alumina, iron oxide, silica, alkali and sulphur is meant be controlled based on the normal definition to avoid this. Additives such as calcium sulphates (gypsum) and calcium chloride are used to speed up or slow down the setting of cement paste.

2.2.1.3 Soundness

The term "cement paste" refers to a combination of cement and water. Sound cement is described as cement that sets and hardens without cracking or disintegrating. (Klemm, 2005). Hydration of free magnesia (MgO), lime (CaO) and sulphates (SO_4) surrounded by cement particles produced unsoundness of cement by preventing easy hydration of free lime (uncombined lime) and other materials during the normal setting period.. To be clean of unsoundness, cement must be properly mixed, burned, and ground. The ASTM C 150 (2012), standard specifies a limit of 0.80 per cent for all Portland types of cement, while the NIS 444:2003 specifies 10 mm as the maximum for all Portland cement types. The chartelier apparatus is a popular laboratory instrument for determining the unsoundness of cement. (Shetty, 2009).

2.2.1.4 Setting time

The physical mechanisms of time setting will be briefly discussed here, with a focus on the actual calculation of setting times. The Vicat apparatus of different penetrating attachments is used to test the cement setting times. BS EN 196-3 (2005) specifies the test process. A circular needle with a diameter of 1.13 mm and 0.05 mm is used to determine the initial collection. This needle is used to penetrate a regular paste quality placed in a special mould, operating under a specified weight. Initial set is described as the stiffening of the paste to the point that the needle can only penetrate to a depth of 5 1 mm from the rim. The period after the mixing water was applied to the cement is referred to as the initial batch. BS EN 197-1 (2000) specifies a minimum curing period of 60 minutes of cements at 42.5 MPa strength, 75 minutes for cements with a 52.5 MPa strength and 45 minutes for cements of greater strengths. The initial set must last at least 45 minutes, according to ASTM C 150 (2012) and must be performed with the Vicat apparatus as specified in ASTM C 191 (2013). Setting time is calculated using Gillmore needles (ASTM C 266, 2008), which yields a higher value.

2.2.1.5 Strength of cement

The European Standard BS EN 196-1(2016) includes a compressive strength test on mortar specimens. 40 mm identical cubes are tested as specimens; they are made from 40 by 40 by 160 mm prisms that are initially broken into halves in flexure or otherwise broken into halves. As a result, a flexural centre point test over a 100 mm stretch is an alternative. The research is carried out on a mortar with a set composition and ‘CEN norm sand.' The sand is pure, rounded, siliceous sand that can be derived from a variety of sources. (The European Committee for Standardization is abbreviated as CEN in French.) It is not standardized in dimension, but is graded from 80 m to 1.6 mm. The sand-to-cement ratio is three and the water-to-cement ratio is fifty per cent. The mortar is mixed in a cake mixer and compacted on a 15 mm drop jolting table, a table which vibrates may also be used, as long as the compaction is equivalent (Neville, 2012).

2.3. Fine aggregate

Fine aggregate is also used in the manufacture of concrete and mortar. The most common of the fine aggregate is sand in traditional mortar and concrete manufacturing. Aggregates that cross the 450 mm (No. 4) sieve but are maintained on the 750 mm (No. 20) sieve are referred to as aggregates crossing the 450 mm (No. 4) sieve. (ASTM C 125, 2015). When combined in the right proportions, they increase the flow potential and segregation resistance. (Okamura and Ozawa 1995; Su *et al*., 2002; Bhattacharya, *et al*., 2008). Mortar flows more with fine aggregate that is well graded. (Hu and Wang, 2005; Benabed *et al*., 2012). Furthermore, a high-graded fine aggregate increases the packed density, resulting in increased concrete strength, deformation, and longevity (Tasi *et al*., 2006).

2.4 Sorghum Husk Ash

Sorghum husk ash is a waste in agriculture generated by milling guinea corn husks. The global production of guinea corn husks is estimated to be about 10 million tons per year. According to Akinloye *et al*., (2014), guinea corn of 1.5million is raised annually in Nigeria alone. However, ash obtained from the complete burning of guinea corn husk has been classified as Pozzolana containing at least 70% silica, alumina, and iron oxide, the silica being mostly in amorphous form, which can react with $Ca(OH)_2$. (Medega *et al*, 2014).

Table 2.1 Sorghum Husk Ash Chemical Composition

Chemical Composition	SiO_2	Fe_2O_3	Al_2O_3	MgO	SO_3	CaO	K_2O	Ph	LOI	SiO_2 $+Al_2O_3$ $+Fe_2O_3$
SHA	51.2	12.5	9.35	0.49	2.1	10.1	9.46	8.3	9.0	73.05

Source (Ogunbode *et al*., 2013)

2.5 Pozzolanic Materials

According to ASTM C 125, (2015), a siliceous or siliceous and aluminous material is referred to as a pozzolan that has little or no cementitious potential in itself but can chemically react with calcium hydroxide in finely separated form and in the presence of moisture at ordinary temperatures to form compounds with cementitious properties. Pozzolan must be finely separated and only then can silica mix with calcium hydroxide (manufactured by Portland cement hydration) with water present to form solid calcium silicates with cementitious properties. (John & Ding, 2007; Neville, 2012). According to a report by Neville (2012), the silica must be amorphous, or shiny, since crystalline silica has a very low reactivity. According to a report by Duggal (2008), the name pozzolana was gotten from Pozzuoli, a town in a European city, Italy near Mount Vesuvious on the Bay of Naples. When sand (volcanic dust) from the area was combined with hydrated lime, cementitious properties were discovered. Pozzolan was mixed with lime to render concrete prior to the arrival of cement, but it is still used to substitute a proportion of cement in concrete. Furthermore, according to Hewlett (2006), pozzolana has two distinct meanings.

The first refers to pyroclastic rocks that are basically glassy and often zeolitized that can be found around Pozzuoli (the ancient Puteoli of Roman times) or around Rome. Real and artificial pozzolanas are also high in silica and alumina, with just a slight amount of alkalis (Duggal, 2008). Volcanic lava, pumice, opalineshales, charred clay, and fly ash are examples of pozzolanic products. To be reactive, the silica in a pozzolana must be glassy or amorphus. Volcanic ash is hard to the touch, it could be red, orange, or black in colour, and must not dissolve in water, highly abrasive, slightly corrosive, and conducts electricity when it comes into contact with water. Pozzolanic materials can be classified into two groups:

i. Artificial pozzolanas

ii Natural pozzolanas

i. Artificial pozzolans are mostly products of heat treatment of natural materials, and they are also materials with low pozzolanic activity that need additional treatments to achieve pozzolanic activity; they derive from chemical or structural alterations of materials that originally had little or only mild pozzolanic properties; they are materials with low pozzolanic activity that need additional treatments to achieve pozzolanic activity. (Ramezanianpour, 2014). Fly powder, Blast furnace slag, Silica Fume, Rice Husk ash, Guinea corn husk ash, and Matakaoline are examples of artificial pozzolans, according to Shetty (2009).

ii. Natural pozzolanas has origin in volcanic, with volcanic ash serving as the real

iii. Pozzolan, according to Neville (2012). Natural pozzolans, according to Parhizkar *et al.*, (2010), are natural materials containing reactive alumina or silica that have little to no binding property on their own but, when combined with Portland cement and as lime is exposed to sunlight, it sets and hardens like cement. Natural pozzolans are divided into four groups depending on the presence of the main lime reactive constituent. (Ramezanianpour, 2014). Volcanic tuff and pumice, unaltered volcanic glass, calcined clay or shale, and raw or calcined opaline silica are the materials in question.

2.5.1 Standard Specifications and Test of Pozzolans

According to (ASTM C 618, 2012), pozzolans are divided into different categories:

i. Class N: Natural pozzolans, calcined or raw, that meet the relevant criteria for the class as stated here, which includes certain diatomaceous earths; shales and opalinecherts; calcined or uncalcined tuffs and pumicites or volcanic ashes; and various materials, such as clays and shales, requiring calcination to induce satisfactory properties

ii. Class F: Fly ash formed by the combustion of bituminous or anthracite coal that complies with the relevant criteria for this class as set forth herein. Pozzolanic properties are found in this kind of fly ash.

iii. Class C: The fly ash formed naturally from sub-bituminous or lignite coal that satisfies the relevant standards for this class as set forth herein. This form of fly ash has pozzolanic and in addition to pozzolanic properties, cementitious properties exist.

To be classified as pozzolanic, a substance must meet the ASTM C618 (2012) physical and chemical specifications mentioned in Tables 2.1 and 2.2.

Table 2.2 ASTM C618 (2012) Standard Chemical Requirements

Material contents	Mineral Admixture Class		
	N	F	C
$\Sigma SiO_2 + Al_2O_3 + Fe_2O_3$ min, %	70.0	70.0	50.0
SO_3 max, %	4.0	5.0	5.0
Moisture content	3.0	3.0	3.0
Loss on ignition, max, %	6.0	6.0	6.0

Source (ASTM C618, 2012)

Table 2.3 ASTM C618 (2012) Standard Physical Requirements

	Mineral Admixture Class		
	[	F	C
Fineness: Amount retained when wet-sieved on 45 µm (No. 325) sieve, max, %	34	34	34
Strength activity index: With Portland cement, at 7 days, min, percent of control	75C	75C	75C
With Portland cement, at 28 days, min, percent of control	75C	75C	75C
Water requirement, max, percent of control	115	105	105
Soundness: Autoclave expansion or contraction, max, %	0.8	0.8	0.8
Uniformity requirements: The density and fineness of individual samples shall not vary from the average established by the ten preceding tests, or by all preceding tests if the number is less than ten, by more than:	5	5	5
Density, max variation from average, % Percent retained on 45-µm (No. 325), max variation, percentage points from average	5	5	5

Source (ASTM C618, 2012)

2.5.2 Pozzolanic Activity

According to a report by Duggal (2008), when pozzolans are combined with ordinary Portland cement, the free lime the combines with silica in the pozzolan produced during cement hydration, resulting in pozzolanic action. The presence of finely divided glassy silica and lime causes pozzolanic action, which results in the formation of calcium silicate hydrate close to that formed during the hydration of Portland cement. The silica in the pozzolan reacts with the lime formed during Portland cement hydration, contributing to strength growth. More hydrated calcium silicate is formed over time, which acts as a binder and fills in the gaps, providing impermeability, resilience, and ever-increasing power.

