Experimental investigation on physio – mechanical and microstructural behavior of bamboo fibered concrete with partial replacement of cement by metakaolin

Heran Boru

A Thesis Submitted to the Department of Civil Engineering

School of Civil and Architecture Engineering

Presented in Partial Fulfillment of the Requirements of Masters of Science in Civil Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

October, 2024

Adama, Ethiopia

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Advisor: - Fikreyesus Demeke (PhD.)

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I hereby declare that this Master thesis entitled "**Experimental investigation on physio – mechanical and microstructural behavior of bamboo fibered concrete with partial replacement of cement by metakaolin** "is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation. It is being submitted for the partial fulfillment for the award of the degree of Master of Science in Civil Engineering (Specialization in Construction Engineering and Management) at Adama Science and Technology University School of Civil Engineering and Architecture.

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ABSTRACT

Concrete has low tensile strength. To improve this, natural fibers like Bamboo are added to enhance its properties. Cement production is a major source of carbon dioxide emissions. Incorporating pozzolanic materials like metakaolin can lower cement consumption and enhance strength. The aim of this study is to optimize the mechanical properties and durability performance of bamboo fiber and Metakaolin-modified concrete. Factors examined include workability, compressive strength, flexural strength, water absorption, sulfate attack resistance, and microstructure. The American Concrete Institute's mix design method was used to develop a C-25 grade concrete mix. The mixes produced included a control mix, as well as variations incorporating different percentages of metakaolin (10%, 15%, and 20% by weight of cement) and bamboo fiber (0.5%, 1%, and 1.5% by volume of concrete). The results show that workability decreases as the bamboo fiber and metakaolin content increases. Compressive and flexural strength reach a peak at the mix with 1% bamboo fiber and 15% metakaolin, and then slightly decline. However, all mixes exhibit improved performance compared to the control. The mix with 1% bamboo fiber and 15% metakaolin demonstrates the best overall results, indicating the optimum combination. The concrete matrix's pore structure is filled due to the formation of calcium silicate hydrate (C-S-H) gel, leading to lower water absorption for this mix. Furthermore, the incorporation of bamboo fiber and metakaolin enhances the concrete's resistance to sulfate attack. The XRD pattern reveals sharp peaks for Albite and lower intensity peaks for calcium hydroxide (CH) and calcium silicate hydrate (C-S-H). Albite reacts with calcium hydroxide from cement hydration to form more C-S-H gel, enhancing concrete's strength and durability. SEM analysis reveals that at optimal fiber content, bamboo fibers are evenly distributed in the concrete matrix, improving overall performance. However, at 1.5% fiber content, excess fibers can adversely affect their orientation. This improvement enables the concrete to last longer, which leads to fewer maintenance needs over time and reduces the environmental impact associated with the demolition of structures.

Keywords*: Bamboo fiber Reinforced Concrete, Bamboo Fiber, Compressive Strength, Flexural Strength, Metakaolin.*

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LIST OF ACRONYMS

ACI	American Concrete Institute
ASTM	American Society for Testing Materials
BF	Bamboo Fibre
MK	Metakaolin
BFRMC	Bamboo Fibre Reinforced Metakaolin Concrete
LOI	Loss of Ignition
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
SCM	Supplementary Cementitious Material
SEM	Scanning Electron Microscope
XRD	X-Ray Diffraction
C-25	Concrete characteristic compressive strength of 25 Mpa
MPa	Mega Pascal

LIST OF CHEMICAL FORMULAS

C-S-H	Calcium Silicate Hydrate
H_2O	Water
$Ca(OH)_2$	Calcium Hydroxide
C_3A	Tricalcium Aluminate
C-C-S-H	Calcium Carbonate Silicate Hydrate
CH	Calcium Hydroxide
$CaCO_3$	Calcium Carbonate MS Magnesium Sulphate
MH	Magnesium Hydroxide (bruite)
$[Ca_3Al(OH)_6\cdot 12H_2O]_2(SO_4)\cdot 32H_2O$:	Ettringite
$[Ca_2Al(OH)_6\cdot 2H_2O]_2(SO_4)\cdot 2H_2O$:	Monosulfate
$Al_2O_3.2SiO_2$	alumino-silicate
$Al_2O_3.2SiO_2.2H_2O$	kaolinite clay

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Concrete is commonly used as the base of infrastructure in most countries. Concrete has the requisite construction properties, such as its ability to withstand large compressive stresses. Concrete is mostly used because it is cheap and readily available. Since it has low tensile strength, the use of concrete is limited. For this reason, it is strengthened and the tensile strength properties of the concrete are improved (Ahmad, Zhou et al. 2023). Many buildings are only made of concrete or mud bricks in certain parts of the world. In the event of seismic activity, this is risky. In the case of an earthquake, these structures have no chance of standing. An ideal solution would be steel reinforcement, but cost is a major issue. For structural structures, scientists and engineers are constantly searching for new materials; the concept of using bamboo as a potential reinforcement has gained popularity (Gupta and Singh 2018) .

