MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING, DESIGN, ART AND TECHNOLOGY

SCHOOL OF BUILT ENVIRONMENT

DEPARTMENT OF CONSTRUCTION ECONOMICS AND MANAGEMENT

BACHELOR OF SCIENCE IN CONSTRUCTION MANAGEMENT

ASSESSING THE EFFECT OF BAMBOO FIBER ON THE MECHANICAL PROPERTIES OF FIBER REINFORCED CONCRETE.

BY

ATIMA ALICE TRACY

18/U/23248/PS

1800723248

A dissertation submitted to the Department of Construction Economics and Management for the Award of a Degree of Bachelor of Science in Construction Management at Makerere University

February 2022

DECLARATION

I declare and affirm that this report is original, has been written by me and has never been presented for any award in any institution before.

Signed:

Date: ....4th.........February.....2022...

APPROVAL

This project report has been submitted to Makerere University, approving that ATIMA ALICE TRACY carried out and completed the research into assessing the effect of bamboo fiber on the mechanical properties of fiber reinforced concrete.

Signature	Date
	..04/02/2022..........

Acheng Opio Pamela

Supervisor

DEDICATION

I dedicate this report to my beloved mom and dad for their endless love, physical, financial and mental support rendered in my academic journey especially for endeavoring to keep me in school and for supporting me throughout this research period. May the Almighty Lord bless and reward them abundantly.

I also dedicate this report to myself, for surviving through tough times, for not breaking down mentally, for remaining sincere to myself and for working hard. I deserve this achievement.

ACKNOWLEDGEMENT

First, I thank the God Almighty who blessed me with life, good health and the strength to carry out this research despite global, national and personal challenges. We give Glory to God.

Secondly, my sincere gratitude to my supervisor, Madam Acheng Opio Pamela for the constructive assistance and time she has greatly invested in me to complete this project. I pray the Almighty blesses you more in all your works.

I would also like to thank my fellow students for sharing knowledge and ideas as regards to each other's research without holding back. We really learned a lot from one another and I hope and pray that we continue with the same spirit in the future.

I would also like to thank myself for being me and not giving up amidst all the challenges. This taught me that I could do and achieve anything if I put my mind to it. Research was a great experience for me and I am grateful I was able to come this far.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

N/Sqmm:	Newton per millimeter squared
Mpa:	Mega Pascal's
Ush:	Uganda Shillings
N/mm^{2}:	Newton per millimeter squared
FRC:	Fiber reinforced concrete

ABSTRACT

Bamboo has a potential as a construction material due to its high tensile strength that makes it comparable to steel as a reinforcement in concrete. It can be used as a fiber in reinforced concrete for improving strength properties of concrete. However, the effect of bamboo fiber on mechanical properties of fiber reinforced concrete are not known. The objective was to assess the effect of bamboo fiber on the mechanical properties of fiber reinforced concrete using compressive, flexural, tensile and slump experimental tests. This was to determine mechanical properties of bamboo, workability of fresh bamboo fiber reinforced concrete, compressive and tensile strength and optimize the bamboo fiber proportion for concrete strength improvement.

The failure load of bamboo under compression and flexure at 1, 3 and 5 years was recorded and used to compute its compressive and flexural strength. The slump of fresh fiber reinforced concrete was measured at 0%, 1% and 2% of bamboo fiber in concrete and used to determine the workability of fresh concrete. The failure load of bamboo fiber reinforced concrete was recorded at 7, 14 and 28 days and used to compute compressive and tensile strengthen gained. These results were used to optimize bamboo fiber proportions.

The results were analyzed using Microsoft Excel. Results indicated bamboo has high compressive strength in the bottom and top parts of the culm for bamboo with and without nodes. Bamboo with nodes had a higher compressive strength on average because the nodes are the strongest part of the bamboo. The flexural strength was higher at the bottom and top parts of the bamboo culm. However, the flexural strength decreased with increase in the age of the bamboo. Workability decreased with increase in fiber proportions in concrete. Compressive strength decreased with increasing bamboo proportions with 1 and 38.5% decrease. There was an increase in tensile strength of bamboo FRC with increase in fiber proportions from 1.9 to 2.7 N/mm^2 at 28 days. The optimum bamboo fiber proportion for concrete strength improvement was at 1% and gave 19.4 and 2.7 N/mm^2 for compressive and tensile strengths at 28 days respectively.

Bamboo fiber enhances the strength properties of fiber reinforced concrete in tension and reduces the compressive strength of the concrete within acceptable ranges up to 1%. Bamboo fiber reinforced concrete should be promoted for use in structures with light loads such as walling units, shades or on pavements and parking for soil reinforcement.

Key words: Bamboo, Bamboo fiber, Fiber reinforced concrete, Tensile, Compressive

CHAPTER ONE

1.1 BACKGROUND

Concrete is one of the oldest and most common construction materials in the world with 4000 thousands of cubic meters of ready mix concrete used in 2021 (Findings & Statistics, 2021). This composite made up of cement sand, aggregates, water and additives or admixtures is mainly used due to its low cost, availability, durability, and ability to sustain extreme weather environments (Li, 2011). However, concrete has good strength in compression, but poor strength in tension. Therefore, requiring reinforcement to be able to handle tensile stresses. Steel fibers have been used, but they possess a high-embodied carbon footprint and are expensive. Alternative natural fibers like bamboo have been investigated and this research will assess the effect of bamboo fiber on the mechanical properties of fiber reinforced concrete.

Freshly mixed concrete or mortar exhibits workability as a property, which determines the ease and homogeneity with which concrete or mortar, can be mixed, placed, consolidated and finished. Therefore, this is the effort required to manipulate concrete or mortar with minimum loss of homogeneity. Concrete can be unworkable, medium workable or highly workable. The compressive strength of concrete is dependent on the workability of the concrete, as workability increases, compressive strength decreases due to increase in water-cement ratio, which affect the bonding of aggregates. The desired workability is always determined on site using the slump test.

The quality of concrete is determined according to its strength, dimensional stability and durability properties, we shall however look at its strength property to measure evaluate its mechanical properties. Mechanical properties are the physical properties that a material exhibits upon the application of forces. Performance of concrete is evaluated from its mechanical properties, which include, compressive strength, tensile strength, flexural strength, shrinkage and creep and modulus of elasticity.

Compressive strength is the ability of a material or structure to carry the loads on its surface without any crack or deflection. One of the most common methods to evaluate concrete performance is by measuring the compressive strength of hardened concrete at an age of twenty five (25) days (Li, 2011).

(NRMCA, 2015) defines flexural strength as a measure of the tensile strength of concrete. The maximum amount of tensile load concrete can bear before failing is known as flexural strength or modulus of rupture. Concrete has very little tensile strength and its flexural strength is the measure of how far the concrete can bend before breaking or cracking. The flexural strength of concrete depends on its compressive strength and this property of concrete is good in reinforced concrete.

Bamboo is one of the oldest traditionally used construction materials. However, until lately, it has been considered a construction material for "poor" settlement. Bamboo is a superior construction material as compared to timber because it has excellent mechanical and anatomical properties for its low weight (Astuti et al., 2015) . Bamboo possesses a high elasticity, which allows it to bend to any shape and tensile strength making it comparable to steel as a reinforcement in concrete. Just like any other material, bamboo cannot be used alone to achieve optimum performance, therefore it is advisable to incorporate the use of bamboo with other materials during construction.

Bamboo is a unique group of gigantic grasses that of which originates in underground rhizomes. It grows naturally in many parts around the world but some species are artificially planted. Bamboo forests are found across tropic and sub-tropic zones between latitudes of about 40 degrees south, that is, ones with mean temperatures from 20^{o}c to 30^{o}c. Bamboo suitable for water pipes grows at altitude from 20 to 3000 meters. The plant is fully mature at an age of three to four years (Terai & Minami, 2012a).

These come in a wide range of sizes. Bamboo grows everywhere except places with cold climate and can be used for a variety of purposes; a source of food to people, especially the shoots, crafting products and as a construction material as it is a renewable resource (Nurdiah, 2016).

Bamboo has been used through history not only because of the strength of the material, but also through the renewable prospects (Nurdiah, 2016). Through history, wood has become more and more scarce, simply because to produce a full grown tree can take up to sixty years and then another sixty years' time for a replacement: species of bamboo equal to the height and width of a tree take as little as sixty days to mature completely (Nurdiah, 2016).

1.2 PROBLEM STATEMENT

Conventional possesses a poor tensile strength. Steel fibers have been used, however, their effect on the environment is detrimental with 1.85 tons of carbon dioxide emitted for every ton of steel produced (Hoffmann et al., 2020). This causes pollution of the environment and damage to the ozone layer. The use of alternative natural fiber as construction materials was adopted but there also arose structural challenges. Other natural fibers used in fiber reinforced concrete like coir could not be used alone and are biodegradable; jute has weak strength properties and is biodegradable and sisal can decompose in alkaline environments or in biological attack. Bamboo fiber has potential; however, due to the variability in species, there is need to assess the effects of bamboo fiber on the mechanical properties of fiber reinforced concrete.

1.3 OBJECTIVES

1.3.1 **Main objective**

The main objective of this research was to assess the effect of bamboo fiber on the mechanical properties of fiber reinforced concrete.

1.3.2 Specific objectives

The specific objectives of this research were:

- To establish the chemical and mechanical properties of bamboo fiber.
- To evaluate the effect of bamboo fiber in varying proportions on the physical properties of concrete (workability).
- To evaluate the effect of bamboo fiber in varying proportions on the mechanical properties of concrete (compressive strength and tensile strength).
- To optimize the bamboo fiber proportions for concrete strength improvement.

1.3.3 Research Questions

1) What are the mechanical properties of bamboo?
2) How does varying bamboo fiber proportions affect the workability of fresh concrete?
3) What is the effect of varying bamboo proportions on the compressive and tensile strength of hardened fiber reinforced concrete?
4) What is the optimum bamboo proportion for preparation of high strength fiber reinforced concrete?

1.4 JUSTIFICATION

The construction industry is looking for sustainable construction methods and use of alternative greener materials and bamboo is readily and cheaply available. there is need to explore the use of natural fibers such as bamboo in reinforced concrete as they possess the potential in strength properties, durability and as a composite material.

Bamboo due to its properties showed potential to be used as a construction material because it was essentially an elastic brittle material with a high tensile strength. Bamboo can be used in the members where load intensity is less such as roof slab of parking area, public toilets, sunshades, security guard cabin etc. Data cited previously from Bhimarao & Patil, (2019) encourages the use of bamboo together with other construction materials.

Incorporating fiber in fiber reinforced concrete helped to control early cracks and shrinkage observed on normal concrete and it also improved the ductility of the concrete used for structural and non-structural engineering works (Geremew et al., 2021).

1.5 SCOPE

1.5.1 Time Scope

This study was done within a period of eight to ten weeks, including the gathering of materials, carrying out the required experiments and compiling of the final report. A chart showing the time covered to complete the project is found in the appendix of this document.

1.5.2 Geographic Scope

This research study was experimental in nature and the experiments were carried out from the Makerere University structural laboratory.

1.5.3 Academic Scope

The experiment was expected to study the mechanical properties of bamboo as a potential construction material and provide results of the behavior of concrete that has been made with bamboo fiber through the observation of its mechanical properties, which is through the slump test, compressive strength and tensile strength tests.

CHAPTER TWO

2.1 LITERATURE REVIEW

This chapter analyzed the existing literature on the effect of bamboo fiber on the mechanical properties of fiber reinforced concrete. Concrete workability, it's compressive and tensile strengths and the tests conducted to determine the above properties would be explained. The effect of bamboo fiber on these properties was evaluated; its importance and drawbacks in the construction industry and the environment were discussed.