The hydration of Portland cement can be expressed as follows:

$$C_3S + H_2O \longrightarrow \underset{\text{(Calcium silicate hydrate)}}{\text{C-S-H}} + \underset{\text{(Lime)}}{Ca(OH)_2} \tag{2.1}$$

Equation (2.1) shows how lime from equation (2.1) reacts with silica from pozzolana to form calcium silicate hydrate.

$$Ca(OH)_2 + \underset{\text{(Silica)}}{SiO_2} \longrightarrow \text{C-S-H} \tag{2.2}$$

The distinction between active pozzolanas and products with identical chemical composition that have less pozzolanic action is that amorphous silica reacts with lime more readily than crystalline silica. Since pozzolanic activity may only occur in the presence of water, sufficient moisture must be made available for an extended period of time in order to complete pozzolanic action. While it is generally assumed that the lime-silica reaction is the primary or only one that occurs, new evidence suggests that alumina and iron, if present, also participate in the chemical reaction (Dwivedi *et al*., 2006; Duggal, 2008). According to

Massaza (2005), there is widespread consensus on the following factors that influence the volume of combined lime:

• The essence of active phases

• In the pozzolan, their content

• The pozzolan's SiO_2 material

• The mixture's lime-to-pozzolan ratio, as well as

• The amount of time it takes to cure

• The rate of lime combination is also determined by;

• The pozzolan's specific surface area

• The water-to-solid percentage in the mixture

2.6 Sustainability and Environmental Benefits

CO_2 emissions from OPC production ranged from 5 per cent to 10 per cent of total greenhouse gas (GHG) emissions in the atmosphere (Obada *et al.*, 2008). As a result, the World Business Council for Sustainable Development (WBCSD) proposed in 2002 that CO_2 emissions from cement manufacturing operations be reduced by 30 per cent by 2020 and 60 per cent by 2050. Cement production is clearly unsustainable at these amounts of CO_2 pollution. These pollution issues are real; for every ton of Portland cement made, 1 to 1.25 tons of CO_2 is emitted into the atmosphere by burning carbon. As a result, reducing OPC demand decreases CO_2 pollution into the atmosphere from cement processing. As a result, lowering the OPC in concrete mixes would result in significant reductions in (GHG) emissions. Because of the tremendous amount of concrete used daily around the world, the sustainability theory for the use of Supplementary Cementitious Materials (SCMs) such as pumice is that even if there is a slight reduction in OPC in concrete uses per ton of concrete made, the resulting environmental benefits are high. (Altwair and Kabir, 2010). As a result, replacing some amount of OPC lowers CO_2 emissions to the atmosphere directly. As a result of the usage of SCMs, the burden of green gas emissions from cement calcinations can be reduced.

2.7 Chemical Admixtures

A chemical admixture is defined as “a material other than water, aggregates, hydraulic cementitious material, and fibre reinforcement that is used as an ingredient in a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or after its mixing,” and a liquid admixture is defined as “a material other than water, aggregates, hydraulic cementitious material, and fibre reinforcement that is used as an ingredient in a cementitious mixture to modify its freshly (ASTM C125, 2015). Chemical admixtures are classified into seven categories according to ASTM C494 (2019). Water-reducing and set-accelerating or retarding characteristics are used to classify the seven groups.

The seven forms of chemical admixture are defined by ASTM C494 (2019) as follows:

i. Type A: Water-reducing admixtures (WRA) are a form of admixture that helps concrete set faster and build early power.
ii. Type B: Retarding admixtures; is an admixture that retards the setting of concrete
iii. Type C: Accelerating admixtures are additives that minimize the amount of water needed to make concrete of a certain quality.

iv. Type D: Water-reducing and retarding admixtures are admixtures that minimize the amount of mixing water needed to manufacture concrete of a certain quality by at least 12 per cent.

v. Type E: Water-reducing and accelerated admixtures are admixtures that minimize the amount of mixing water used to create a given hardness of concrete while also speeding up the setting and early strength production of the concrete.

vi. Type F: Water-reducing, high-range admixtures are admixtures that minimize the amount of mixing water needed to manufacture concrete of a given quality while still delaying the settling of concrete.

vii. Type G: Water-reducing, high-range, and retarding admixtures are admixtures that minimize the amount of mixing water needed to manufacture concrete of a given quality by at least 12 per cent and delay the setting of concrete.

Adsorption is often affected by the form of cement used and the use of supplementary cementitious materials for a given admixture (SCMs). On eight separate cements, including mixed cements containing slag and fly ash, Uchikawa *et al*., (1992) calculated the degree of adsorption of -naphthalene sulfonic acid condensate admixtures and lignosulfonate admixtures. The adsorption of both admixtures differed depending on the cement form. Admixtures were also shown to be adsorbed preferentially to the interstitial process and free lime. Admixtures with similar chemical structures can compete for adsorption when many chemical admixtures are present in cement. Admixtures with a high anionic charge density will adsorb preferentially in this situation, stopping low anionic charge density admixtures from adsorbing. (Plank and Winter, 2008).

2.8 Properties of Fresh and Hardened Concrete

2.8.1 Workability

The amount of useful internal work (physical property of concrete and work or energy needed to overcome the internal tension between the individual particles in the concrete) required to achieve maximum compaction was described by Neville and Brooks (2010). The capacity of the concrete mix to be positioned inside the formwork, around some reinforcement, and compacted effectively by hand or mechanical means to clear stuck air pockets is referred to as workability. (Lyon, 2007). Mix proportions, water cement ratio, aggregate scale, grading, and form, as well as the use of admixtures, are all factors that influence the workability of fresh concrete (Shetty, 2009).

2.8.2 Bleeding

Bleeding, also known as water benefit is a form of segregation in which some of the water in the mix rises to the surface of freshly placed concrete. According to, the primary source of concrete bleeding is the failure of the rigid constituents of the mix to retain any of the mixing water as it settles downwards (Neville and brooks, 2010).

2.8.3 Segregation

According to Shetty (2009), division occurs where the component materials of mortar/concrete are separated and their distribution is no longer consistent. A decent mortar/concrete is one in which all of the materials are evenly dispersed and the mixture is homogeneous. It's a state of concrete in which the constituents are isolated from one another, preventing the target from being realized.

2.8.4 Density

The density of mortar/concrete was described by Kazjonovs *et al*., (2010) as mass per unit length. BS EN 12390-7 (2009) can be used to calculate density, also known as unit mass or unit weight in air. Density is calculated by dividing the total mass of all the materials in a batch of concrete by the amount filled by the concrete. Standard weight mortar/concrete is defined as concrete samples with a density greater than 2000kg/m^3 (ASTM C 140, 2003).

2.8.5 Compressive strength

According to Shetty (2009), the strength of mortar/concrete is its resistance to rupture, which can be calculated in a variety of ways, including friction, stress, shear, and flexure. According to Garba (2008), the compressive power of mortar/concrete is a significant property since it is closely applicable to many other properties, and hence is the most commonly used in concrete practice. Part of the strength of concrete is determined by the proportions of asphalt, fine and coarse aggregates. Form, amount, and consistency of cement, degree of compaction, water/cement ratio, age, and curing conditions all affected the compressive strength of concrete. The cube test is commonly used to assess the compressive strength of concrete. This is done on a cube that has been crushed in a compressive measuring unit, either electrical or manual. (Neville, 2012).

2.8.6 Abrasion resistance

Abrasion, according to Lamond and Pielart (2006), is the wear and tear caused by hard particles or hard protrusions being forced into and rolling over a solid surface. The capacity of a surface to avoid being rubbed away by rubbing and friction is known as abrasion resistance.

The following are the different types of concrete wear:

i. Wear on concrete surfaces

ii. Heavy trucking and cars, with and without studded snow tires or chains, cause wear on concrete road surfaces (attrition, plus scraping and percussion).

iii. Abrasive materials borne by running water cause wear on hydraulic systems such as dams, spillways, bridge piers, and abutments (erosion).

iv. Wear on concrete bridges, spillways, tunnels, and other water-transport structures subjected to high velocities and negative pressure. Cavitation erosion is the term for this (Castro *et al*., 2011).

To survive abrasion caused by scratching, scouring, scratching, impact, cracking, attrition, percussion, gouging, or cutting from mechanical or hydraulic forces, the following considerations must be addressed in the design and construction of concrete surfaces. The failure of concrete surfaces to withstand abrasion can be attributed to a number of factors, including soft aggregate, insufficient compressive power, excessive curing or finishing, or over handling during the finishing process (Castro *et al*., 2011).

2.8.7 Water absorption

Absorption is characterized as the mechanism by which liquid penetrates and fills porous medium within a solid body, such as paste, mortar, or concrete (as a measure of permeability) (ASTM C125, 2015). Water absorption is a critical consideration for quantifying the longevity of cementitious structures, according to Castro *et al.*, (2011). Specifications and analytical research use it to include a metric that may explain an attribute of concrete longevity. Concrete's longevity in extreme conditions is primarily determined by its transport properties, which are affected by the pore method. According to research, water absorption in concrete is primarily determined by the total number of pores, filler type, density, and permeation mechanisms (Nambiar & Ramamurthy, 2007). Water absorption is described by Castro *et al.*, (2011) as the ability of concrete samples to absorb water through capillary suction. Concrete with a low water absorption rate can protect the reinforcing design inside it better. According to Pitroda and Shah (2014), the total absorption of concrete test specimens should not exceed 5 per cent, and individual units should not exceed 7 per cent. Saraswathy and Song (2007) conducted a water absorption test for concrete containing up to 30 per cent RHA in accordance with ASTM C642 (2013). As concrete was replaced with RHA in all percentages, the co-efficient of water absorption decreased, according to the author.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Framework

Figure 3.1 describes the experimental program for the research. The laboratory work is divided into three phase. Phase 1 depicts the characterisation of the constituent materials, which are fibre, aggregates binders and admix phase 2 illustrate the procedure adopted in the mix design and optimization, while phase 3 describes the various test conducted in the fresh and hardened fibre reinforce concrete

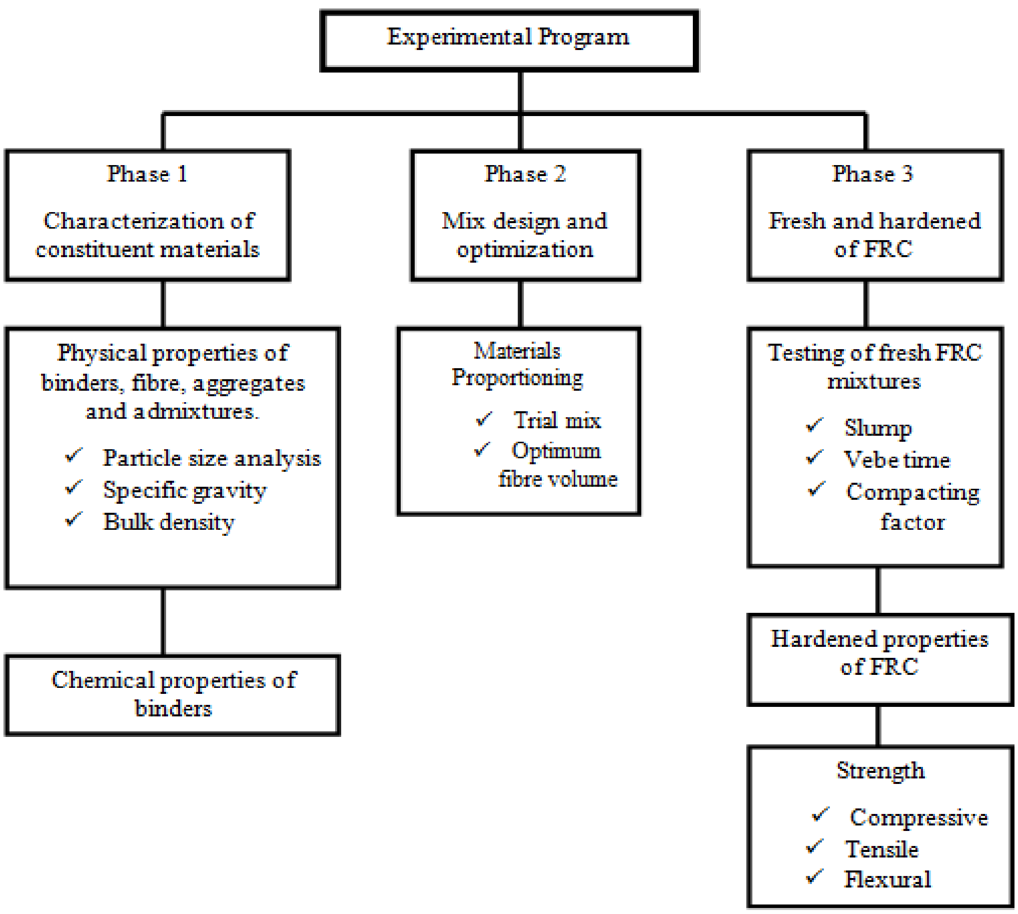

Figure 3.1: Experiment Frame Work for the Research

3.2 Materials

This chapter outlines the materials used to accomplish the study's goals and objectives, which are detailed below. Nigerian kenaf fiber, cement, aggregate, water, SHA, superplasticizer, and sodium hydroxide were used as concrete constituent materials in this study.