The building industry indirectly plays a major role in environmental damage, so it is our responsibility to find more environmental techniques of construction for development. One of the solutions is to search for a new material that can be recycled and reused. Therefore, it is necessary to go for a new material that is naturally available such as bamboo, glass, agricultural product, coconut shell rice husk, ceramic, silica, crump rubber etc.(Ahmad, Zhou et al. 2023). Bamboo is one of the renewable natural resource known to us. But sufficient care has not been given to investigation and change in bamboo. Due to the beneficial physical characteristics of bamboo, research has been made of bamboo as fiber material in concrete. With the development of science and technology, new techniques are implemented for treating of bamboo to make it durable and more working in terms of construction materials (Ahmad, Raza et al. 2014).

Environmental destruction such as pollution of air and water has been occurring in some regions by rapid development and production of materials like iron, steel, glass, cement and aluminum that use limited mineral resources. On the other hand, plants and fibers are annually reproducible clean resources (Bittner and Oettel 2022).

The use of fibers in the concrete mix as a reinforcing material was first recorded with Egyptians mixing straw and hairs of animal in the concrete as a reinforcing material for fixing of bricks in walls. The concept of using fibers to improve the characteristics of construction materials is very old. The modern development of fiber reinforced concrete started in the early sixties(Okubo, Fujii et al. 2004). There are 3 different types of fibers; synthetic, natural-organic and natural-inorganic fibers. Compared to natural inorganic fibers, natural-organic fibers are renewable, environmentally friendly and economical as its production cost is very low. Bamboo is a plant which is abundant in Ethiopia. It is renewable and eco-friendly, as it consumes Nitrogen which could be a part of huge effort to prevent air pollution. This plant grows and reaches its maximum strength in just few years. A fiber of Bamboo is a natural organic fiber which serves to reinforce concrete materials and improves tensile strength of a concrete (Lokesh, Kumari et al. 2020).

Natural fibers such as bamboo can be used as bio composites and integrated into sustainable, eco-friendly and well-designed industrial products which can minimize or replace the dominance of petroleum based products in future. Method of extraction and preparation of bamboo fiber reinforced composites was proposed by (Kumarasamy, Shyamala et al. 2020). According to them, mechanical extraction methods are more ecofriendly than chemical methods, and steam explosion and chemical methods significantly affect the microstructure of bamboo fibers. (Terai and Minami 2012) developed composites using bamboo fiber which could yield maximum tensile capacity of 180 MPa and also evaluate the process parameters, such as temperature, pressure and press/hold time.

Bamboo has mechanical properties such as high tensile strength and high strength to weight ratio which had made bamboo a natural engineering material itself (Mousavi, Zamani et al. 2022). Durability of the concrete is improved to reduce in the crack width. The reinforcement, fiber and concrete matrix are combined to resist external loads before concrete cracking occurs. After concrete cracks, the fiber mixed in the concrete have a significant effect on impending the growth of tensile cracks in concrete (Gupta and Singh 2018).

Meta kaolin is refined kaolin clay that is fired under carefully controlled conditions to create an amorphous aluminosilicate that is reactive in concrete. Like pozzolans such as silica fume, fly ash and blast furnace slag, Meta kaolin reacts with the calcium hydroxide by-products produced during cement hydration (Ambroise, Maximilien et al. 1994). The particle size of Meta kaolin is generally smaller than cement particles, though not as fine as silica fume. Meta kaolin is another pozzolanic material which is a highly efficient pozzolana and reacts rapidly with the excess calcium hydroxide resulting from cement hydration, to produce calcium silicate hydrates (CSH) and calcium aluminosilicate hydrates (Wang, Kovler et al. 2018).

Rebekhal et al. (2019) study's the performance of concrete by using both Bamboo Fiber and Metakaolin with respect to tensile strength and compressive strength. Methodology, for each test that was conducted, cubes, and cylinders were prepared. Cubes and cylinders were prepared to obtain the compressive strength and splitting tensile strength respectively. However, the study had its limitations.

1.2. Statement of the Problem

The building industry indirectly plays a major role in environmental damage, so it is our responsibility to find more environmental techniques of construction for development. One of the solutions is to search for a new material that can be recycled and reused. Therefore, it is necessary to go for a new material that is naturally available such as bamboo. Bamboo is one of the renewable natural resource known to us. But sufficient care has not been given to investigation and change in bamboo. Due to the beneficial physical characteristics of bamboo, research has been made of bamboo as fiber material in concrete (Ahmad, Zhou et al. 2023).

Concrete is commonly used as the base of infrastructure in most countries. Concrete has the requisite construction properties, such as its ability to withstand large compressive stresses. Concrete is mostly used because it is cheap and readily available. Since it has low tensile strength, the use of concrete is limited. For this reason, it is strengthened and the tensile strength properties of the concrete are improved (Gupta and Singh 2018).

The behavior of RC structures is affected by concrete core; control of crack and deflection. To overcome this problem fiber is added into concrete. This increases flexural strength, first crack strength, ductility, tensile strength, and stiffness. The use of certain types of fibers, such as steel and carbon, has become common in many developed countries. However, the high cost of these materials can be prohibitive. As a more economical alternative, utilizing natural fibers derived from plants offers a viable method for enhancing the structural performance of concrete (Jayakumar, Jagadheshwran et al. 2020).