(Geremew et al., 2021) provided an overview about the mechanical properties of concrete using natural fiber and concluded that; as the addition of natural fiber increases in fiber reinforced concrete, its slump value decreased but the mechanical property of the concrete improved up to a certain value. Then it started to decline compared to the control mix design and the mode of failure changes from brittle to ductile with addition of natural fiber

2.1.1 Chemical and mechanical properties of bamboo

(Xiaobo, 2004) found that the alcohol-toluene extractive content showed a continuous increase from one-year-old bamboo to five-year-old bamboo. Holocellulose and alpha-cellulose content increased from the bottom to the top portion. There was no significant variation in lignin content and ash content from the bottom to the top portion of bamboo. Outer layer of bamboo had the highest holocellulose, alpha-cellulose, and Klason lignin content and the lowest extractive content and ash contents. The epidermis had the highest extractive and ash content and had the lowest holocellulose and alpha-cellulose content.

(Gutu, 2013) in his studies on strength properties of bamboo to enhance its utilization reported the strength properties of bamboo to be more than those of most soft woods and some of the hard woods. The researcher also noted that a high moisture content reduces the strength property of bamboo. The researcher reported the compressive strength of bamboo to be 6585N, its modulus of rupture to be 205.505336N and its bending properties were reported to be 4536N for which he recommended the utilization of bamboo as an additional material for wood in Zimbabwe.

(Wang, 2020) in determining the physical and mechanical properties of bamboo found that; the compressive strength across the length was found to be between 77-79 MPa, the average tensile strength of the samples tested was 95.781 MPa and the shear strength in single shear was 85.3 MPa while that in double shear was found to be 99.71 MPa.

2.1.2 Workability

The slump test was conducted to determine the workability of fresh concrete. Workability was defined as the ease with which concrete can be mixed, transported, placed and compacted (Tahara et al., 2021). This test was used to determine the consistency of a fresh concrete sample before curing.

(Tahara et al., 2021) conducted a research on the performance of beting bamboo as partial replacement for coarse aggregates in concrete. The slump results found that the percentage of bamboo that was replaced affected the degree of workability of fresh concrete. Concrete with 0% bamboo delivered the highest slump value compared to that of 15% bamboo composition as it delivered the lowest slump value, which specified a low degree of workability.

In a journal paper by (Terai & Minami, 2012b) on the basic study on mechanical properties of bamboo fiber reinforced concrete written in 2012, the results obtained from fresh properties of concrete indicated a decrease in the slump. This followed an increase in the amount of fiber added to the concrete therefore making the concrete less workable as the bamboo fiber content increased.

2.1.3 Compressive Strength

The strength of a material was broadly defined as the ability of the material to resist imposed forces (Styles & Yuen, 2009). It was also defined as the ability of a material or structure to carry the loads on its surface without any crack or deflection. The compressive strength of concrete depended on many factors for example; water-cement ratio, cement strength, quality of concrete material, quality control during the production of concrete, etc. The compressive strength of concrete for general construction varied from 15MPa to 30MPa and could be obtained from the equation below:

$$compressive\ strength = \frac{Load}{Cross\ sesctional\ Area}\ \ (MPa)$$

The compressive strength of concrete could be obtained from laboratory compressive cube tests. This test was carried out to assess the strength of concrete after seven (7) days, fourteen (14) days or twenty-eight (28) days of casting. The cubes used were of dimensions 15cm x 15cm x 15cm or 10cm x 10cm x 10cm, depending on the size of aggregates used. The load was applied gradually at the rate of 140 kg/cm^2 per 2 minute until the specimens failed.

In a previous research by (Ahmad et al., 2014), where experiments were made to determine the mechanical properties of bamboo fiber reinforced concrete, tests were conducted on concrete cubes with 1% bamboo fiber, which fiber was first treated in lethal anti termite solution to minimize its deterioration. The results obtained were compared to those of plain concrete cubes and it was found that the ultimate strength of bamboo fiber reinforced concrete marginally increased after 28 days and this was because of the low strength at early stages, which may be due to weak bond between the bamboo fibers and concrete in early days. The research concluded that the strength of concrete cubes with bamboo fiber does not show much improvement up to 28 days but the strength doubles at 50 days testing. It also concluded that bamboo fibers can be used as replacement with concrete and can save the expensive concrete $10000cm^3$ per $1m^3$ of concrete.

In a journal paper by (Terai & Minami, 2012b) on the basic study on mechanical properties of bamboo fiber reinforced concrete written in 2012. It was observed that the compressive strength of bamboo fiber reinforced concrete significantly decreased with an increased volume fraction of fibers, since the bond stress between the cement matrix and aggregates reduced because of adding the fibers. The research concluded that the compressive strength of bamboo fiber reinforced concrete was not significantly affected by the adding bamboo fiber volume content. It also concluded from all tests that were carried out for 28 and 56 days, the strength had increased significantly from 28 to 56 days.

2.1.4 Splitting Tensile Strength

The tensile strength of concrete was defined as its capacity to resist cracking or breaking under tension. Tensile strength was measured in units of force per cross-sectional area (N/Sqmm or MPa). Concrete is weak in tension because of its brittle nature, concrete is weakest in the interface transit zone; this is the area of bond between cement paste and aggregates. This is because under tension, the forces are pulling the aggregates away from each other hence causing weakness points, especially if there are voids present in the hardened concrete.

The splitting tensile test is an indirect method of testing for tensile strength of concrete in which a standard test cylinder is loaded in compression on its side and a value of tensile strength can be computed by use of equations (Strength, 1926). Laboratory comparisons show that the tensile strength indicated by this test may be as much as 150 percent of the direct tensile strength (Strength, 1926).

In a journal paper by (Terai & Minami, 2012b) on the basic study on mechanical properties of bamboo fiber reinforced concrete written in 2012, the tensile strength of bamboo fiber reinforced concrete significantly increased with an increased volume fraction of fibers. The increase is 50% for fiber content at 3% volume fraction. Therefore, bamboo fiber is expected to be effective in cracking resistance of concrete. The research concluded that the tensile strength of specimens reinforced with different fiber contents significantly increased with an increased volume fraction of fibers.

.

CHAPTER THREE

3.1 MATERIALS AND METHODS

This chapter contains a detailed account of the materials used, methods used and also provides logic to why they were used or selected. The materials include bamboo, ordinary Portland cement, fine and coarse aggregates and water.

3.1.1 Experimental program

To achieve the objectives of the study, an experimental plan was developed to create bamboo fiber reinforced concrete. Different ratios of bamboo were varied by volume for use of checking the effect of bamboo fiber on the mechanical properties of fiber reinforced concrete. Bamboo fiber reinforced concrete percentages that were varied include; 0%, 1% and 2%.

Specimens were prepared and cured for 28 days, with samples taken off for testing at 7, 14 and 28 days. Compressive strength and tensile strength for the concrete cubes and cylinders was carried out using a Universal Testing Machine following the **BS 1881 part 116**, and **BS 1881 part 116**, with each mix ratio test carried out for three replicates. The mechanical properties of bamboo; flexural and compressive strength were also tested using the universal testing machine following **BS 1881 part 116**.

3.1.2 Material resources

a) Bamboo

Bamboo was sourced from Kiteezi Ward Parish, Wakiso district, from a bamboo plantation in Kawanda. This was transported to a nearby shade and air dried for days. The bamboo was then cut to portable pieces, 500mm for flexural test, 200 mm for compressive test, 3 samples with a joint and three samples without a joint. One sample selected form the bottom, middle and top parts of the bamboo. Other pieces were cut off for preparation of bamboo fiber. The chemical properties of bamboo obtained from literature in percentages are shown if the table below.

Table 1: Chemical properties of bamboo

Chemical Properties	Bamboo
Solubility in ethanol- benzene (%)	1.52
Lignin (%)	35.19
Holocellulose (%)	83.75
Ash (%)	2.37
Silica (%)	1.05

b) Bamboo fiber

Bamboo fiber was obtained from cutting bamboo into 10 mm wide strips and hitting those strips with a mallet to loosen the fibers. The bamboo was dried immediately after for two hours to reduce its moisture content (Figure 14). The dried bamboo was later cut into shorter lengths of 30mm that were used to manufacture the bamboo fiber reinforced concrete in reference to (Terai & Minami, 2012b, 2012a).

c) Ordinary Portland cement

Ordinary Portland cement of grade 42.5, manufactured from Tororo cement factory was used as a binder for the concrete specimens.

d) Aggregates

Lake sand was used as fine aggregates and crushed rock of 20 mm nominal size was used as coarse aggregated. A sieve analysis was carried out to determine the particle size distribution of the aggregates to ensure that there are no missing aggregate sizes in the concrete.

e) Water

Portable water free from impurities and salts was used for making the concrete.

3.1.3 Batching information and Mix Design

Batching by weight was adopted to make the bamboo fiber reinforced concrete cubes and cylinders. The concrete was designed to achieve a strength of C20 after 28 days of curing under water. A water-cement ratio of 0.45 was used and a mix ratio of 1:1.5:3 was used to achieve a strength of C20 after 28 days of curing.

The concrete was made in three batches containing 0%, 1% and 2% bamboo fiber proportions by volume of concrete and mixing was by use of a diesel-powered concrete mixer and cast manually into the formwork.

3.1.4 Experimental Tests

All tests were conducted from the structural laboratory at Makerere University.

3.1.4.1 **Mechanical properties of bamboo fiber**

The mechanical tests for bamboo, which include compressive strength and flexural strength shall be conducted in accordance with ISO 22157 (Methods, 2001). The compressive strength of the bamboo was tested parallel to the grain as shown in Figure 16.

a) Compressive strength

The tests were carried out on two different categories of bamboo, that is; bamboo pieces with nodes and bamboo pieces without nodes. A sample was selected from the bottom, middle and top part of the bamboo culm to be tested for compressive strength of bamboo using the universal testing machine. The forces at which failure occurred were recorded. The formula used for calculating the compressive strength of bamboo is;

$$Compressive\ Strength = \frac{Force}{Area}$$

Where area is $= \frac{\pi}{4}\left({D_2}^2 - {D_1}^2\right)$

Where;

D_2 is the outer diameter of the bamboo specimen

D_1 is the inner diameter of the bamboo specimen

b) Flexural strength

The flexural strength of bamboo was also tested using the manual universal testing machine using the three-point bending test on whole bamboo. Bamboo pieces 500mm long were placed on two rollers 300mm apart and a loading pin was placed at the center of the specimen prior to administering the load.

A specimen was selected from the bottom, middle and top part of the bamboo culm for testing. The force at which failure occurred was recorded and flexural strength calculated from the formula;

$$Flexural\ Strength = \frac{M}{S}$$

And; $S = \frac{\pi\left({D_2}^4 - {D_1}^4\right)}{32D_2}$

Where; M is the failure load applied to the specimen

3.1.4.2 Fresh concrete properties (workability)

The slump test, a measure of the consistence and workability of concrete was conducted in correspondence to BS 1881; part 102. The slump test was carried out for all bamboo fiber proportions in concrete with an assumption that no anomaly would be observed in values in reference to the proposed slump test value range.

A clean mould, dampened on the inside was placed on a metallic plate with a flat surface with the wider open end at the bottom. The mould was filled with freshly mixed concrete and 25 blows from a tamping rod were applied to the concrete after every third of concrete was filled in the mould. Excess concrete was cleaned away when the mould was filled up and the mould lifted off the concrete carefully. The slump was measured and recorded.

3.1.4.3 Casting of cube and cylinder specimens

The cube moulds that were prepared were of nominal size 150mm and they required use of aggregates not exceeding 20mm nominal size. The cylinder mould were 100mm diameter and 50mm height.