3.2.1 Preparation of Nigeria based kenaf fibre

The curled long fibres of kenaf were gathered in Manchok, Kaura Local Government Area, Kaduna State, Nigeria. The harvested fiber was subjected to a bacterial retting operation. The kenaf fibre was thoroughly cleaned to extract soil from the surface, and it was then dried at room temperature. The fiber was treated because of its hydrophilic qualities, which are moisture soptivity properties (Plate I). The reagent grade sodium hydroxide was used to modify the surface of the fibres, a process known as mercerization. The reagent was purchased from a Nigerian chemical dealer in Abuja.

Plate 1: (a) Curl Kenaf Fibre and (b) Alkaline treated chopped Kenaf fibre

3.2.2 Cement (ASTM C 150, 2004)

The thesis used type 1 cement, 42.5N, with the Dangote brand name in the entire set of tests. In the laboratory, type 1 cement was held in an airtight bag.

3.2.3 Fine Aggregate

In both of the mixes, natural river sand was used as fine aggregate, with an overall particle size of 4.75mm (No 4) in the upper limit according to ASTM delineation. Until application, the sand was graded and held at saturated and surface dry (SSD) condition with a fineness modulus of 2.9, specific gravity of 2.65, and water absorption of 0.70 per cent. The SSD condition of the aggregate was obtained by adding 3% water content to approximately 1000g of aggregate used in the concrete manufacturing process. The percentage was calculated by dividing the mass of SSD aggregate by the mass of water of equal volume.

3.2.4 Coarse Aggregate

All of the mixes are made with locally available air-dried crushed granite with a maximum scale of 10 mm, a specific gravity of 2.7, and water absorption of 0.5 per cent. Organic matter such as dried muds, leaves, and other deleterious materials is carefully removed from the aggregate.

3.2.5 Sorghum Husk Ash

Plate II(a), the Sorghum husk used in this study was harvested from a local grain mill in Garatu village along the Minna-Bida road in Bosso Local Government Area, Niger State. Plate II(b), set up of the locally fabricated incinerator Plate II(c), the harvested Sorghum husk was then burned in the open air with a locally fabricated incinerator (d). The

SHA that resulted was dried and sieved to remove larger materials and reduce carbon content. The burnt SHA particles were ground to a size of less than 150 μm using a local milling unit. Finally, the field ash was sieved with a 75 μm sieve, and the particles that passed through were used as the experiment's SHA.

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Plate II: (a) Sorghum husk collected (b) set up of the locally fabricated incinerator (c) burning into ash using the incinerator (d) Sorghum husk ash produced from the incinerator

3.2.6 Water

The water used for the processing and curing of concrete samples in this study was portable water from the Federal University of Technology, Minna Building Laboratory.

3.2.7 High range water reducing admixture

To trigger the desired slump, a water-reducing admixture was used. To improve the workability of concrete, a superplasticizer (SP) with the trade name CONPLAST SP430 was used as a water-reducing admixture that met ASTM C494 (2019) requirements. The superplasticizer was dissolved in part of the mixing water before being added to the fresh concrete mixing phase due to its high viscosity.

3.2.8 Sodium Hydroxide (NaOH)

Sodium hydroxide is used in this research for the treatment of kenaf fibre been used in this study, it removed cellulose, pectin, lignin which reduce degradation of the fibre and helps eliminate hydrophilic nature of the fibre which also aid binding to the cement matrix.

Plate III: Sodium Hydroxide used for the Treatment of Kenaf Fibre

3.3 Method

3.3.1 Mix proportioning

Natural fibrous concrete has a much different mixing technique than plain concrete. Ogunbode (2017) created a mixing method for natural fibrous concrete, which was adopted and used in this research. The simple concrete was constructed using the Department of the Environment's (DOE) concrete construction techniques. The coarse and fine aggregates were charged into the concrete mixer and blended with one quarter of the water used for mixing for four minutes in the first step of the fibre mixing process. The mixer was turned off for 2 minutes to allow the air dried aggregate to absorb the required water for saturation. This is essential to prevent the superplasticizer from being absorbed by the aggregates.

The CEM I and SHA cementing materials were then added to the mixer. With the addition of the second and third quarters of the mixing water, the mixer was restarted, and the stirring began for another 6 minutes. To ensure fair distribution of the fibres, all of the soaked water and fibres were gently drizzled into the matrix. The workability of fresh concrete was found to be significantly reduced. This is due to the hydrophilic nature of the kenaf fibre in the solution, which causes considerable accumulation of water intended for the concrete mixture as well as hydrolysis. The SP was then drained from the fourth quarter of the mixing water and returned to the concrete mix, where it was mixed for 5 minutes. the mixing was paused. After another 4 minutes of stirring, the mixture was poured and cast into oiled steel moulds as required. An oscillatory style pan mixer with a standard capacity of $0.02m^3$ was used to blend the concrete mixtures. The specimens were cast, compacted using a table vibrating machine and water cured in accordance with ASTM C192.

The fibrous concrete mix proportions are mentioned in Table 3. A total of ten concrete mixes were made, with the first batch serving as a control mix (Plain) with no fibre or SHA. Five batches contained CEM I cementing content (plain) with fibre volume fractions of 0 per cent, 0.25 per cent, 0.5 per cent, 0.75 per cent, and 1.0 per cent (0K0S–1.0K0S) among the ten blends. As seen in Table 3.3, five separate batches were made with SHA replacing CEM I cementing content by 10% for the corresponding fibre volume fractions (0K10S–1.0K10S).

Table 3.1: Mix proportion of different concrete mixtures

Mix	Cement (kg/m3)	SHA (%)	SHA (kg/m3)	Vf* (%)	Vf (kg/m^3)	Fine aggregate (kg/m3)	Coarse aggregate (kg/m3)	Water (kg/m3)
0K0S	539	-	-	-	-	832	832	205
0.25K0S	539	-	-	0.25	3	832	832	205
0.5K0S	539	-	-	0.5	6	832	832	205
0.75K0S	539	-	-	0.75	9	832	832	205
1.0K0S	539	-	-	1.0	12	832	832	205
0K10S	485.1	10	53.9	-	-	832	832	205
0.25K10S	485.1	10	53.9	0.25	3	832	832	205
0.5K10S	485.1	10	53.9	0.5	6	832	832	205
0.75K10S	485.1	10	53.9	0.75	9	832	832	205
1.0K10S	485.1	10	53.9	1.0	12	832	832	205

**fibre volume fraction*

3.3.2 Specimen Preparation

The criteria used in performing various tests on concrete strength are presented and examined, as well as the fabrication of test specimens and test procedures for testing fresh and hardened state properties. Only the introduction of strict criteria on material selection allows PC, SHA, and KBFCC to reliably fulfil the requirements of workability and power. This material proportioning construction approach and the use of high-quality materials in concrete manufacturing were used in this analysis to achieve the desired concrete strength. The preliminary test calculated a mix proportion that is optimal for the processing of PC, SHA, and KBFCC.

3.3.3 Fresh Concrete Test

Concrete workability was assessed using the Slump, Vebe, and Compacting Element. The aim of the test is to find the water cement ratio that meets the construction mix requirements for both fibreless and fibre-containing concrete. Both experiments were carried out in the presence of a steady amount of water lowering admixture.

3.3.3.1Slump of PC, Blended PC and KBFCC

The workability of the concrete was assessed in terms of slump to determine the ease of handling of the concrete in its fresh condition. This evaluation procedure was commonly used to ensure that the product was usable. The concrete depression should be between 80 and 120mm. The slump measurement method is in line with BS 1881: sections 1 & 2. (1983) (Plate IV). Slump measurements are taken just after the concrete has been poured. CONPLAST SP 430, as stated earlier, was used in both plain concrete and green fibrous concrete to achieve a satisfactory slump. The slump was tracked by gradually increasing SP at a rate of 0.5 per cent of the overall cementitious content, despite the fact that there is no minimum criterion for the quantity of SP in concrete. The test's results are discussed in Chapter 4. A satisfactory slump was achieved by adding 1% SP by weight of the binder.

Plate IV: Slump Testing

3.3.3.2 Vebe Test (BS EN 12350-3: 2009)

The Vebe test, as defined in BS EN 12350-3, will determine the workability of concrete installed, including fibrous concrete, by measuring the behaviour of concrete subjected to external vibration. It effectively assesses fibrous concrete's mobility, or its ability to flow under vibration, as well as the ease at which entrapped air can be removed.

Plate V: VeBe Time Testing

3.3.3.3 Compacting Factor Test (BS EN 1881-103: 1993)

The procedure is carried out in compliance with British Standard EN 1881. The compacting factor, which is the proportion of the weight of the partly compacted concrete, is calculated after the test is completed. It should be remembered that the compacting factor should be between 0.8 and 0.92 for the range of concrete to be deemed natural. The compacted value is determined with equation 3.1

$$CF = \frac{weight\ of\ partially\ compacted\ concrete}{weight\ of\ fully\ compacted\ concrete} \quad (3.1)$$

Plate VI: Compacting Factor Testing

3.3.3.4 Fresh Density of Concrete

The compacting factor instrument's container was used to test fresh density. The weight of the container packed with fresh concrete was used to calculate the volume and weight of the empty container. The test specimen is the same as the one used in the workability test.

Plate VII: Fresh Density Testing

3.4 Tests on Hardened Properties of OPC and KBFCC

3.4.1 Compressive strength

The compressive strength test was performed in accordance with BS 1881: Parts 1 and 2 of the British Standard. The specimens are properly placed, the loading machine is cleaned, and the digital unit of the machine is programmed with the required sample information prior to testing. A constant loading rate was chosen and applied until the specimen failed. The result was also validated using the following stress equation.

$$f_{c} = \frac{P}{A_c} \qquad (3.2)$$

Where:

f_c= compressive strength (N/mm^2)

F = the maximum load at failure (N)

A_c= the cross sectional area of the specimen (mm^2)

Plate VIII: Compressive Testing Machine Loaded with Specimen

3.4.2 Splitting tensile strength

The indirect tensile strength test was carried out in compliance with BS 1881: Parts 1 and 2 of the British Standard (1983). In this strain, cylindrical test specimens conforming to BS 1881 (1983) were used. To ensure consistent load distribution, a 25 X 250 mm rectangular plywood board was used as capping material at the top and bottom of all the checked specimens. Until the specimen broke into two hemispheres, a constant loading rate was chosen and applied. The results were further validated using the following equation:

f_{ct}=$\frac{2F}{\pi ld}$ (3.3)

Where:

f_{ct}= splitting tensile strength (N/mm^2)

F = maximum load (N)

l= length of the specimen (mm)

d = cross-sectional dimension (mm)

Plate IX: Splitting Tensile Testing

3.4.3 Flexural strength

The British standard specification of BS 1881 was used to test flexural power (1983). At a fixed constant loading time, prisms were loaded constantly and without shock. The following equation was used to calculate flexural strength:

f_{cf} = $\frac{Fl_r}{d_1(d2)^2}$ (3.4)

Where:

f_{cf} = flexural strength (mPa)

F = flexural load (Pa)

l_r= distance between the lower roller (mm)

d_1 and d_2= lateral dimension of the specimen (mm)

Plate X: Flexural Testing Machine Loaded with Specimen

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results on Physical Properties of Fine and Coarse Aggregates.

Tables 4.1 and 4.2 summarize the physical properties of fine and coarse aggregates, respectively.

Table 4.1: Physical Properties of Fine Aggregate

Properties	Fine Aggregate	Maximum Allowable Value	Relevant Reference
Material finer than 75µ	0.4%	3%	ASTM C33, C117
Bulk density (unit weight)	1611kg/m^3	1600-1700kg/m^3	Kosmatka *et al*., 2002
Void content	33.8%	40-50%	Kosmatka *et al*., 2002
Specific gravity on saturated surface dry (SSD)	2.64	2.40-3.00	Neville, 2012
Total evaporated moisture content	1.0%	0.05-0.80%	Neville, 2012

Table 4.1 shows that the fine aggregate used in this study complies with the appropriate requirements, as determined by ASTM C33 and C117.

4.1.1 Grading of Fine Aggregate

Figure 4.1 depicts the results of the fine aggregate sieve analysis and grading. The fine aggregate grading curve has a coefficient of grading of 1.0, which is less than 1. As a result, the fine composite was deemed to be properly graded.

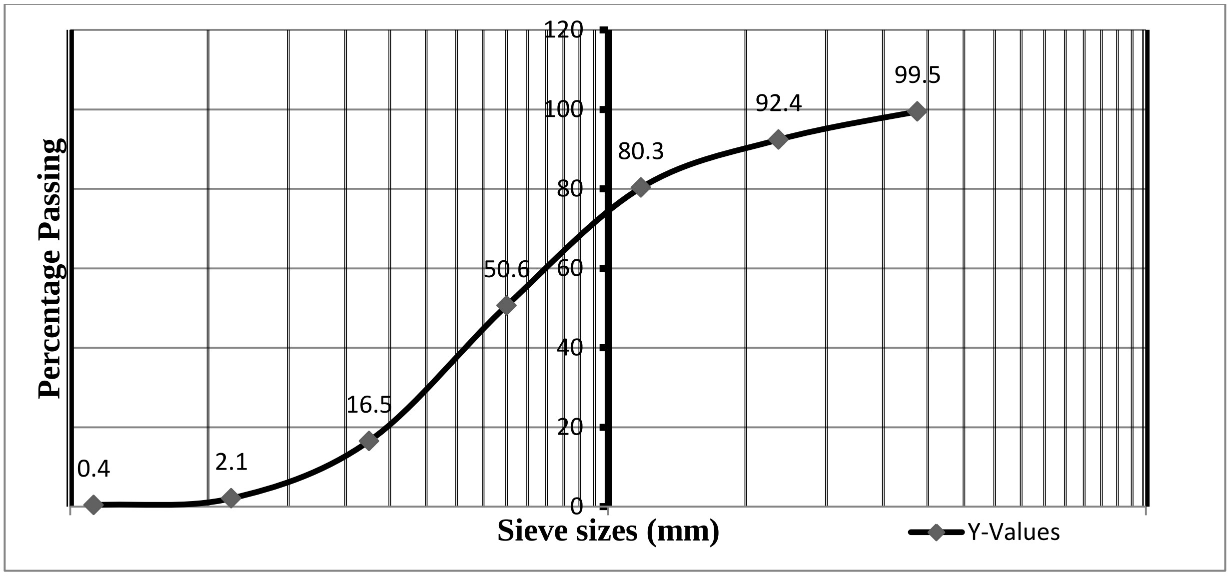

Figure 4.1: Sieve Analysis Graph of Fine Aggregate

Fine aggregate had a nominal overall size of 4.75mm and a fineness modulus of 2.40, respectively. The fineness modulus of fine aggregate is usually between 2.4 and 3.2. Fine aggregate's fineness modulus indicates that it is ideal for concrete work. This is because aggregate that meets the ASTM C33 grading limit normally produces concrete that is strong and durable. A well-graded aggregate reduces the need for water and superplasticizer, resulting in improved concrete strength and workability.

Table 4.2: Physical Properties of Coarse Aggregate

Property	Test Value	Maximum Allowable Value (%)	Relevant Reference
Material finer than 75µm	0.8%	1%	ASTM C33, C117
Bulk density (Unit weight)	1635kg/m^3	1200-1750kg/m^3	Kosmatka, et al., 2002
Void Content		30-45%	Kosmatka, et al., 2002
Specific Gravity on saturated surface dry(SSD)	2.67	2.40-2.90	Neville, 2012
Total evaporated moisture content	0.65%	0.5-4.50%	Neville, 2012

With a loose density to compacted density ratio of 0.89, the oven dry bulk density was 1635kg/m3 for compacted and 1392kg/m3 for uncompacted bulk density. This is in line with the findings of the survey (Kosmatka *et al.*, 2002). According to Kosmatka *et al.*, (2002), coarse aggregate bulk density ranges from 1200 to 1750 kg/m^3. On an oven dry basis bulk density basis, the void volume of coarse aggregate foundation was 40%. As a consequence, the measured void content is an average approximation of the void percentage between rodded aggregates. The void content of coarse aggregate varies from 30 to 45 per cent, and the specific gravity on a saturated dry basis was 2.61, which was considered acceptable since most natural aggregates have a specific gravity of 2.4 to 2.9.

Table 4.2 shows that the coarse aggregate used in this analysis satisfies the normal criteria and is thus suitable for use.

4.1.2: Grading of Coarse Aggregate

Figure 4.2 depicts the coarse aggregate sieve analysis and scoring effects. The coefficient of grading from the coarse composite grading curve was 1.05. It shows that the coarse aggregate was properly graded. According to Shetty (2009), a good-graded aggregate has a gradient coefficient in the range of 1 to 3. The result shows that the coarse aggregate fineness modulus is 4.0, which is in accordance with BS EN 12620 (2013), which specifies a fineness modulus of 4.0-7.0 range. The coarse aggregate grading has an effect on the segregation resistance of concrete because it affects the packing state of the aggregate. The workability and segregation of KBFCC containing SHA may be harmed by poorly graded aggregate.

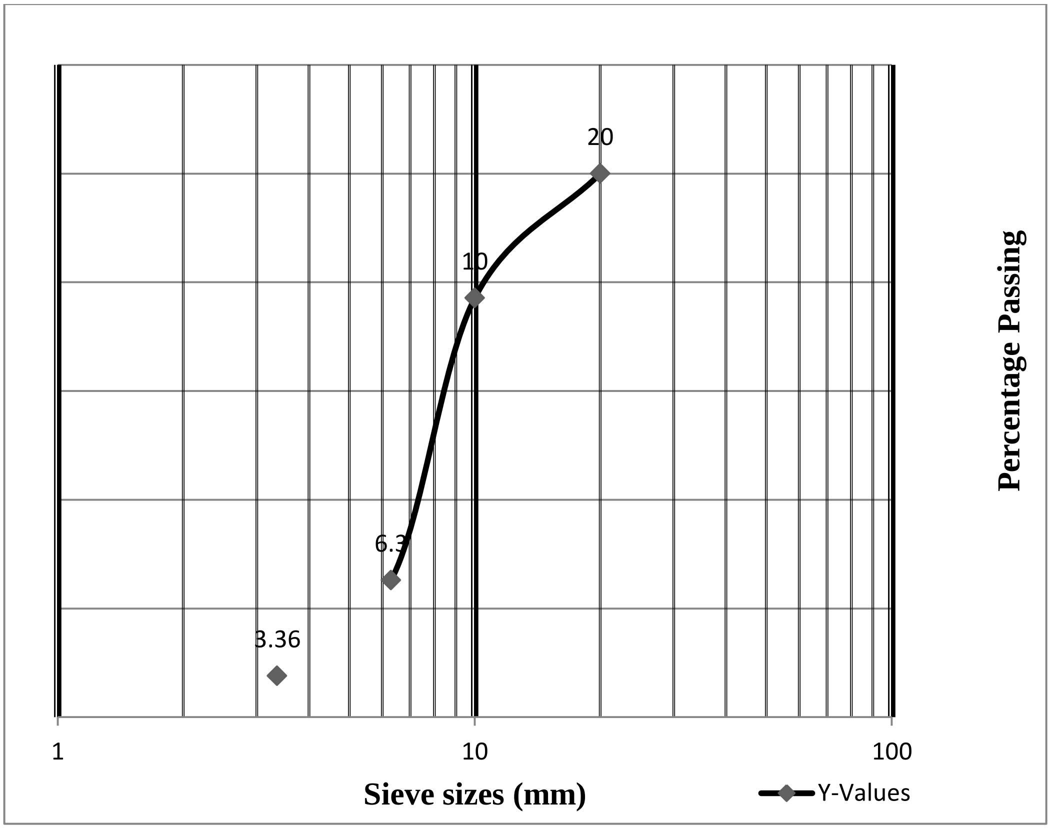

Figure 4.2: Sieve Analysis of Coarse Aggregate

4.2 Chemical Composition of Portland cement and SHA

Table 4.3 shows that Portland cement has a lower SHA than CaO, making it better in concrete than SHA. In comparison to Portland cement, the SHA has a higher SiO2 content.

Table 4.3: Chemical Composition of Portland cement and SHA

Constituent	Cement (%)	SHA (%)
SiO_2	10.2	51.2
Al_2O_3	2.7	9.35
Fe_2O_3	3.94	12.5
CaO	73.96	10.1
MgO	-	0.49
SO_3	2.38	2.1
K_2O	1.0	9.46
PH	-	8.3
LOI	-	9.0
Total	100	
% of essential oxides (SiO2+Al2O3+FeO3)		73.05

Source: Ogunbode *et al*., (2016)

4.3 Workability

The VeBe, Slump, and Compacting factor measurements were used to assess the workability of fresh concrete. The test values of the concrete's workability, as well as its densities, are shown in Table A1 in Appendix A.

4.3.1 Slump Test

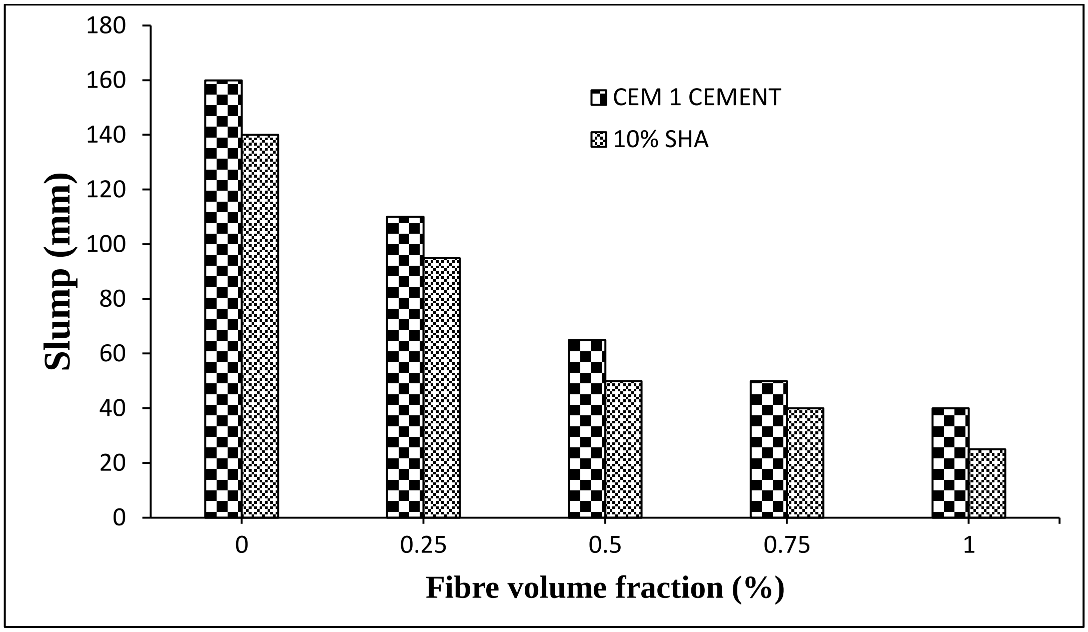

Figure 4.3: Slump Test

Figure 4.3: The concrete mixtures' slump values decreased as the fibre content increased. The slump was 160 mm for the control mixture, which was fibreless and lacked SHA. As the fibre quality was increased in 0.25 per cent increments from 0 to 1 per cent, the slump value decreased, as seen in Table A1 in Appendix A. It was discovered that using 10% SHA reduced the value of the slump more than using just Portland cement. The slump values were 95 mm, 50 mm, 40 mm, and 25 mm for volume fractions of 0.25 per cent, 0.5 per cent, 0.75 per cent, and 1.0 per cent, respectively, for SHA-based kenaf bio fibrous concrete, with slump values of 0.25 per cent, 0.5 per cent, 0.75 per cent, and 1.0 per cent.