The moulds were filled with concrete in three layers; each layer was compacted with a tamping rod evenly over the layer. Filled moulds were then smoothened at the top and labelled with a code name that can distinguish it from other specimen.

The concrete in the moulds was allowed to set in the moulds overnight, the hardened cubes were carefully removed from the moulds and submerged in a water tank to allow curing to take place. Curing occurred for 7, 14 and 28 days respectively before the specimen were tested.

3.1.4.4 Hardened concrete property tests (compressive strength and tensile strength)

A destructive compressive strength test was done using a universal testing machine. Concrete cubes of 150mm nominal size were used in the determination of compressive strength with varying proportions of bamboo fiber. Compressive strength corresponding to 7 days, 14 days and 28 days were carried out. When the corresponding testing date arrived, each cube was separately treated as follows; the cubes were removed from the soaking tank and allowed to drain for 45 minutes, each cube was then weighed using a weighing scale and its weight was recorded. Each cube was centered on the universal testing machine and a compressive force was applied at a constant increasing rate until the cube failed. The maximum load was then recorded and used to compute compressive strength for each cube using the formula;

$$Compressive\ Strength = \frac{Force}{Area}$$

A destructive tensile strength test was done using a universal testing machine. Concrete cylinders of were used in the determination of tensile strength with varying proportions of bamboo fiber. Tensile strength corresponding to 7 days, 14 days and 28 days were carried out. When the corresponding testing date arrived, each cylinder was separately treated as follows; the cylinders were removed from the soaking tank and allowed to drain for 45 minutes, each cylinder was then weighed using a weighing scale and its weight was recorded. Each cylinder was centered on the universal testing machine and a tensile force was applied at a constant increasing rate until the cylinder failed. The maximum load was recorded and tensile strength for each cylinder was computed using the formula;

$$Fct = \frac{2P}{\pi L d}$$

Where;

Fct is the tensile strength of concrete

P is the maximum loads in N/Sqmm

L is the length of the specimen

D is the diameter of the specimen

3.1.4.5 To optimize the bamboo fiber proportions for concrete strength improvement

Graphs showing the performance of bamboo fiber reinforced concrete under tension and compression were observed further to determine the percentage replacement with optimum performance and were compared with the limits provided by the ministry of works and transport to determine the maximum bamboo fiber percentage that would provide the highest strength of the concrete.

CHAPTER FOUR- ANALYSIS OF RESULTS AND DISCUSSION

4.1 Mechanical properties of bamboo

4.1.1 Compressive strength of bamboo

Two different samples from the bamboo culm were tested for compressive strength from bamboo aged 1, 3 and 5 years. The two samples include bamboo with a node and bamboo without a node. A specimen of each sample was tested from the bottom, middle and top part of the bamboo culm and the compressive strength results for both samples are presented below.

Table 2: Compressive strength performance for untreated bamboo with nodes

Age of Bamboo	Sample label	Compressive strength (Mpa)
1 year	Bottom	36.9
	Middle	33.1
	Top	35.4
3 years	Bottom	55.3
	Middle	32.6
	Top	41.2
5 years	Bottom	42.1
	Middle	34.8
	Top	48.5

The compressive strength performance for untreated bamboo with nodes is indicated more clearly in Figure 1 below.

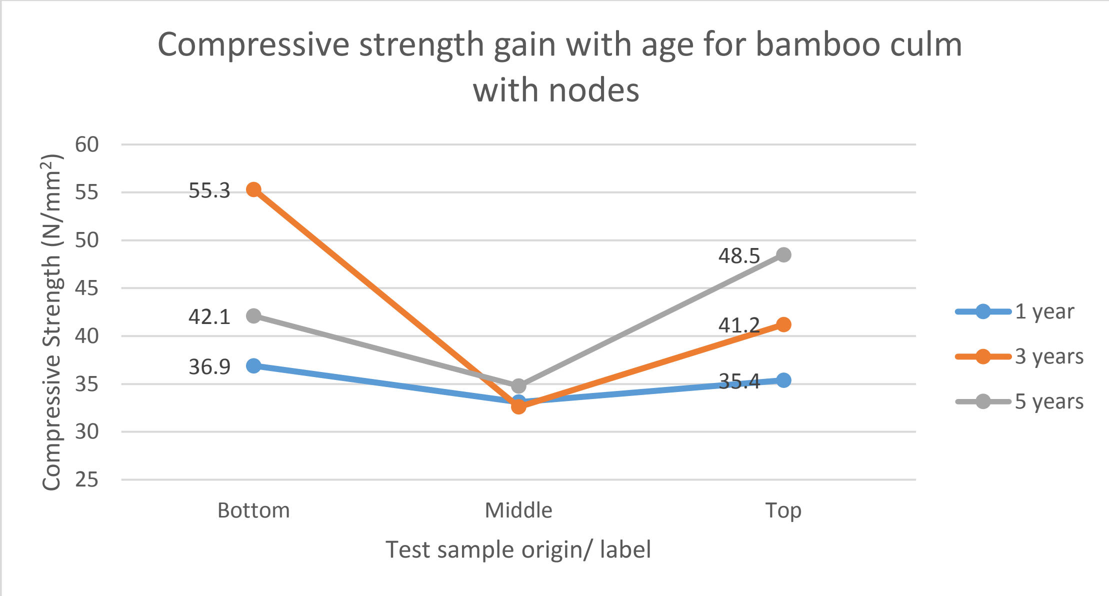


Figure 1: Compression strength gain properties of bamboo with nodes at different ages

From the table and figure above, irrespective of age, bamboo possesses a high compressive strength at the bottom and top parts of the bamboo culm and it was noticed that bamboo of 3 years old had the highest compressive strength making it a better candidate for use in fiber reinforced concrete. Age and moisture content affect the compressive strength of bamboo. The lower the age, the higher the moisture content hence low compressive strength.

Table 3: Compressive strength performance for untreated bamboo without nodes

Age of Bamboo	**Sample label**	**Compressive strength (Mpa)**
1 year	Bottom	24.4
	Middle	21.9
	Top	56.0
3 years	Bottom	46.8
	Middle	19.1
	Top	46.9
5 years	Bottom	43.5
	Middle	43.2
	Top	22.5

The compressive strength performance for untreated bamboo without nodes indicated more clearly in Figure 2 below.

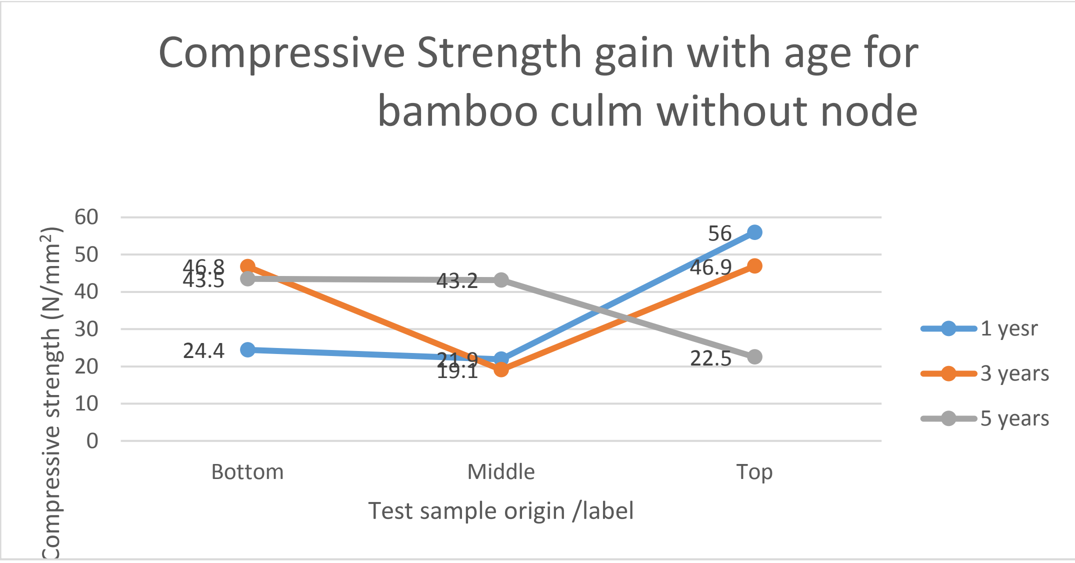


Figure 2: Compression strength gain properties of bamboo without nodes at different ages

Similarly, from the table and figure above, irrespective of age, bamboo possesses a high compressive strength at the bottom and top part of the bamboo culm and it was noticed that bamboo of 5 years old kept decreasing gradually in strength. This is attributed to weaker internodes of the bamboo with increase in age.

The average compressive strength of bamboo with and without nodes was computed and the results are presented in the table below.

Table 4: Average compressive strength for bamboo with and without nodes

Age of bamboo	**Avg. Strength with nodes**	**Avg. Strength without nodes**
1 year	35.1	34.1
3 years	43.0	37.6
5 years	41.8	36.4

The average compressive strength for bamboo with and without nodes over age is indicated in Figure 3 below.

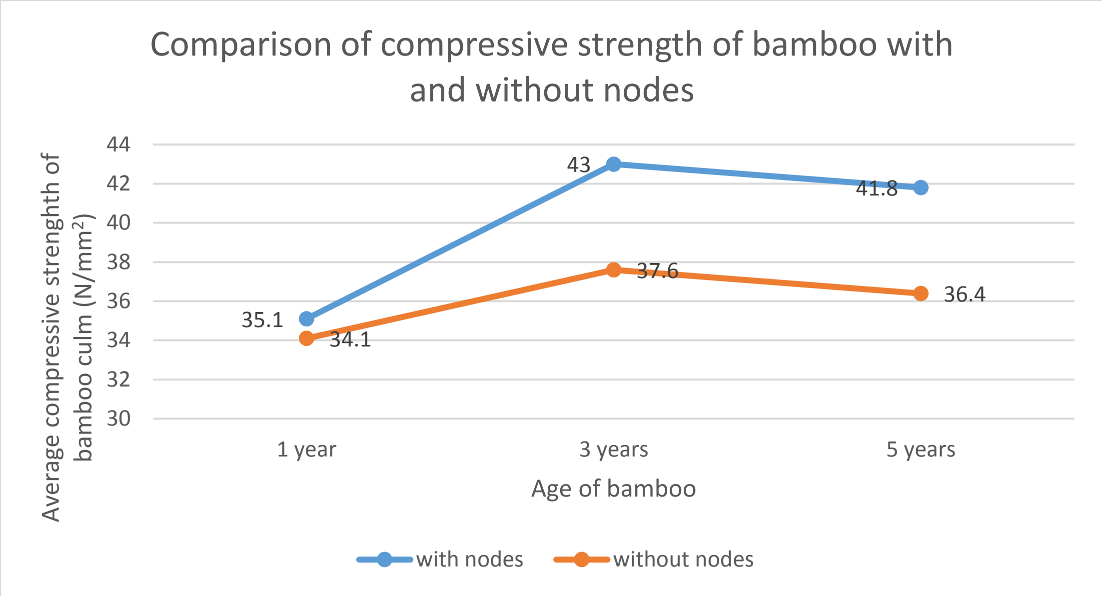


Figure 3: Comparison of compressive strength of bamboo with and without nodes

From the table and figure above, bamboo with nodes on average has a high compressive strength compared to bamboo without nodes. Therefore, bamboo with nodes should be considered for use in making bamboo fiber reinforced concrete, however, according to the international organization for standardization, the test samples should not contain nodes because the samples would not provide accurate results as the nodes are the strongest areas in a bamboo stem, therefore the internodes should be considered.

The bamboo without nodes was what I selected to use as fiber in the making of fiber reinforced concrete specimens because they are the weakest point of a bamboo pole and they would provide accurate results.