4.3.2: VeBe Test

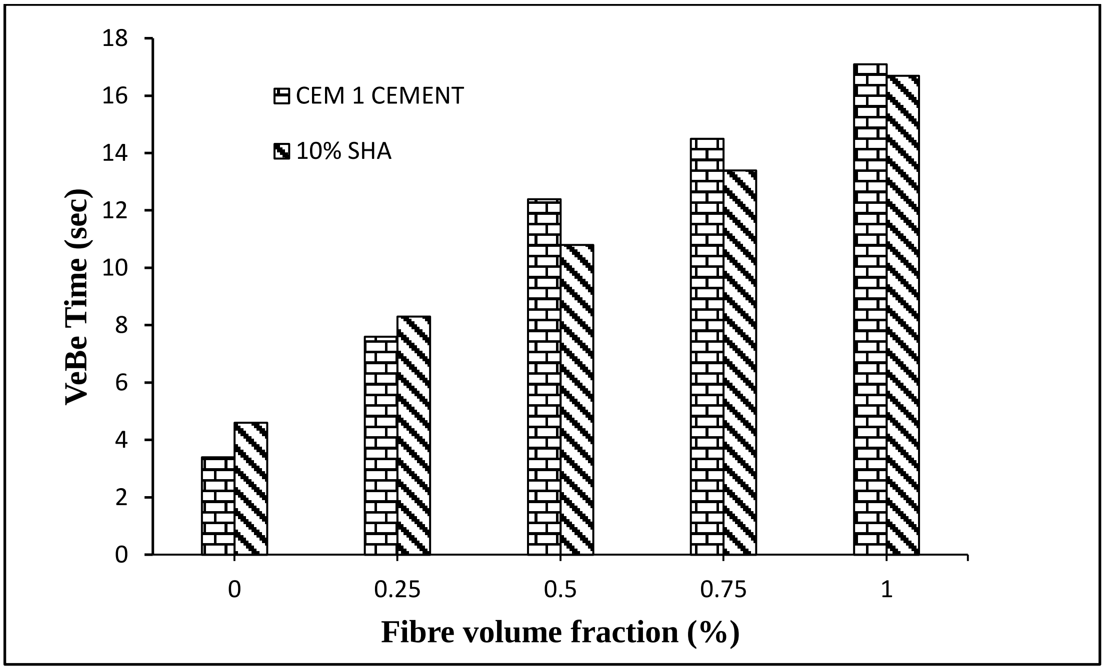

Figure 4.4: VeBe Time

It was discovered that as the amount of fibre in the SHA increased, the VeBe time increased, because of the high rate of KF and the resulting increased surface area, more pasted cement and sand were plastered around the fibres, resulting in a strong fibre-matrix bond in the concrete mixture, which harmed workability. The observed workability behaviour is consistent with Lam and Jamaludin (2016), Ogunbode *et al.* (2017) and Ogunbode *et al.* (2019) reports on bio/natural fibre in concrete mixtures. This also shows why natural fibre is hydrophilic.

4.3.3 Compacting Factor

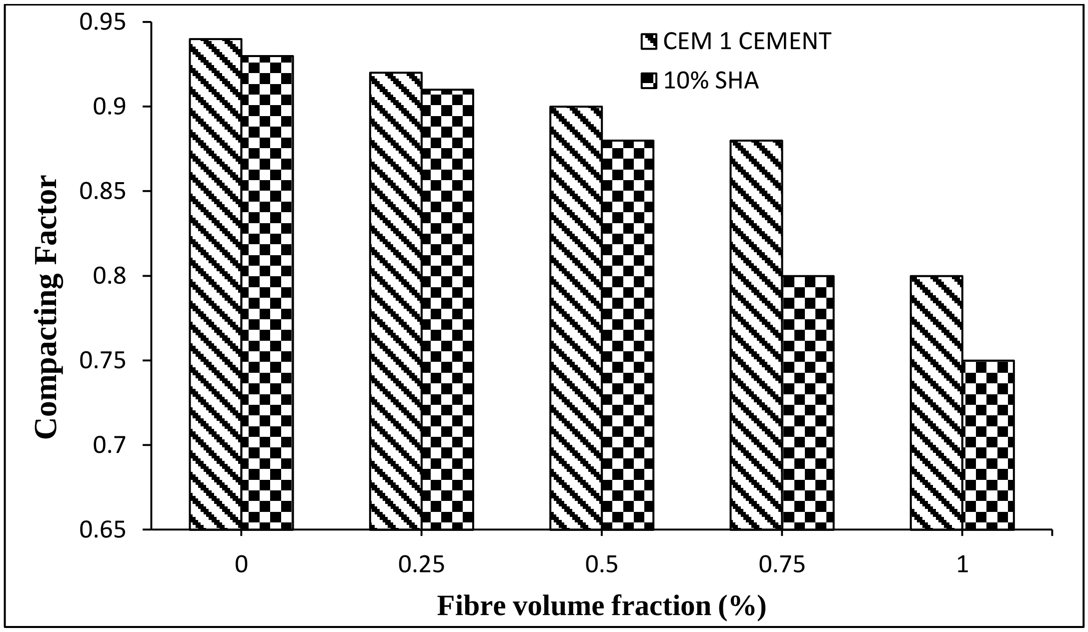

Figure 4.5: Compacting Factor

The compacting factor measure was used to assess the workability of freshly mixed concrete. Figure 4.5 shows that plain concrete has a higher compacting factor than concrete that only contains fibre or concrete that contains both SHA and kenaf fibre. The compacting factor values decreased as the mixture volume of the fibre increased. This workability behaviour is consistent with Lam and Jamaludin (2016), Ogunbode *et al*., (2017), and Ogunbode *et al*. (2019) reports on bio/natural fibre in concrete mixtures.

4.3.4 Fresh Density Test

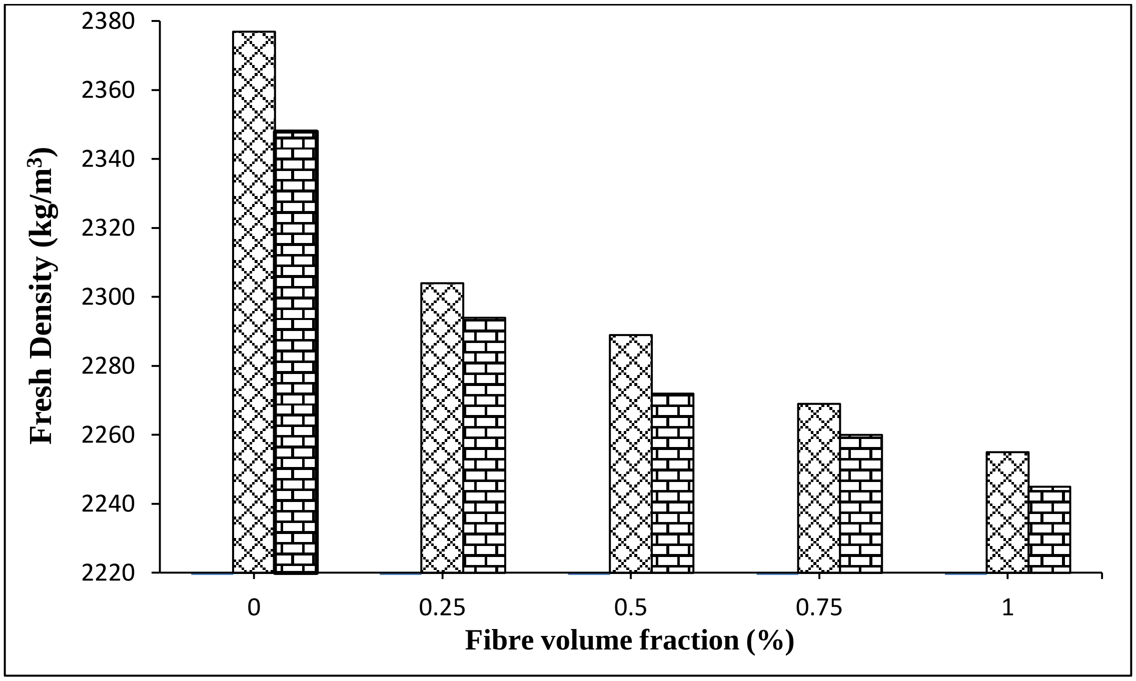

Figure 4.6: Fresh Density of Concrete

As seen in Figure 4.6, the fresh-state density of the various concrete mixes decreased as the fibre volume fraction increased. Because of the density of KF (1200 kg/m^3) which is low relative to Plain concrete, this was anticipated. Concrete mixes containing SHA also had lower density than those made solely with CEM I cementing content (Portland cement). This could also be because SHA has a lower specific gravity (2.32) than CEM I cementing material (3.15). It also shows that the mixture containing 10% SHA and 1.0 per cent KF has the lowest fresh-state density, which was roughly 6% reduced than the control blend of no fibre or SHA.

4.4 Compressive Strength of Cube Specimen

Table 4.4 shows the compressive strength effects for mixtures with different fibre volume and their combinations with and without SHA material. The incorporation of fibre decreased the compressive power of the mixture, as can be shown. Figure 4.7 shows that at the age of 28 days, 0.25 per cent, 0.5 per cent, 0.75 per cent, and 1 per cent fibre volume had a 5 per cent, 8 per cent, 11 per cent, and 16 per cent decrease in compressive power, respectively. Figure 4.8 also shows that replacing the OPC with SHA has an impact on the concrete's strength property. Simple concrete had a higher compressive strength than SHA-containing concrete in the early stages. Increase in fibre volume content by more than 0.5 per cent, on the other hand, decreased compressive strength even more, but this decrease remained within acceptable strength limits. For 0.25 per cent, 0.5 per cent, 0.75 per cent, and 1.0 per cent fibre volume and SHA material, compressive intensity decreased by 15 per cent, 18 per cent, 24 per cent, and 27 per cent after 28 days, respectively. The SHA fibrous mixtures with lower compressive strength may be attributed to lower pozzolanic action, particularly at younger ages, the presence of voids due to the inclusion of KF, and the presence of weak interfacial bonds between natural fibre and particles of pozzolanic cement (Azzmi & Yatim (2018); Ogunbode, 2017).

Table 4.4: Effect of kenaf fibre and SHA on compressive strength of concrete at 7, 28 and 56 days

M ix	Compressive Strength N/mm^2		
	7 Day	28 Day	56 Day
0K0S	35.20	46.50	49.95
0.25K0S	32.90	43.98	49.10
0.5K0S	31.40	42.71	46.80
0.75K0S	30.65	41.23	45.20
1.0K0S	28.85	38.85	43.65
0K10S	30.50	43.20	48.05
0.25K10S	27.60	39.30	46.20
0.5K10S	25.70	37.70	44.70
0.75K10S	24.20	35.20	41.30
1.0K10S	22.95	33.75	39.40

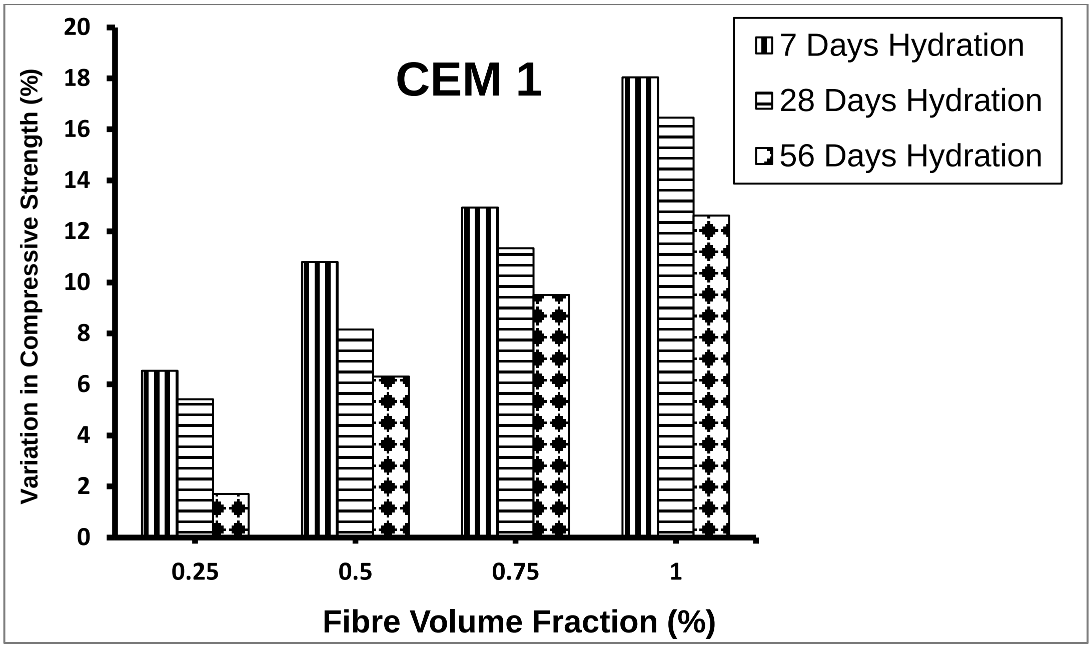

Figure 4.7: Variation in compressive strength with respect to control mix (CEM 1)

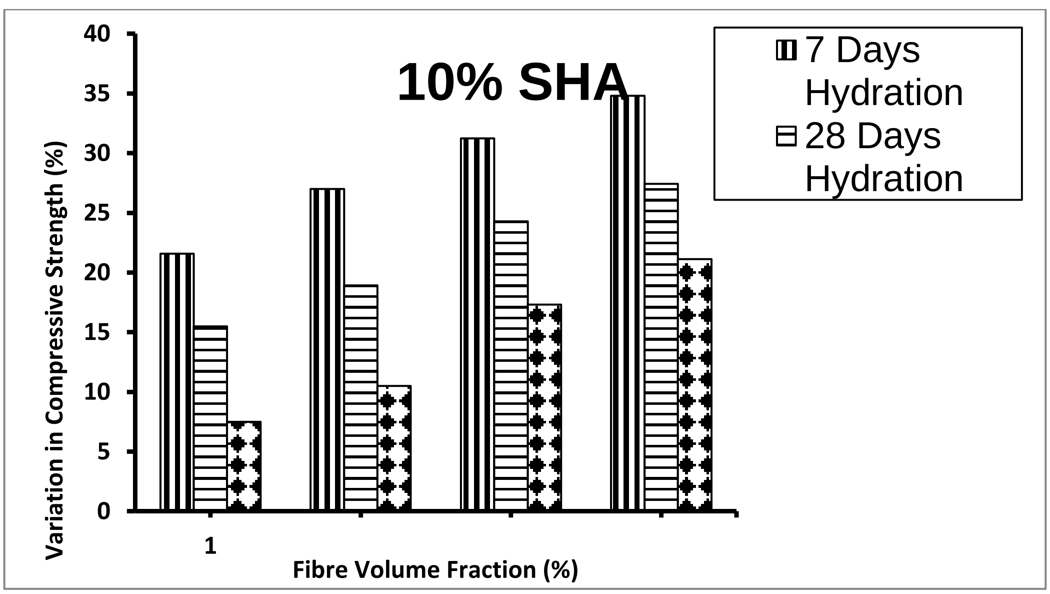

Figure 4.8 : Variation in compressive strength with respect to control mix (10% SHA)

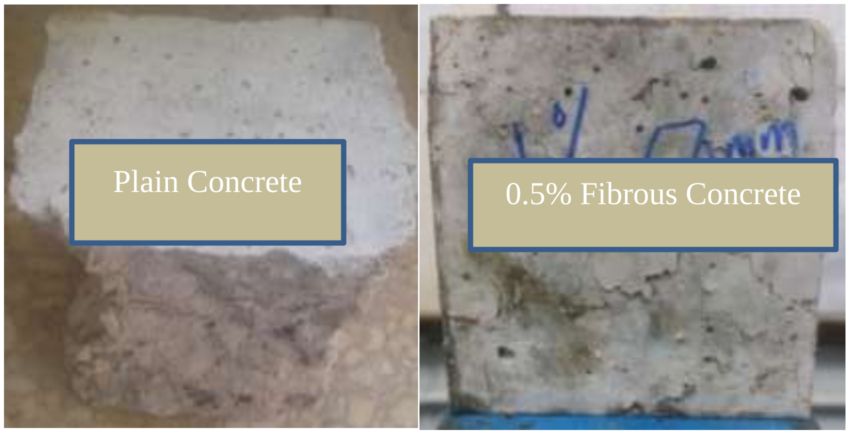

Plate XI: Failure modes of concrete cubes specimen

4.5 Splitting Tensile Strength

Table 4.5: The effect of kenaf fibre on concrete splitting tensile strength at 7, 28, and 56 days

M ix	**Tensile Strength N/mm^2**		
	7 Day	28 Day	56 Day
0K0S	3.10	4.75	4.90
0.25K0S	3.35	4.85	5.10
0.5K0S	3.50	5.05	5.35
0.75K0S	3.40	5.00	5.20
1.0K0S	3.38	4.90	5.15
0K10S	3.00	4.75	5.00
0.25K10S	3.25	4.60	5.05
0.5K10S	3.40	4.85	5.15
0.75K10S	3.35	4.70	5.25
1.0K10S	3.30	4.60	5.10

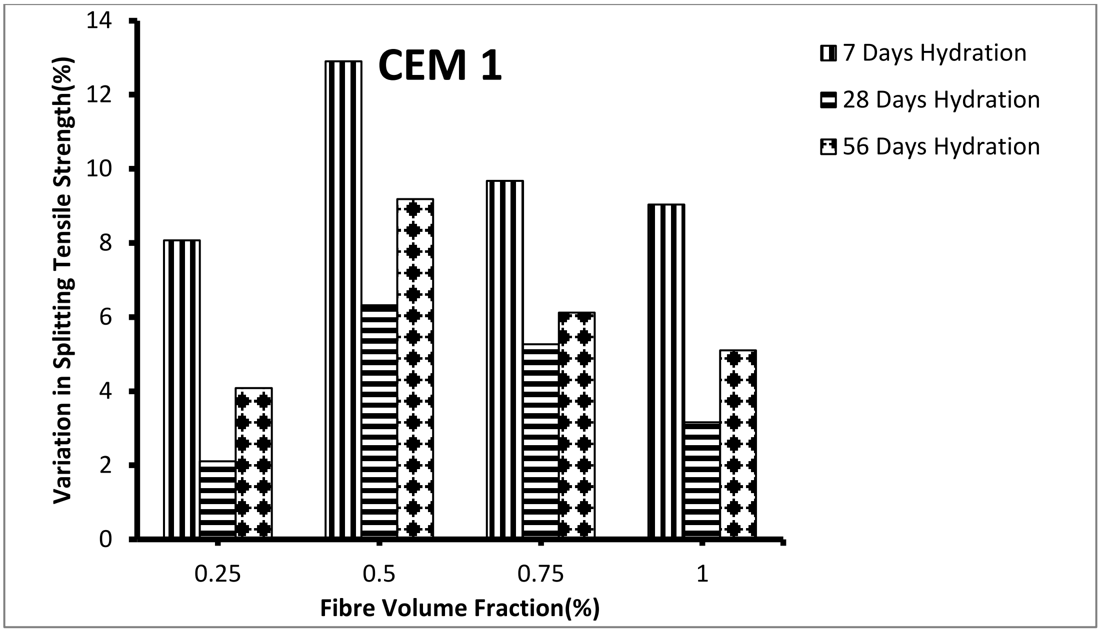

Figure 4.9: Variation in splitting tensile strength with respect to control mix (CEM 1)

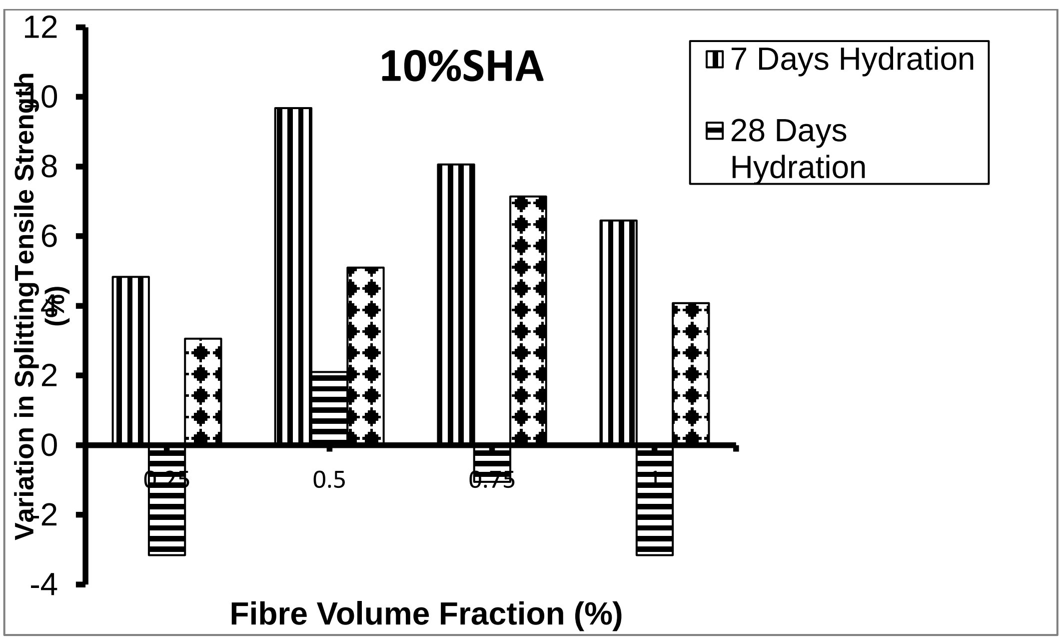

Figure 4.10 : Variation in splitting tensile strength with respect to control mix (10% SHA)

The fracturing concrete specimens bearing KF tensile forces is considerably higher than those of control concrete lacking any fibre, as seen in Figures 4.10 and 4.11. It can be deduced from the findings in Figures 4.10 and 4.11 that the mixture of SHA and KF led to the growth of concrete splitting tensile strength. For example, at 28 days, the tensile strength of mixtures of cement alone improved by 2.11 per cent and 6.32 per cent, but then began to decrease by 5.26 per cent and 3.16 per cent, respectively, relative to pure concrete without fibre for KF contents of 0.25 per cent, 0.5 per cent, 0.75 per cent, and 1 per cent. It's worth noting that adding SHA to fibrous mixtures aided in the production of tensile strength for certain fibre volume fractions. However, owing to the pozzolanic aspect of SHA, the rate of strength growth was poor at an early age; say after 7 days of curing. At 56 days, the addition of SHA to fibre reinforced concrete mixes improved tensile strength by 3.06 per cent, 5.10 per cent, 7.14 per cent, and 4.08 per cent, respectively, relative to the combination without SHA and fibre material. The increased contact area between fibres and the paste-aggregate matrix due to the increased volume of hydrated materials, this is attributed to SHA's increased pozzolanic action as healing time increases., may be attributed to this improvement. Figure 4.12 depicts the cylinder's failure state.