4.1.1 Flexural strength of bamboo

Samples from the bamboo culm were tested for flexural strength from bamboo aged 1, 3 and 5 years. A specimen was tested from the bottom, middle and top part of the bamboo culm and the compressive strength results are presented below.

Table 5: Flexural strength performance for untreated bamboo

Age of Bamboo	Sample label (origin)	Flexural strength (Mpa)
1 year	Bottom	3.0
	Middle	3.1
	Top	6.3
3 years	Bottom	1.1

	Middle	1.1
	Top	1.7
5 years	Bottom	1.0
	Middle	0.8
	Top	1.5

The flexural strength performance for bamboo parts over time is indicated in Figure 4 below.

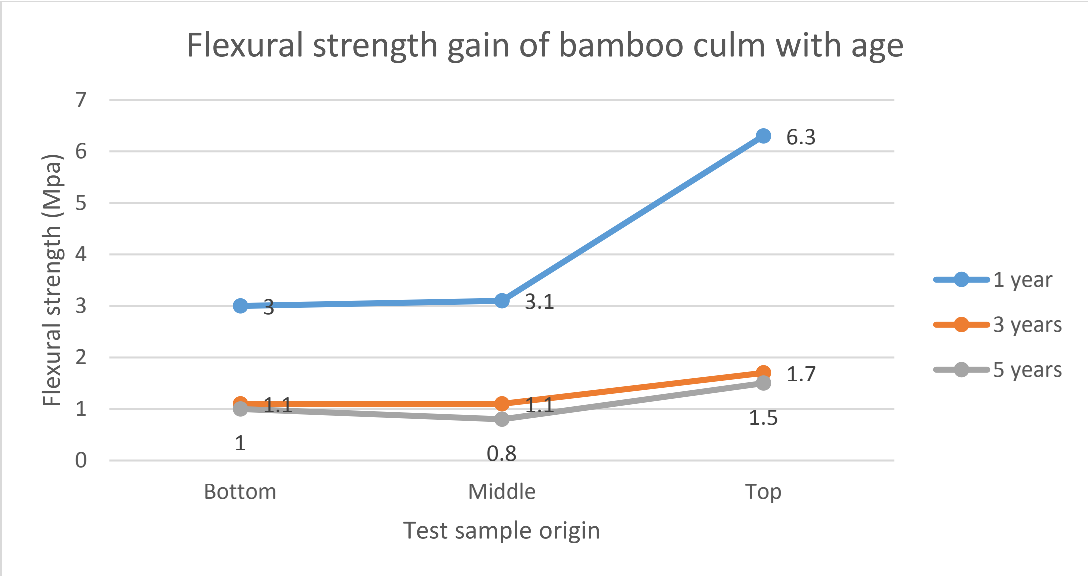


Figure 4: Flexural strength gain of bamboo culm with age

From the table and results above, the flexural strength of bamboo culm is observed to be higher in the top and bottom part of the bamboo culm. It is also noticed that the entire bamboo culm becomes weaker in flexural strength as it grows older. This is because bamboo is a plant, which made up of more than 60% water when it is young giving it the ability to bend and be bent with ease; this water composition however reduces as the bamboo grows making it difficult for older bamboo to possess high flexural strength.

4.2 Fresh Concrete properties

4.2.1 Particle size Distribution

Lake sand and crushed rock of 20 mm nominal size was used as aggregate. A sieve analysis was carried out to determine the particle size distribution of the aggregates to ensure that there are no missing aggregate sizes in the concrete. Particle size distribution graphs for coarse and fine aggregates are shown in Figure 5 and Figure 6 below.

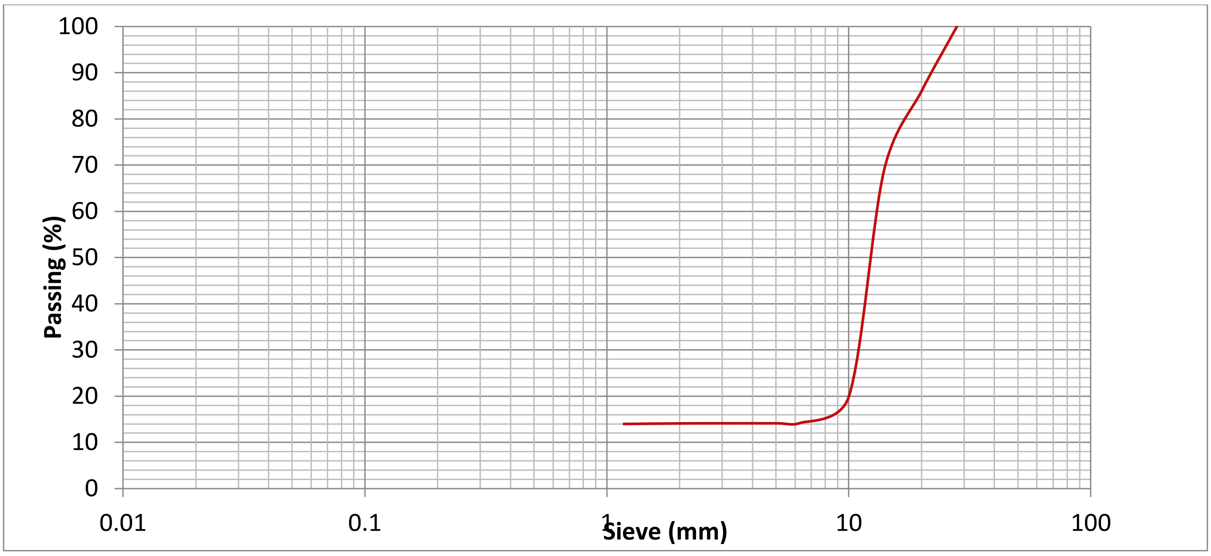


Figure 5: Particle size distribution for coarse aggregates

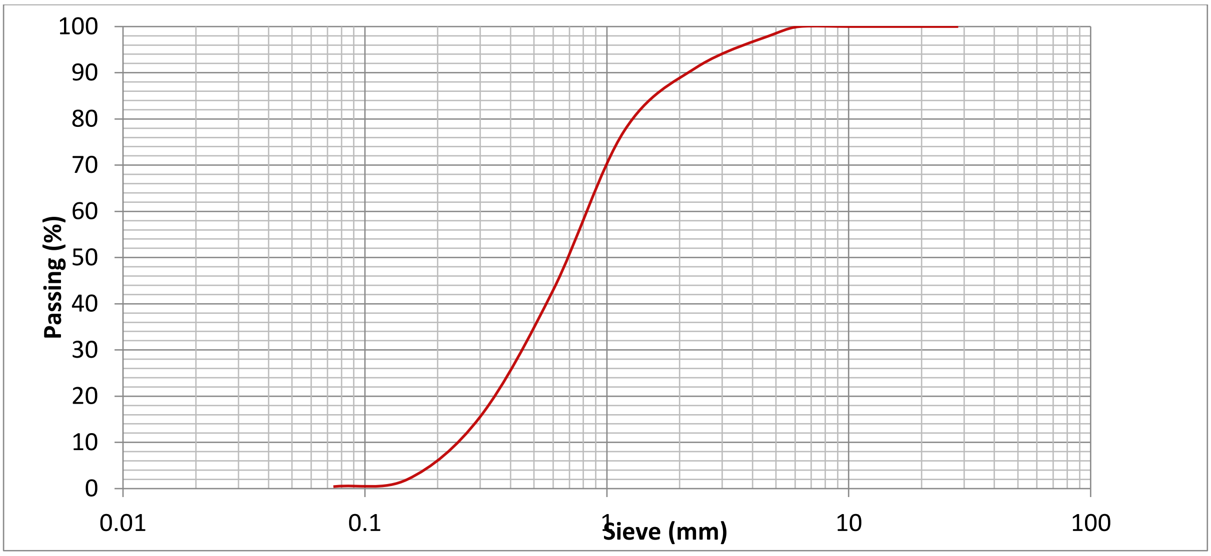


Figure 6: Particle size distribution for fine aggregates

3.2.2 Batching information and Mix Design

Batching by weight was adopted to make the bamboo fiber reinforced concrete that would achieve a strength of C20 after 28 days of curing under water. A water-cement ratio of 0.45 was used and a mix ratio of 1:1.5:3 was used to achieve a strength of C20 after 28 days of curing. The mix proportions for fiber reinforced concrete were quantified as follows;

Density of concrete: 2400kg/m^3

Volume of concrete cubes: 0.15 x 0.15 x 0.15

= 0.003375 m^3

Mass = density x volume

= (2400) kg/m^3 x (0.003375) m3

= 8.1kg

Volume of concrete cylinders = $\pi r^2 h$

=3.14 x 0.05^2 x 0.055

=0.00043175 m^3

Mass of concrete cylinder = density x volume

=2400 x 0.00043175

=1.0362kg

Quantities of material for each specimen

Total ratio= 1+1.5+3 =5.5

Cement quantity per cube= 8.1 x (1/5.5)

=1.47 kg

Sand quantity per cube = 8.1 x (1.5/5.5)

=2.21 kg

Stone quantity per cube = 8.1 x (3/5.5)

=4.42 kg

Cement quantity per cylinder =1 x (1/5.5)

=0.18 kg

Sand quantity per cylinder =1 x (1.5/5.5)

=0.27 kg

Stone quantity per cylinder =1 x (3/5.5)

=0.54 kg

The quantities above are quantities of one cylinder and one cube. 9 cylinders and 9 cubes were cast for each concrete mix with a varying bamboo composition to be tested at 7, 14 and 28 days. The quantified data and quantities for the mix made for each batch are shown in the table below;

Table 6: Quantities for materials used in bamboo fiber reinforced concrete

Mix sample	Cement quantity	Sand quantity	Stone quantity	Bamboo fiber	Cement quantity	Sand quantity	Stone quantity	Bamboo fiber
	CONCRETE CUBES				CONCRETE CYLINDERS			
0%	13.23	19.89	39.78	0	1.62	2.43	4.86	0
1%	13.32	19.89	39.78	0.729	1.62	2.43	4.86	0.09324
2%	13.32	19.89	39.78	1.458	1.62	2.43	4.86	0.18648

The concrete was made in three batches containing 0%, 1% and 2% bamboo fiber proportions by volume of concrete and mixing was by use of a diesel-powered concrete mixer and cast manually into the formwork.

4.2.3 Slump Test

Slump is one of the key indicators of workability for fresh concrete. The values obtained from testing the workability of fresh concrete are presented in the table below.

Table 7: Slump values obtained from varying proportions of bamboo fiber in concrete

Variation of bamboo fiber	**Date**		**Slump Value (cm)**
	Production	**Test**	
0%	16th November 2021	16th November 2021	11
1%	18th November 2021	18th November 2021	10.5
2%	18th November 2021	18th November 2021	9

The slump values observed with varying proportions of bamboo fiber are indicated in Figure 7 below.