Plate XII: Failure modes of concrete cylinder specimen

4.6 Flexural Strength

Table 4.6: Effects of kenaf fibre and SHA on concrete flexural intensity at 7, 28, and 56 days

M ix	**Flexural Strength N/mm^2**		
	7 Day	28 Day	56 Day
0K0S	3.95	4.60	5.25
0.25K0S	4.40	5.05	5.70
0.5K0S	4.95	5.40	6.55
0.75K0S	4.35	5.20	6.00
1.0K0S	4.10	4.95	5.65
0K10S	3.80	4.25	5.35
0.25K10S	4.60	4.75	5.50
0.5K10S	4.75	5.10	5.90
0.75K10S	4.60	4.95	5.60
1.0K10S	3.90	4.80	5.40

Table 4.6 lists the flexural strength test findings for the concrete composite blends, which are shown in Figures 4.13 and 4.14. With raising the KF content from 0–1.0 per cent, the concrete composite blends reached flexural strengths ranging 7, 28, and 56 days, respectively, from 3.95–4.10 N/mm^2, 4.60–4.95 N/mm^2, and 5.25–5.65 N/mm^2. The flexural strength of concrete made with KF was found to be higher than that of concrete without fibres. The flexural strength of fibre reinforced concrete specimens followed a similar pattern to that of tensile strength. The combination with 0.5 per cent fibre, for example, had the maximum at the age of 56 days; the flexural intensity was 6.10 N/mm^2, which was 19.5 per cent higher than the control mix without SHA or fibre. After curing for

longer times, SHA improved the flexural performance, as seen in the tensile strength. The combined effect of SHA and KF was discovered, and 0.5 per cent fibre yielded a 13.4 per cent improvement in flexural strength in comparison to non-fibrous concrete at 10% SHA.

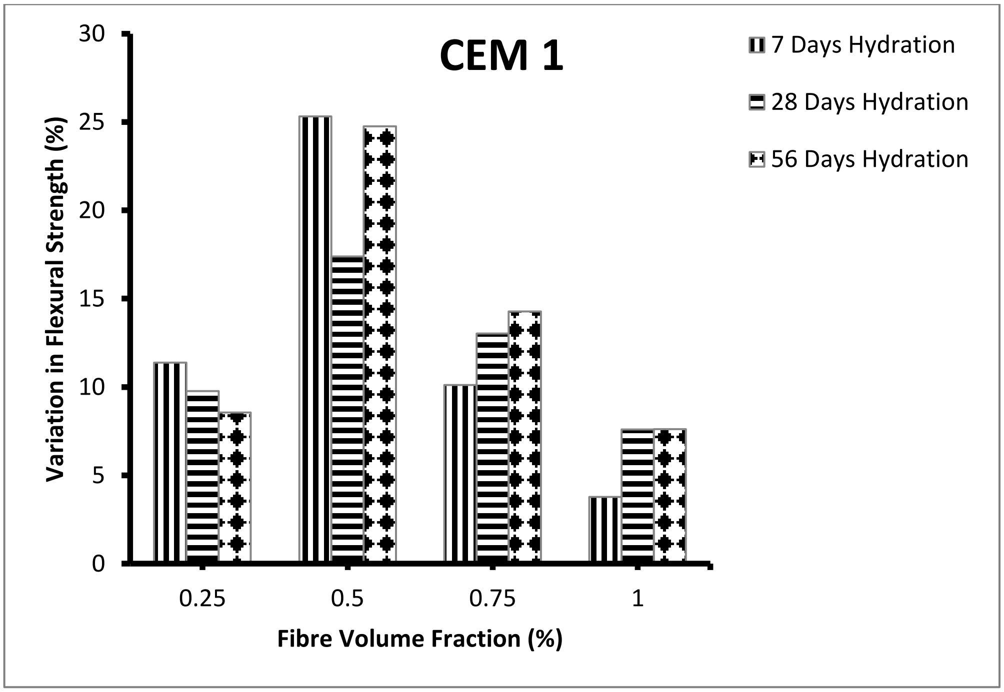

Figure 4.11: Variation in flexural strength with respect to control mix (CEM 1)

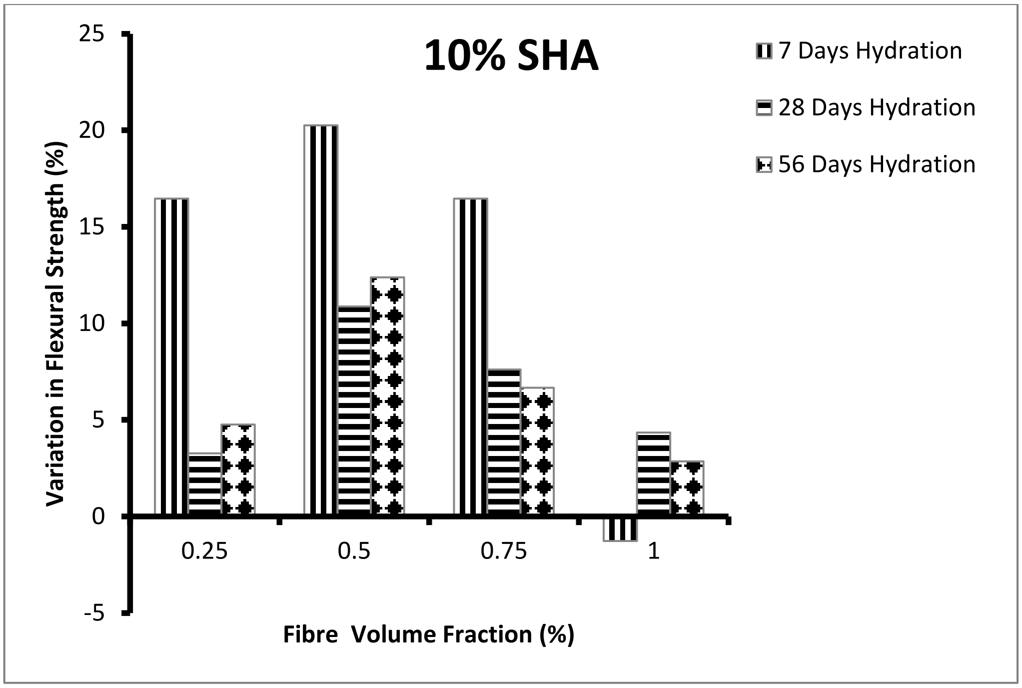

Figure 4.12: Variation in flexural strength in respect to control mix (10% SHA)

Plate XIII: Failure mode of concrete prism specimen

4.7 Relationship between Compressive, Tensile and Flexural Strength

A regression analysis was used to determine the impact of kenaf fibre on the fracturing tensile strength of concrete with and without SHA. A linear regression method, which is one of the most widely used mathematical methods, was added to the test results to demonstrate the relationships between the concrete compressive, tensile, and flexural forces. Figures 4.16, 4.17, and 4.18 demonstrate the relationships between tensile, compressive, and flexural strengths and experimental results. At all ages, tensile and compressive strengths, as well as flexural and compressive strengths, have a close relationship, is clearly shown. The coefficient of determination (R^2) for equations 1 and 2 was 0.59 and 0.60, respectively, indicating how much of the average change in the dependent variables is compensated for by the regression equation.

$$y = 0.0149x + 3.7874 \tag{4.1}$$

$$y = 0.0549x + 2.8251 \tag{4.2}$$

In reality, similar factors as the cube compressive strength could influence the splitting tensile and flexural strengths of plain concrete without kenaf fibre: w/c ratio, curing time, aggregate form, method of testing and sample size (Abdul Awal *et al.*, 2005). Other factors that affect the splitting tensile and flexural capabilities of kenaf fibre reinforced concrete include the fibre form, weight, shape, and aspect ratio, as well as the fibre material. Furthermore, the number of tests to be analyzed is important since a larger set of test results will provide the most accurate statistical confirmation of a variety of problems.

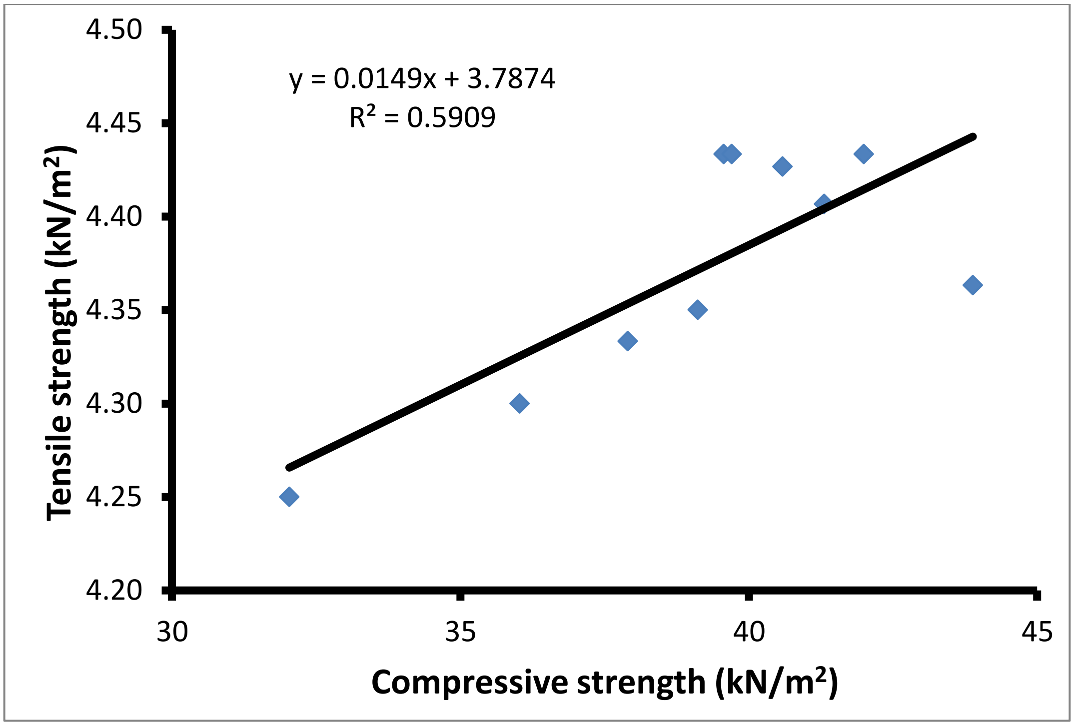

Figure 4.13: Relationship between tensile-compressive strengths of concrete mixtures