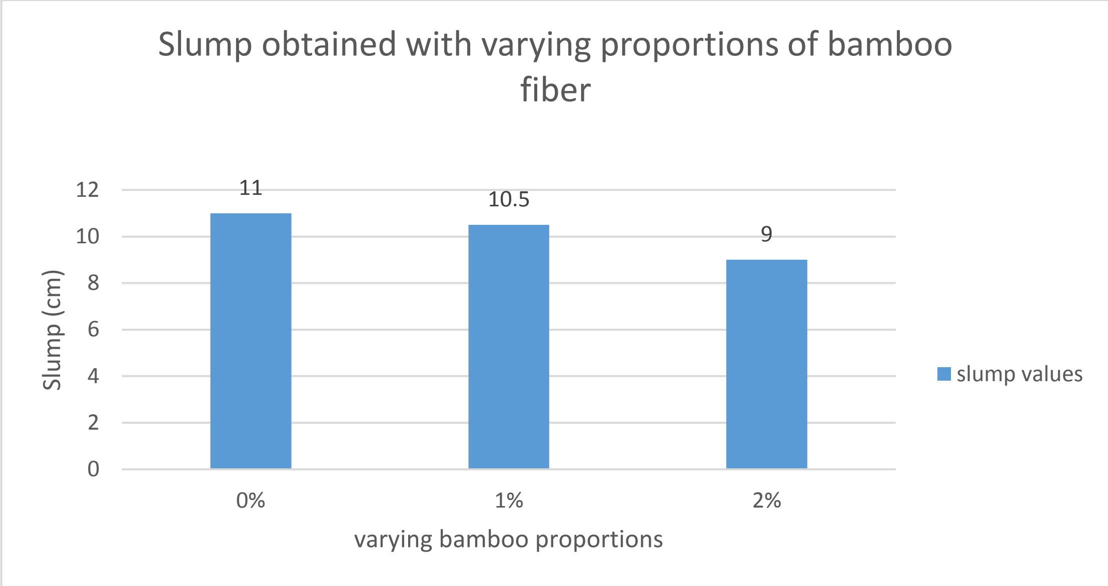


Figure 7: Slump obtained with varying proportions of bamboo fiber

From the obtained results, the slump was observed to decrease with increase of bamboo fiber in the mix. This implies that the more fiber content in the concrete, the less workable the concrete. This is due to the reduction in workability when fiber content is increased and absorption of water by the fibers from the concrete mix. Concrete with 2% fiber content was also observed to have taken longer time to set.

4.3 Mechanical Properties of Fiber reinforced Concrete

Hardened concrete is tested for compressive and tensile strength to ascertain its performance. The table bellows shows the dates on which concrete was cast and the specimen were tested.

Table 8: Date of casting and testing of concrete specimens

Specimen	**Date of casting**	**Date of 7 days test**	**Date of 14 days test**	**Date of 28 days test**
0% fiber	16th Nov 2021	24th Nov 2021	1st Dec 2021	15th Dec 2021
1% fiber	18th Nov 2021	26th Nov 2021	3rd Dec 2021	17th Dec 2021
2% fiber	18th Nov 2021	26th Nov 2021	3rd Dec 2021	17th Dec 2021

4.3.1 Compressive Strength

The compressive strength of the concrete was tested at 7, 14 and 28 days and the results are presented in the table below alongside the percentage strength gained by the varied proportions at 28 days.

Table 9: Compressive strength performance of bamboo fiber reinforced concrete at 7, 14 and 28 days

Variation percentage (%)	Compressive strength (N/mm^2)			Percentage final strength
	7 Days	14 Days	28 Days	
0%	15.7	17	19.6	98
1%	12.4	16.2	19.4	97
2%	10.7	11.0	11.9	59.5

The compressive strength gain of bamboo FRC with varying proportions is indicated clearly in Figure 8 below.

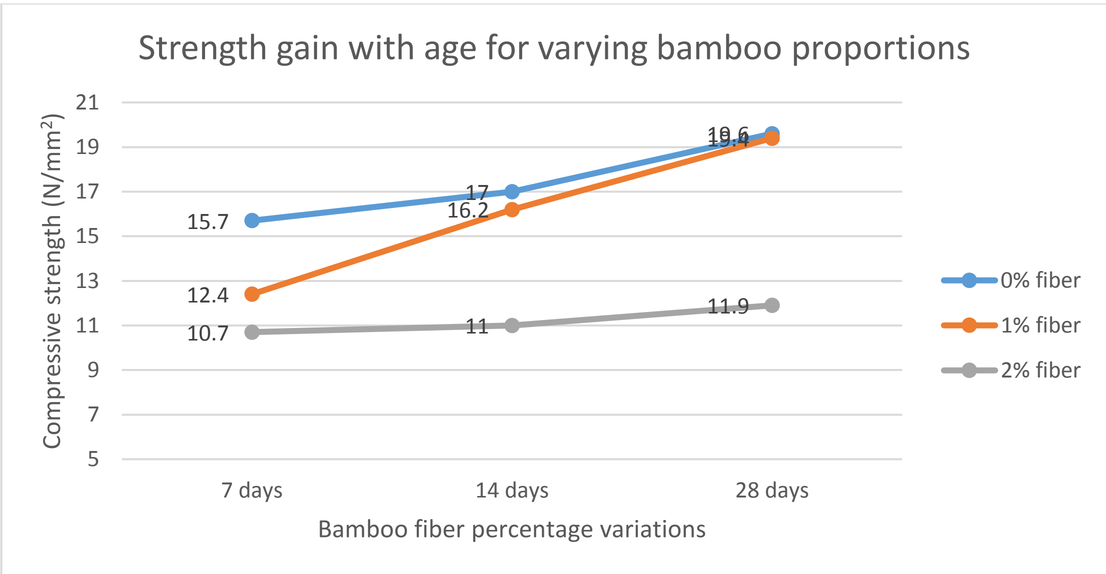


Figure 8: Compressive Strength gain with age for varying bamboo proportions

From the table and figure above, it was observed that for each fiber variation, there was an increase in the compressive strength of the concrete with increase in age. This implies that concrete with bamboo fiber retains its characteristic of achieving strength with time. Concrete strength is formed through hydration; a reaction between cement and water to form a paste and bind all the materials together, incorporation of bamboo fiber does not affect this process in any way. Therefore, bamboo FRC behaves in a similar way as conventional concrete, this can be seen from the performance of concrete with 1% bamboo fiber composition.

A general decrease in compressive strength for each age with increasing percentage variation of fiber. This is attributed to the fact that bamboo fiber interferes with the bonding of the aggregates and cement paste, creating a formation of a weaker bond. As a result, the more bamboo fiber added to the concrete mix, the less the overall compressive strength of the resultant concrete mix.

4.3 2 Tensile Strength

The tensile strength of the concrete was tested at 7, 14 and 28 days and the results are presented in the table below.

Table 10: Tensile strength performance of bamboo fiber reinforced concrete at 7, 14 and 28 days

Varied proportions	Tensile Strength (N/mm^2)		
	7 Days	14 Days	28 Days
0%	2.2	2.6	1.9
1%	2.5	2.8	2.7
2%	2.5	2.9	2.7

The tensile strength gained by the bamboo FRC concrete over a period of 28 days is indicated clearly in Figure 9 below.

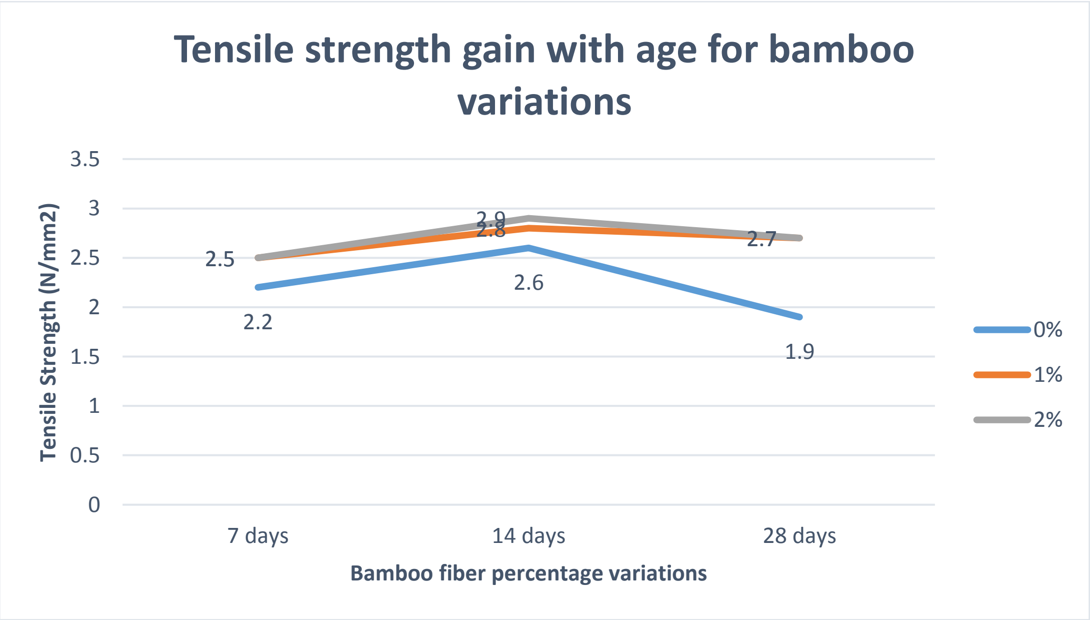


Figure 9: Tensile strength gain with age for bamboo variations

From the table and figure above, it was observed that for each fiber variation, there was an increase in the tensile strength of the concrete with increase in age up to 14 days, and then a decrease was recorded up to 28 days. This implies that concrete with bamboo fiber retains its characteristic of achieving strength with time.

A significant increase in tensile strength for each age with increasing percentage variation of fiber. This is because conventional concrete is weak in tension and bamboo fiber provides reinforcement hence the gain in compressive strength. As a result, the more bamboo fiber added to the concrete mix, the more the overall tensile strength of the resultant concrete mix.

4.4 Optimization of bamboo fiber for concrete strength improvement

The acceptance criteria adopted by IS:456-200; states that every sample shall have a test strength not less than the characteristic strength, fck or if the test sample of one or more samples is less than the characteristic strength, each case should not be less than the greater of;

$= fck - 1.35\sigma$ ……………… (1)

And

$= 0.8\, fck$……………………… (2)

Where;

Fck; characteristic strength of concrete (20N/mm^2)

σ standard deviation adopted (5)

From ………….. (1)

= 20 - 1.35 x 5

=13.25 N/mm^2

From :…….(2)

= 0.8 x 20

= 16 N/mm^2

All test samples at 28 days are greater than the values above except for 2% fiber composition.

From the standard specifications for building works, provided by the Ministry of works and transport, the table below is provided and it contains the minimum strengths acceptable for the appropriate class of concrete.

Table 11: Acceptable strengths for concrete tests

Grade	**Characteristic compressive strength at 28 days (N/mm^2)**		**Cube strength (N/mm^2)**		**Characteristic tensile strength at 28 days (N/mm^2)**	**Modulus of elasticity at 28 days (N/mm^2)**
15	15	12	90	100	1.1	25x103
20	20	16	13.5	25.0	1.3	27x103
25	25	20	16.5	31.0	1.5	29x103
30	30	24	20.0	37.0	1.7	32x103
40	40	32	28.0	50.0	2.1	35x103
50	50	40	36.0	60.0	2.5	37x103

Results of strength values from tested specimen at 7, 14 and 28 days have been tabulated and plotted on a graph; the characteristic strengths for compressive and tensile strength were also plotted and the optimum fiber proportion for concrete strength improvement was determined.

Table 12: Tensile and compressive strengths achieved at 7, 14 and 28 days of curing

Age of curing (days)	**Compressive strength (N/mm2)**			**Tensile strength (N/mm2)**		
	0%	**1%**	**2%**	**0%**	**1%**	**2%**
7 days	15.7	12.4	10.7	2.2	2.5	2.5
14 days	17	16.2	11.0	2.6	2.8	2.9
28 days	19.6	19.4	11.7	1.9	2.7	2.7

The values in the table above are clearly illustrated in the figure below from which an optimum fiber proportion was selected.

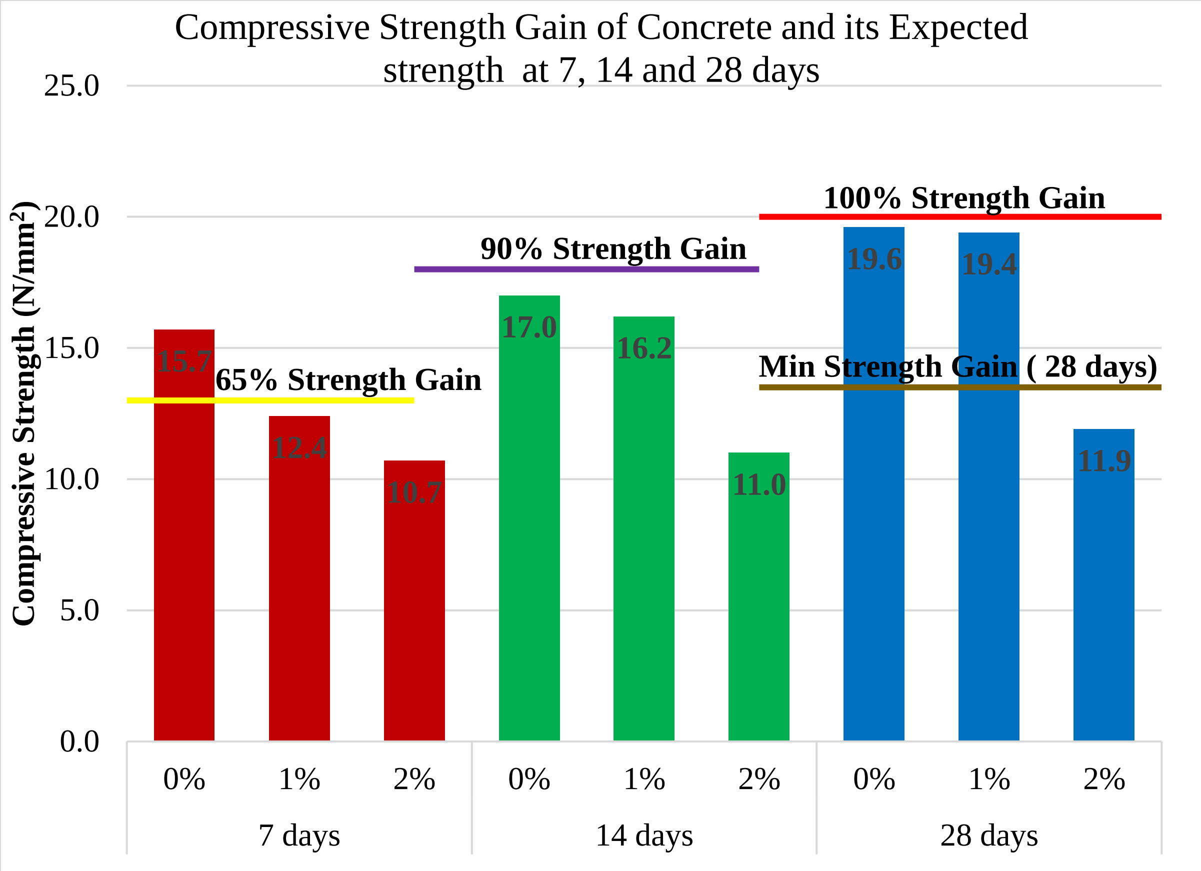


Figure 10: Optimization of fiber composition for concrete strength improvement.

From Figure 10 above, hardened concrete was expected to have gained 65% of its final strength at 7 days, 90% strength at 14 days and 100% strength at 28 days, however, only 0% fiber proportion achieved 65% strength at 7 days and no specimen achieved required strength at 14 and 28 days after curing. At 28 days, 0% fiber composition achieved a strength of 19.6 N/mm^2, compared to 1% and 2%, which achieved 19.4 and 11.9 N/mm^2. Increasing fiber from 0 to 1% reduces the concrete strength by 1%, however increasing the fiber from 1 to 2% reduces the concrete strength by 39%.

Cube strength of C20 hardened concrete at 28 days is expected to fall between 13.5 and 25 N/mm^2. 0% and 1% fiber proportions fall within this acceptable range, however, 2% fiber proportions at 28 days had only gained 11.9N/mm^2, which is below the minimum cube strength acceptable at 28 days. All fiber variation were however above the minimum acceptable strength of 1.3N/mm^2 for tensile strength.

Therefore, the optimum bamboo fiber composition for concrete strength improvement is 1% fiber content by volume. This is because it passed the minimum strength at 28 days for both tensile and compressive strength.

CHAPTER FIVE- CONCLUSIONS AND RECOMMENDATIONS

This chapter focuses on the researcher's conclusions and recommendations about the different findings made during the entire project research. It gives an insight of what is happening and what should be the way as regards assessing the effect of bamboo fiber on the mechanical properties of fiber reinforced concrete.

5.1 Conclusions

In reference to the research carried out, bamboo was studied, that is, its compressive and flexural strength at different ages. This was because it was important to know the age of bamboo that would provide optimum strength properties for fiber reinforced concrete.

Bamboo with nodes provided a higher compressive strength compared to bamboo without nodes meaning bamboo with nodes is stronger than bamboo without nodes. One-year-old bamboo provided highest results for flexural strength, followed by 3 year old and then 5-year-old bamboo. This is because one-year-old bamboo possesses a high moisture content making it flexible. Five-year-old bamboo also has a very low moisture content, making it brittle. Three-year-old bamboo is suitable for use in concrete where flexural strength is of high importance.

Bamboo fiber reinforced concrete decreased in compressive strength with increase in the amount of bamboo fiber, this is because of the replacement of the cement with bamboo. The tensile strength of bamboo fiber reinforced concrete increased with increase in bamboo in the mix, this is because conventional concrete is weak in tension and bamboo fiber provides reinforcement, making it stronger in tension.

The optimum bamboo fiber proportion to be used in fiber reinforced concrete is 1% fiber by volume of cement. This is because it provided a high strength of concrete in both tension and compression with-in the acceptable characteristic strengths.

Bamboo fiber can be used in low compressive strength concrete.

5.2 Recommendations

Based on my research, I would recommend the use of bamboo fiber reinforced concrete in structures with light load for example concrete wall units, shades, or on pavements and parkings intended for light parking.

I would also recommend other researchers to continue with further studies either individually or in comparison to this research on the limitations of my research listed below.

1. Testing and using various bamboo species and compare their results
2. Using treated bamboo to conduct all tests done in this research
3. Investigating the durability of bamboo
4. Investigating the effect of fiber length on the mechanical properties of fiber reinforced concrete.

CHAPTER SIX

6.0 REFERENCES

Ahmad, S., Raza, A., & Gupta, H. (2014). Mechanical properties of bamboo fibre reinforced concrete. *2nd International Conference on Research in Science, Engineering and Technology, Dubai*, 21–22.

Astuti, S. I., Arso, S. P., & Wigati, P. A. (2015). 済無No Title No Title No Title. *Analisis Standar Pelayanan Minimal Pada Instalasi Rawat Jalan Di RSUD Kota Semarang*, *3*, 103–111.

Bhimarao, B. M., & Patil, S. K. (2019). *Replacement of Steel with Bamboo as Reinforcement*. *June*, 3615–3618.

Findings, H., & Statistics, N. (2021). *No Title*. *44*(October), 1–21.

Geremew, A., Winne, P. De, Adugna, T., & Backer, H. De. (2021). Mechanical properties of concrete using natural fibres-An overview. *AIP Conference Proceedings*, *2404*(1), 80034.

Gutu, T. (2013). *A Study on the Mechanical Strength Properties of Bamboo to Enhance Its Diversification on Its Utilization*. *5*, 314–319.

Hoffmann, C., Hoey, M. Van, & Zeumer, B. (2020). *Decarbonization challenge for steel The steel industry decarbonization challenge*. 12. https://www.mckinsey.com/~/media/McKinsey/Industries/Metals and Mining/Our Insights/Decarbonization challenge for steel/Decarbonization-challenge-for-steel.pdf

Li, Z. (2011). Introduction to Concrete. *Advanced Concrete Technology*, *April*, 1–22. https://doi.org/10.1002/9780470950067.ch1

Methods, T. (2001). *N315* (Issue December).

NRMCA. (2015). CIP 16- Flexural Strength Concrete. *Concrete in Practice - What, Why & How?*, *102*(1), 2121–2136. http://dx.doi.org/10.1016/j.jclepro.2011.05.018%5Cnhttp://dx.doi.org/10.1016/j.conbuildmat.2015.08.112%5Cnhttp://dx.doi.org/10.1016/j.conbuildmat.2015.05.038%5Cnhttp://dx.doi.org/10.1016/j.conbuildmat.2015.04.024%5Cnhttp://dx.doi.org/10.1016/j.conbuil dmat

Nurdiah, E. A. (2016). The Potential of Bamboo as Building Material in Organic Shaped Buildings. *Procedia - Social and Behavioral Sciences*, *216*(October 2015), 30–38. https://doi.org/10.1016/j.sbspro.2015.12.004

Strength, K. O. F. (1926). The Strength of Concrete. *Science*, *64*(1660). https://doi.org/10.1126/science.64.1660.xii.t

Styles, J. R., & Yuen, S. T. S. (2009). Geomechanics & Geotechnical Engineering. *Geomechanics & Geotechnical Engineering*, *d*, 1–38.

Tahara, R. M. K., Hasnan, M. H., & Azizan, N. Z. N. (2021). Performance of Beting Bamboo (Gigantochloa Levis) as Partial Replacement for Coarse Aggregate in Concrete. *IOP Conference Series: Earth and Environmental Science*, *920*(1), 12014.

Terai, M., & Minami, K. (2012a). Basic study on mechanical properties of bamboo fiber reinforced concrete. *Global Thinking in Structural Engineering: Recent Achievements, January 2012*.

Terai, M., & Minami, K. (2012b). Basic study on mechanical properties of bamboo fiber reinforced concrete. *Glob. Think. Struct. Eng. Recent Achiev*, *8*, 17–24.

Wang, H. (2020). Physical and Mechanical Properties of Bamboo Scrimber. *Hans Journal of Civil Engineering*, *09*(08), 755–768. https://doi.org/10.12677/hjce.2020.98080

Xiaobo, L. (2004). *Physical, chemical, and mechanical properties of bamboo and its utilization potential for fiberboard manufacturing*.