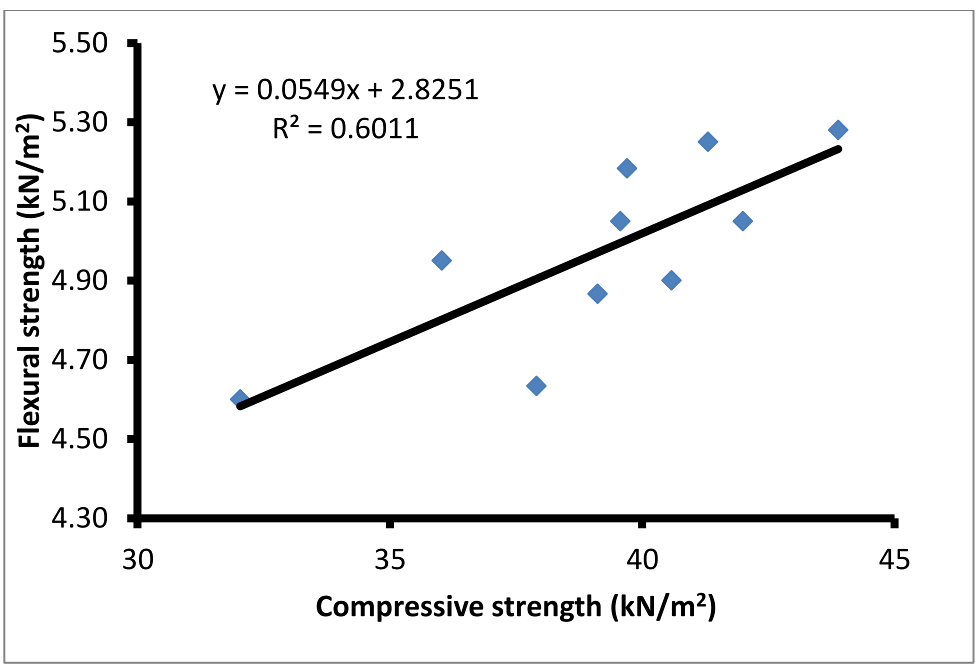

Figure 4.14: Relationship between flexural-compressive strengths of concrete mixtures

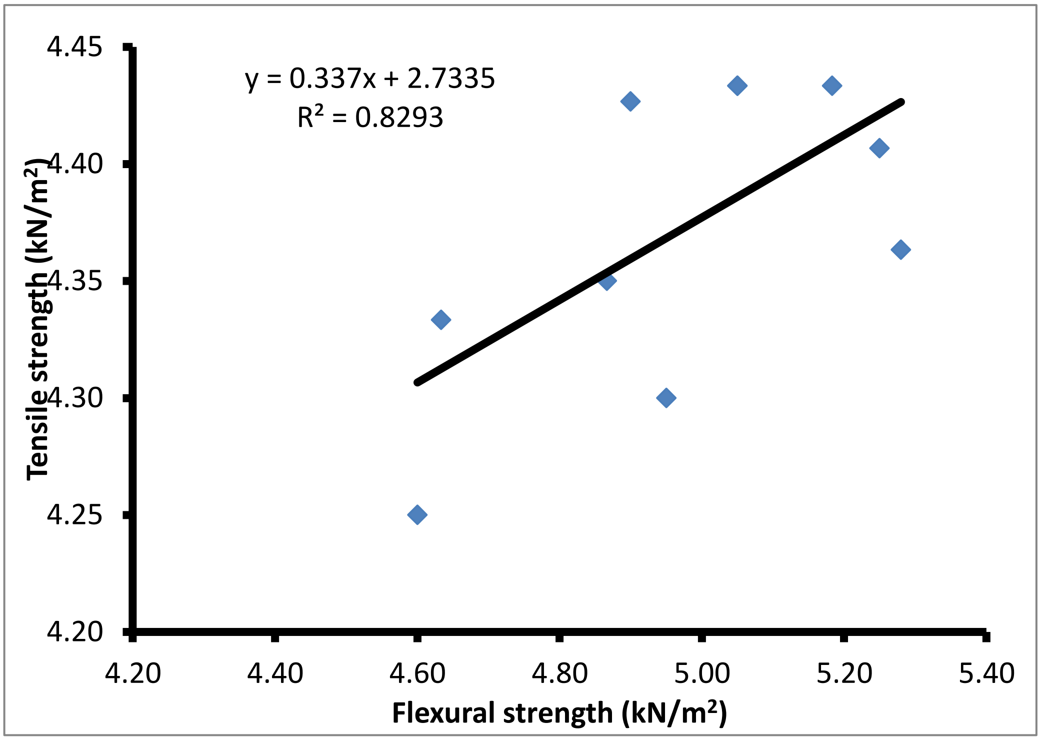

Figure 4.15: Relationship between tensile-flexural strengths of concrete mixtures

Figure 4.18 depicts the effects of the separating tensile and flexural experiments, as well as their relationships. To compare the experimental effects of separating flexural strength and tensile strength, a linear regression approach was used, resulting in equation (4.3) with a coefficient of determination (R^2) of 0.83, indicating high faith in the relationship. The findings showed that the flexural and tensile strength values for kenaf fibre reinforced concrete containing SHA is closely linked to each other and that the ratio of strength growth followed a trend comparable to that of fibrous concrete mixtures with CEM 1 cement. It can also be shown that as tensile strength increases, so does flexural strength, as seen by equation (4.3). All of the strength parameters for fibrous mixtures containing SHA are within the standard values for concrete made with CEM 1 cement alone, according to the findings of this report.

$$y = 0.337x + 2.7335 \tag{4.3}$$

4.8 Summary of Findings

i. The Kenaf fibrous concrete built on SHA has good workability, the workability reduces as the amount of kenaf fibre increases and the SHA material is added at a steady volume fraction of 10%, according to experience. This is due to the irregular kenaf fibers' wide surface area, which absorbs cement paste and grit, stiffening the matrix.

ii. Concrete specimens that do not contain SHA or Kenaf fibers (plain concrete) had higher fresh concrete unit weight values than the specimens containing either only kenaf fibre or SHA and kenaf fibre.

iii. The addition of kenaf fibres to concrete composites increased their ductility and energy absorbing potential, resulting in a more uniform crack distribution.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Waste sorghum husk ash and Kenaf fibre have various effects on the properties of concrete composite in the hardened and fresh states are investigated in this study. By promoting environmentally friendly fibre and recycling agro-wastes, the use of kenaf fibre and the use of sorghum husk ash in concrete composites have proved to be beneficial to meet the need for maintaining a cleaner atmosphere and manufacturing green concrete. The following points are taken based on the investigational findings and observations:

- The addition of kenaf fiber to concrete decreased its workability. The longer the VeBe period and the lower the values of the slump, as the fibre volume fraction increase.
- With rising fibre material, the compressive strength of the fibre matrix decreased. Concrete containing kenaf fiber and SHA had lower cube compressive strengths than plain concrete. The results, however, were within the acceptable range for structural applications.
- Despite smaller increases in compressive strength, major improvements in tensile and flexural strength were observed. Because of a stronger fibre-cement matrix interface and matrix densification, SHA and concrete containing kenaf fibre worked better in the growth of flexural and tensile strengths at all ages. At 56 days, the tensile strength of CEM I cement and SHA material mixtures improved by 5.35 per cent and 5.15 per cent, respectively, for mixes containing 0.5 percent fibre. For the same conditions, flexural efficiency increased by 6.55 per cent and 5.90 per cent,

respectively.

- Because of the bridging operation of the fibres, the ductility of kenaf fibre concrete performed better than plain concrete.
- There exists a good relationship between tensile and compressive strengths as well as between flexural and compressive strengths at all ages for the kenaf fibre reinforced concrete incorporating SHA. The coefficient of determination (R2), which demonstrates how much of the overall change in the dependent variables is accounted for by the regression equation, was 0.59, 0.60 and 0.83 for equation 1, 2 and 3 respectively. The observations made in this study suggest that all of the strength parameters for fibrous mixtures containing SHA are within the typical values for concrete with CEM 1 cement alone.

5.2 Recommendations

i. SHA as a waste material can be easily put to use for good waste control, and recycling the materials can aid in the manufacture of a sustainable concrete material which will in turn provide maximum economic value.

ii. Based on the findings and review of this study, SHA and KF is recommended to be integrated into mixing concrete to improve the fracturing and flexural strength. However, strict caution should be exercised if optimum compressive strength is needed, in which case high strength concrete should be included in the mix.

iii. The findings and observations in this study indicate that concrete composites with kenaf fiber and sorghum husk ash can be used in the construction of in building slabs, road pavements, and bridge decks and other related applications with adequate engineering properties.

iv. Future research into the large-scale application of kenaf fibre and its consistency is recommended for reinforced concrete members

5.3 Contribution to Knowledge

The thesis established that the use of Kenaf Fibre at 50mm and fibre volume of 0.5% incorporated with Sorghum Husk Ash at 10% in the production of sustainable green concrete is technical and environmentally viable

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APPENDIX A

Mix Design

CHARACTERISTIC STRENGTH: 45N/mm^2 28 days

Standard Deviation: 8 N/mm^2

Margin: k = 1.64

1.64 x 8 = 13.12

Target Mean Strength: 45 + 13.12 = 58.12 N/mm^2

Fine Aggregate Type: Uncrushed

Coarse aggregates type: Crushed

Free Water Cement Ratio: 0.38

STAGE2

Slump: 10-30 mm

Aggregate Size: 10 mm

Water Content: 205 kg/m^3

STAGE 3

Cement Content: 205 / 0.38 = 539.474 kg/m^3

STEP 4

Specific Gravity: 2.7

Concrete Density: 2408.70 kg/m^3

Total Aggregate Content: 2408.70 – 205 – 539.474= 1664.226 kg/m^3

STAGE 5

Grading of Fine Aggregate: Percentage passing 600µm sieve 50.6%

Proportion of Fine Aggregate: 50%

Fine Aggregate Content: 1664.226 x 0.5 = 832.113kg/m^3

Coarse Aggregate Content: 1664.23 – 832.113 = 832.113kg/m^3

TRIAL MIX

Cement	539.474kg/m^3
Water	205kg/m^3
Fine Aggregate	832.113kg/m^3
Coarse Aggregate	832.113kg/m^3

APPENDIX B

FIBRE CALCULATION

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

Mass/Weight = volume X density

Density of kenaf fibre = 1200kg/m^3

Volume = volume of specimen (cube, cylinder and prism)

Cube specimen (100mm X 100mm X 100mm) or (0.1m X 0.1m X 0.1m)

Volume of cube specimen = 0.001m^3

Fibre content (0.25%, 0.5%, 0.75% and 1%) for 0.25%

Cube specimen (0.1m X 0.1m X 0.1m) containing fibre content of 0.25% = 0.001 X 0.0025

Volume of 0.25% fibre = 0.001 X 0.0025 = 0.0000025m^3

Mass/Weight = volume (0.25%) fibre content X density of kenaf fibre

Mass/Weight = 0.0000025 X 1200 = 0.003kg

APPENDIX C

Table A1:Fresh state properties of concrete mixtures.

Mix	Fibre (%)	Ash (%)	Vebe time (sec)	Compacting factor	Slump (mm)	Fresh Density (kg/m^3)
0K0S	0	0	3.4	0.94	160	2377
0.25K0S	0.25	0	7.6	0.92	110	2304
0.5K0S	0.5	0	12.4	0.90	65	2289
0.75K0S	0.75	0	14.5	0.88	50	2269
1.0K0S	1.0	0	17.1	0.80	40	2255
0K10S	0	10	4.6	0.93	140	2348
0.25K10S	0.25	10	8.3	0.91	95	2304
0.5K10S	0.5	10	10.8	0.88	50	2272
0.75K10S	0.75	10	13.4	0.80	40	2260
1.0K10S	1.0	10	16.7	0.75	25	2245