APPENDIX

ACTUAL PROJECT EXPENDITURE	
Ordinary Portland cement	45000
Sand	20000
Aggregates	75000
Transporting cement	4000
Transporting aggregates	15000
Bamboo transportation	40000
Cylinder moulds	90000
Cube moulds	100000
Lab assistance	180000
Stationary	123000
Preparation of bamboo	20000
TOTAL	**712,000 Ush**

Figure 11: estimated project budget

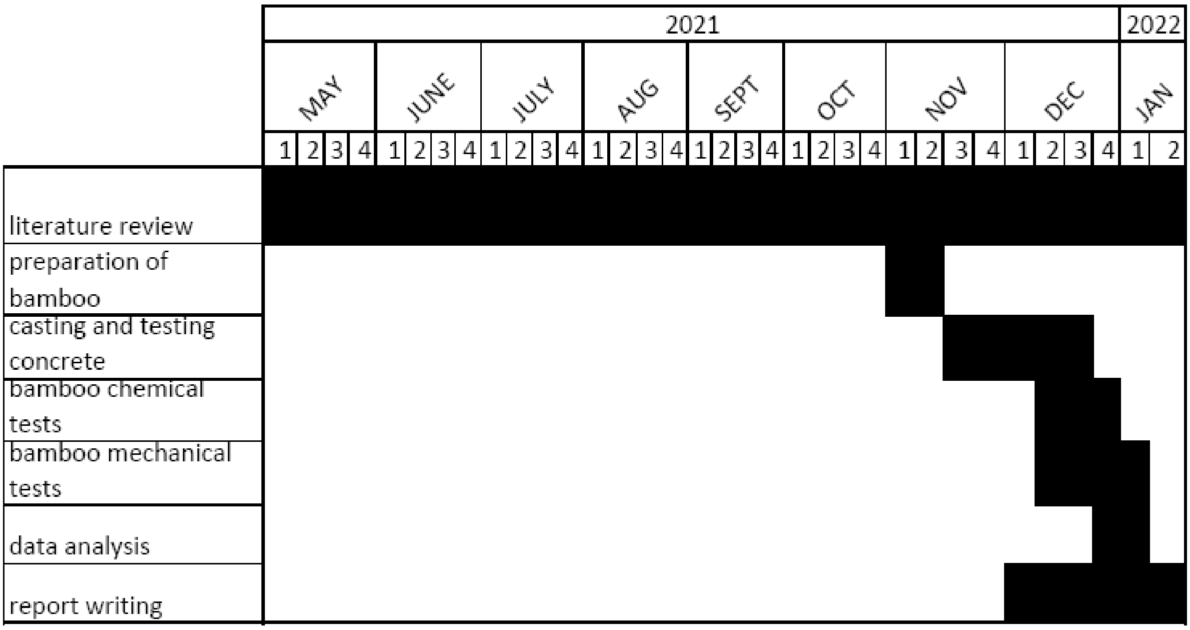


Figure 12: project work plan

Figure 13: Bamboo plantation

Figure 14: Loosened bamboo being dried

Figure 15: Bamboo fiber ready for mixing in concrete

Figure 16: Testing compressive strength of bamboo

Figure 17: Testing flexural strength of bamboo

Figure 18: Sieve analysis for fine aggregates

Figure 19: Measurement of slump value

Figure 20: Casting bamboo FRC cubes and cylinders

Figure 21: Concrete cubes and cylinders after removing them from moulds

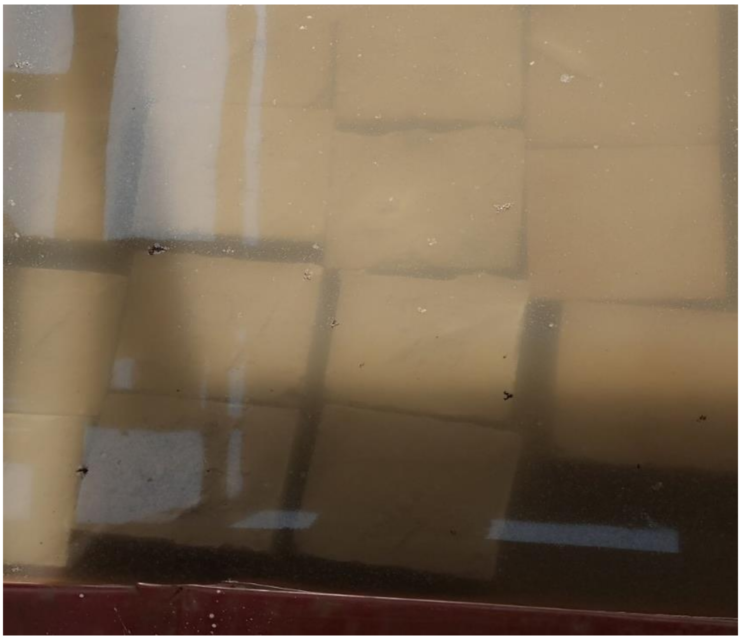


Figure 22: Concrete specimen submerged in water for curing

Figure 23: Concrete specimen draining before testing

Figure 24: Testing tensile strength of concrete

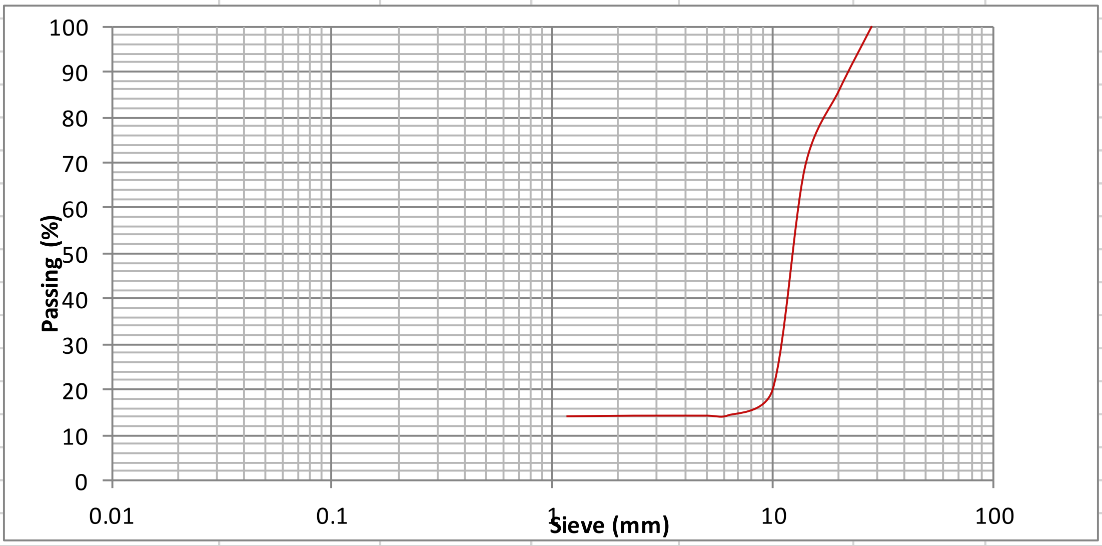
The sieve analysis results and computations for coarse and fine aggregates are tabulated and presented below.

MAKERERE UNIVERSITY
COLLEGE OF ENGINEERING DESIGN ART AND TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING
HIGHWAYS/MATERIALS LABORATORY

SIEVE ANALYSIS OF AGG

Sample No		Sample Ref.		Sampling Date	
Origin:				Testing Date	
Location				Technician	
Sample Description	AGG				
Dam Location					
Initial wt before washing	4780.6			Moisture Content	
Dry wt after washing				Initial Dry Weight	4780.6
				G.M	#REF!

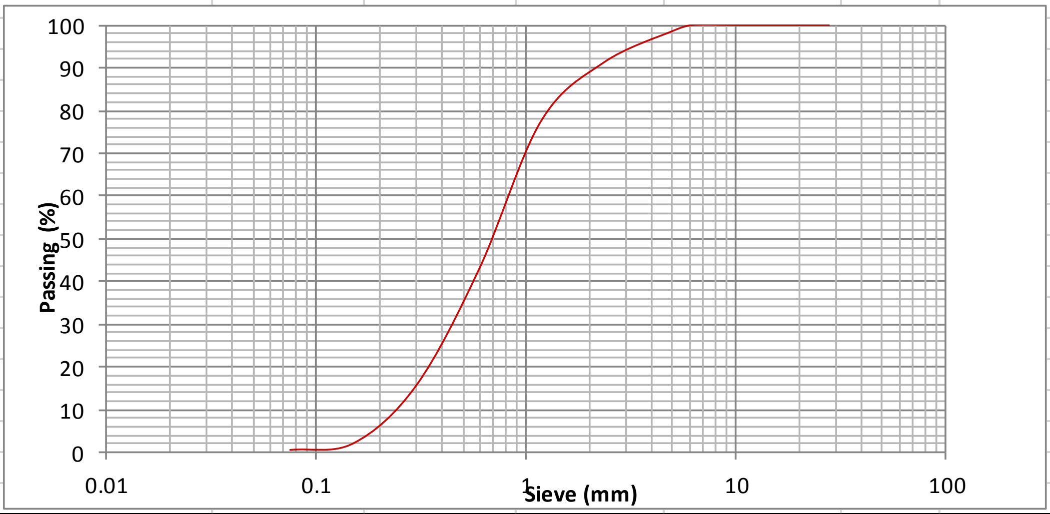
Sieve (mm)	Partial Retained Mass(g)	Cumulative Retained Mass (g)	Cumulative Retained (%)	% Passing (%)	Grading Limits (%)	
28	0.0	0.0	0.0	100		
20	668.8	668.8	14.0	86		
14.0	1487.1	1487.1	31	69		
10.0	2345.1	3832.2	80	20		
6.3	269.1	4101.3	86	14		
5.00	3.6	4104.9	86	14		
2.360	0.2	4105.1	86	14		
1.180	6.7	4111.8	86	14		



MAKERERE UNIVERSITY
COLLEGE OF ENGINEERING DESIGN ART AND TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING
HIGHWAYS/MATERIALS LABORATORY

SIEVE ANALYSIS OFSAND

Sample No		Sample Ref.		Sampling Date	
Origin:				Testing Date	
Location				Technician	
Sample Description		SAND			
Dam Location					
Initial wt before washing		754.6		Moisture Content	
Dry wt after washing				Initial Dry Weight	754.0
				G.M	1.10
Sieve (mm)	**Partial Retained Mass(g)**	**Cumulative Retained Mass (g)**	**Cumulative Retained (%)**	**% Passing (%)**	**Grading Limits (%)**
28	0.0	0.0	0.0	100	
20	0.0	0.0	0.0	100	
14.0	0	0.0	0	100	
10.0	0	0.0	0	100	
6.3	0	0.0	0	100	
5.00	11	11.0	1	99	
2.360	55.1	66.1	9	91	
1.180	104.2	170.3	23	77	
0.600	259.8	430.1	57	43	
0.300	206.3	636.4	84	16	
0.150	102.5	738.9	98	2	
0.075	11.7	750.6	100	0	
	2.3				



The compressive strength results and computations for bamboo and bamboo fiber reinforced concrete are tabulated below;

COMPRESSIVE STRENGTH OF BAMBOO WITHOUT NODES

Tested Element	Bamboo Code	Dimensions L (mm)	D2	D1	Mass kg	Density kg/m^3	Area mm^2	Failure Load(kN)	Compressive Strength N/mm^2	Average Strength N/mm^3
bottom	1	200	53	36	0.2141	263.1	1187.7	29	24.4	34.1
	2	200	51	33	0.2025	296.1	1186.9	26	21.9	
	3	200	42	30	0.261	461.8	678.2	38	56.0	
Tested Element	**Bamboo Code**	**Dimensions L (mm)**	**D2**	**D1**	**Mass kg**	**Density kg/m^3**	**Area mm^2**	**Failure Load(kN)**	**Compressive Strength N/mm^2**	
middle	1	200	62	49	0.289	191.7	1132.8	53	46.8	37.6
	2	200	66	45	0.267	210.0	1829.8	35	19.1	
	3	200	61	50	0.299	190.4	958.5	45	46.9	
Tested Element	**Bamboo Code**	**Dimensions L (mm)**	**D2**	**D1**	**Mass kg**	**Density kg/m^3**	**Area mm^2**	**Failure Load(kN)**	**Compressive Strength N/mm^2**	
top	1	200	70	55	0.372	195.8	1471.9	64	43.5	36.4
	2	200	70	57	0.393	192.6	1296.0	56	43.2	
	3	200	70	35	57	74093.3	2884.9	65	22.5	

COMPRESSIVE STRENGTH OF BAMBOO WITH NODES

Tested Element	Bamboo Code	Dimensions L (mm)	D2	D1	Mass kg	Density kg/m^3	Area mm^2	Failure Load(kN)	Compressive Strength N/mm^2	Average Strength N/mm^3
bottom	1	200	45	32	0.2141	332.9	785.8	29	36.9	35.1
	2	200	45	32	0.2025	314.9	785.8	26	33.1	
	3	200	47	29	0.261	494.2	1073.9	38	35.4	
Tested Element	**Bamboo Code**	**Dimensions L (mm)**	**D2**	**D1**	**Mass kg**	**Density kg/m^3**	**Area mm^2**	**Failure Load(kN)**	**Compressive Strength N/mm^2**	
middle	1	200	61	50	0.289	184.1	958.5	53	55.3	43.0
	2	200	63	51	0.267	163.5	1073.9	35	32.6	
	3	200	64	52	0.299	176.1	1092.7	45	41.2	
Tested Element	**Bamboo Code**	**Dimensions L (mm)**	**D2**	**D1**	**Mass kg**	**Density kg/m^3**	**Area mm^2**	**Failure Load(kN)**	**Compressive Strength N/mm^2**	
top	1	200	72	57	0.372	182.3	1519.0	64	42.1	41.8
	2	200	72	56	0.393	199.6	1607.7	56	34.8	
	3	200	68	54	0.334	182.4	1340.8	65	48.5	

COMPRESSIVE STRENGTH OF CONCRETE WITH 0% FIBER PROPORTION

Tested Element	Cube Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	W(mm)	H(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	Compressive Strength N/mm^2	Average Strength N/mm^3
	1	17-Nov-21	24-Nov-21	7	150	150	150	7.925	2348.1	320	14.2	
	2	17-Nov-21	24-Nov-21	7	150	150	150	7.678	2275.0	320	14.2	15.7
	3	17-Nov-21	24-Nov-21	7	150	150	150	8.012	2373.9	420	18.7	
Tested Element	Cube Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	W(mm)	H(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	Compressive Strength N/mm^2	
	1	17-Nov-21	1-Dec-21	14	150	150	150	8.069	2390.8	370	16.4	
	2	17-Nov-21	1-Dec-21	14	150	150	150	7.979	2364.1	400	17.8	17.0
	3	17-Nov-21	1-Dec-21	14	150	150	150	7.777	2304.3	380	16.9	
Tested Element	Cube Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	W(mm)	H(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	Compressive Strength N/mm^2	
	1	17-Nov-21	15-Dec-21	28	150	150	150	7.935	2351.1	440	19.6	
	2	17-Nov-21	15-Dec-21	28	150	150	150	7.83	2320.0	480	21.3	19.6
	3	17-Nov-21	15-Dec-21	28	150	150	150	7.88	2334.8	400	17.8	

COMPRESSIVE STRENGTH OF CONCRETE WITH 1% FIBER PROPORTION

Tested Element	Cube Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	W(mm)	H(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	Compressive Strength N/mm^2	Average Strength N/mm^3
	1	19-Nov-21	26-Nov-21	7	150	150	150	8.007	2372.4	240	10.7	
	2	19-Nov-21	26-Nov-21	7	150	150	150	7.26	2151.1	280	12.4	12.4
	2	19-Nov-21	26-Nov-21	7	150	150	150	7.923	2347.6	320	14.2	
Tested Element	Cube Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	W(mm)	H(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	Compressive Strength N/mm^2	
	1	19-Nov-21	3-Dec-21	14	150	160	150	7.461	2072.5	460	19.2	
	2	19-Nov-21	3-Dec-21	14	150	150	150	7.799	2310.8	300	13.3	16.2
	2	19-Nov-21	3-Dec-21	14	150	150	150	8	2370.4	360	16.0	
Tested Element	Cube Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	W(mm)	H(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	Compressive Strength N/mm^2	
	1	19-Nov-21	17-Dec-21	28	150	130	150	4.125	7.0	390	20.0	
	2	19-Nov-21	17-Dec-21	28	150	150	150	3.963	7.7	320	14.2	19.4
	2	19-Nov-21	17-Dec-21	28	150	150	150	3.963	8.0	540	24.0	

COMPRESSIVE STRENGTH OF CONCRETE WITH 2% FIBER PROPORTION

Tested Element	Cube Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	W(mm)	H(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	Compressive Strength N/mm^2	Average Strength N/mm^3
	1	19-Nov-21	26-Nov-21	7	150	150	150	7.498	2221.6	220	9.8	10.7
	2	19-Nov-21	26-Nov-21	7	150	150	150	7.512	2225.8	260	11.6	
	2	19-Nov-21	26-Nov-21	7	150	150	150	7.454	2208.6	240	10.7	
Tested Element	Cube Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	W(mm)	H(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	Compressive Strength N/mm^2	
	1	19-Nov-21	3-Dec-21	14	150	160	150	7.998	2221.7	300	12.5	11.0
	2	19-Nov-21	3-Dec-21	14	150	150	150	7.544	2235.3	200	8.9	
	2	19-Nov-21	3-Dec-21	14	150	150	150	7.491	2219.6	260	11.6	
Tested Element	Cube Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	W(mm)	H(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	Compressive Strength N/mm^2	
	1	19-Nov-21	17-Dec-21	28	150	150	150	7.771	2302.5	300	13.3	11.9
	2	19-Nov-21	17-Dec-21	28	150	150	150	7.7607	2299.5	300	13.3	
	2	19-Nov-21	17-Dec-21	28	150	150	150	7.857	2328.0	200	8.9	

The tensile strength results and computations for bamboo fiber reinforced concrete are presented below;

MAKERERE UNIVERSITY
COLLEGE OF ENGINEERING, DESIGN ART and TECHNOLOGY (CEDAT)
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
STRUCTURES / CIVIL ENGINEERING MATERIALS LABORATORY

TENSILE STRENGTH FOR 0% FIBER COMPOSITION

CLIENT:

Tested Element	Cylinder Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	D(mm)	r(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	TENSILE Strength N/mm^2	AVERAGE TENSILE Strength N/mm^3
	1	17-Nov-21	24-Nov-21	7	55	100	50	0.952	3461.8	18	2.1	
	2	17-Nov-21	24-Nov-21	7	55	100	50	0.933	3392.7	20	2.3	2.2
	3	17-Nov-21	24-Nov-21	7	55	100	50	1.0629	3865.1	20	2.3	
Tested Element	Cylinder Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	D(mm)	r(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	TENSILE Strength N/mm^2	
	1	17-Nov-21	1-Dec-21	14	55	100	50	0.9404	3419.6	23	2.7	
	2	17-Nov-21	1-Dec-21	14	55	100	50	0.9498	3453.8	20	2.3	2.6
	3	17-Nov-21	1-Dec-21	14	55	100	50	1.0594	3852.4	24	2.8	
Tested Element	Cylinder Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	D(mm)	r(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	TENSILE Strength N/mm^2	
	1	17-Nov-21	15-Dec-21	28	55	100	50	1.08	3927.3	18	2.1	
	2	17-Nov-21	15-Dec-21	28	55	100	50	1.042	3789.1	16	1.9	1.9
	3	17-Nov-21	15-Dec-21	28	55	100	50	0.9347	3398.9	14	1.6	

MAKERERE UNIVERSITY
COLLEGE OF ENGINEERING, DESIGN ART and TECHNOLOGY (CEDAT)
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
STRUCTURES / CIVIL ENGINEERING MATERIALS LABORATORY

TENSILE STRENGTH FOR 1% FIBER PROPORTION

CLIENT:

Tested Element	Cylinder Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	D(mm)	r(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	TENSILE Strength N/mm^2	AVERAGE TENSILE Strength N/mm^3
	1	19-Nov-21	26-Nov-21	7	55	100	50	1.043	3792.7	23	2.7	
	2	19-Nov-21	26-Nov-21	7	55	100	50	0.946	3440.0	21	2.4	2.5
	3	19-Nov-21	26-Nov-21	7	55	100	50	0.938	3410.9	22	2.5	
Tested Element	Cylinder Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	D(mm)	r(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	TENSILE Strength N/mm^2	
	1	19-Nov-21	3-Dec-21	14	55	100	50	1.042	3789.1	23	2.7	
	2	19-Nov-21	3-Dec-21	14	55	100	50	0.94	3418.2	25	2.9	2.8
	3	19-Nov-21	3-Dec-21	14	55	100	50	0.917	3334.5	24	2.8	
Tested Element	Cylinder Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	D(mm)	r(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	TENSILE Strength N/mm^2	
	1	19-Nov-21	17-Dec-21	28	55	100	50	0.932	3389.1	24	2.8	
	2	19-Nov-21	17-Dec-21	28	55	100	50	0.951	3458.2	20	2.3	2.7
	3	19-Nov-21	17-Dec-21	28	55	100	50	0.962	3498.2	26	3.0	

MAKERERE UNIVERSITY
COLLEGE OF ENGINEERING, DESIGN ART and TECHNOLOGY (CEDAT)
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
STRUCTURES / CIVIL ENGINEERING MATERIALS LABORATORY

TENSILE STRENGTH FOR 2% FIBER PROPORTION

CLIENT:

Tested Element	Cylinder Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	D(mm)	r(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	TENSILE Strength N/mm^2	AVERAGE TENSILE Strength N/mm^3
	1	19-Nov-21	26-Nov-21	7	55	100	50	1.033	2392.6	24	2.8	
	2	19-Nov-21	26-Nov-21	7	55	100	50	0.95	2200.3	22	2.5	2.5
	3	19-Nov-21	26-Nov-21	7	55	100	50	0.952	2205.0	20	2.3	
Tested Element	Cylinder Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	D(mm)	r(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	TENSILE Strength N/mm^2	
	1	19-Nov-21	3-Dec-21	14	55	100	50	1.052	2436.6	22	2.5	
	2	19-Nov-21	3-Dec-21	14	55	100	50	0.908	2103.1	23	2.7	2.9
	3	19-Nov-21	3-Dec-21	14	55	100	50	1.056	2445.9	31	3.6	
Tested Element	Cylinder Code	Date Cast	Date Tested	Age (Days)	Dimensions L (mm)	D(mm)	r(mm)	Mass kg	Density kg/m^3	Failure Load(kN)	TENSILE Strength N/mm^2	
	1	19-Nov-21	17-Dec-21	28	55	100	50	0.991	2295.3	20	2.3	
	2	19-Nov-21	17-Dec-21	28	55	100	50	1.017	2355.5	30	3.5	2.7
	3	19-Nov-21	17-Dec-21	28	55	100	50	0.905	2096.1	21	2.4	

The flexural strength results and computations for bamboo are tabulated below;

FLEXURAL STRENGTH

Tested Element	Bamboo Code	Dimensions L (mm)	D2 (mm)	D1 (mm)	Mass kg	Density kg/m³	Area mm²	Failure Load(kN)	FLEXURAL Strength N/mm²	AVERAGE FLEXURAL Strength N/mm²
1 YEAR	BOTTOM	500	47	35	0.546	284.0	7054.7	21	3.0	4.1
	MIDDLE	500	47	33	0.59	345.1	7711.7	24	3.1	
	TOP	500	37	28	0.29	235.8	3340.2	21	6.3	
Tested Element	Bamboo Code	Dimensions L (mm)	D2 (mm)	D1 (mm)	Mass kg	Density kg/m³	Area mm²	Failure Load(kN)	FLEXURAL Strength N/mm²	AVERAGE FLEXURAL Strength N/mm²
3 YEARS	BOTTOM	500	68	48	1.037	286.7	23193.5	26	1.1	1.3
	MIDDLE	500	69	48	1.114	308.0	24685.8	28	1.1	
	TOP	500	61	44	0.702	230.9	16243.3	28	1.7	
Tested Element	Bamboo Code	Dimensions L (mm)	D2 (mm)	D1 (mm)	Mass kg	Density kg/m³	Area mm²	Failure Load(kN)	FLEXURAL Strength N/mm²	AVERAGE FLEXURAL Strength N/mm²
5 YEARS	BOTTOM	500	72	56	1.028	208.8	23222.0	24	1.0	1.1
	MIDDLE	500	75	52	1.234	290.7	31830.5	25	0.8	
	TOP	500	71	57	1.089	213.5	20531.2	30	1.5	