Bamboo, in particular, is a readily available natural material that boasts impressive mechanical properties, including high tensile strength and a favorable strength-to-weight ratio, making it an effective engineering material. Various studies have explored the incorporation of bamboo with other materials, such as Sisal fiber (Hoda, Patil et al. 2018), Alccofine (Jayakumar, Jagadheshwran et al. 2020), and Fly ash (Aweke and Mohammed 2020). These investigations indicate that bamboo shows promising results in improving concrete properties.

Cement production is one of the major reasons for carbon oxides emissions into atmosphere during cement manufacturing process. The use of pozzolanas for making concrete is considered efficient, as it allows the reduction of the cement consumption while improving the strength and durability properties of the concrete. MK when used as a partial replacement of cement is known to enhance both the mechanical characteristics and durability of concrete (Sherif 2017).

The addition of supplementary materials in cement has dramatically increased along with the development of concrete industry, due to the consideration of cost saving, energy saving, environmental concerns both in terms of damage caused by the extraction of raw materials and carbon dioxide emission during cement manufacture have brought pressures to reduce cement consumption. Metakaolin looks to be a promising supplementary cementitious material for concrete (Narmatha and Felixkala 2016).

More literature is done on the mechanical strength of BFRC but limited study is found on the flexural strength and durability of concrete using bamboo fiber and Metakaolin. Therefore, this study evaluates the structural behavior of concrete incorporating both bamboo fiber and Metakaolin through experiments on workability, Mechanical strength, durability, micro-structural properties of C-25 concrete.

1.3. Objective

General objective

The objective of this study is to investigation on physio – mechanical and microstructural behavior of bamboo fibered concrete with partial replacement of cement by metakaolin**.**

Specific objective:

- Characterizing the physical and mechanical properties of bamboo fiber and Metakaolin.
- Optimizing the dosage of bamboo fiber and Metakaolin to enhance the compressive strength and flexural strength of concrete mixtures.
- Evaluating the durability performance of bamboo fiber and Metakaolin-modified concrete by conducting water absorption and sulfate attack tests.
- Investigating the influence of bamboo fiber on the internal structure and hydration products of concrete through scanning electron microscopy (SEM) and X-ray diffraction (XRD).
- Cost Comparison of Plain Concrete vs. Bamboo Fiber and Metakaolin-Modified Concrete

1.4. Significance of the research

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 (Okubo, Fujii et al. 2004).

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 and 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, De Winne et al. 2021).

Although researches have been conducting on the mechanical strength of BFRC no study found on the durability of bamboo fibre reinforced concrete and metakaolin. Thus in this research, experiments were conducted to answer whether or not the addition of bamboo fiber and metakaolin improves the mechanical strength and durability of concrete.

Ethiopia is one of the countries which are rich in bamboo plant. Hence, the findings of this research surely benefit engineers, builders and local authorities when constructing civil infrastructures.

1.5. Scope of Study

The experiments in this specific research were conducted using Lowland bamboo (Oxytenanthera Abyssinian) species. This specific research is also limited to investigate the mechanical properties and durability of concrete mixes incorporating bamboo fiber and Meta kaolin.

The experimental study Workability (slump), compressive strength, flexural strength and durability tests were under taken to monitor fresh and hardened concrete properties respectively. One grade of concrete (C-25) is selected for the study with bamboo fiber 0.5%,1%,1.5% by weight of concrete and meta kaolin 10%,15%,20% by weight of cement.

1.6. Organization of the Thesis

This thesis was organized with five chapters: The first chapter gives a brief description of the thesis background, problem statement, objectives (general and specific), significance of the study and scope of the study. The second chapter provided with a detailed literature review on the characteristics of Natural Fiber Reinforced Concrete, the effect of bamboo fiber on the mechanical strength of concrete and its application.

The third chapter deals with materials used to prepare the specimens and methodologies or testing methods and test setups used to investigate the strength of concrete. The fourth chapter is about the results of the experiments and discussion. The last chapter deals with conclusions given on the bamboo fibers and Meta kaolin on mechanical properties and durability of concrete and recommendations which shall be studied in the future.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Concrete is weak in tension and has a brittle character. The concept of using fibers to improve the characteristics of construction materials is very old. Early applications include addition of straw to mud bricks, horse hair to reinforce plaster and asbestos to reinforce pottery. Use of continuous reinforcement in concrete (reinforced concrete) increases strength and ductility, but requires careful placement and labor skill. Alternatively, introduction of fibers in discrete form in plain or reinforced concrete may provide a better solution (Althoey, Awoyera et al. 2022). The modern development of fiber reinforced concrete (FRC) started in the early sixties. Addition of fibers to concrete makes it a homogeneous and isotropic material. When concrete cracks, the randomly oriented fibers start functioning, arrest crack formation and propagation, and thus improve strength and ductility. The failure modes of Fiber Reinforced Concrete are either bond failure between fiber and matrix or material failure (Bittner and Oettel 2022).

2.2. Concrete Material

Concrete is a product obtained artificially by hardening of the mixture of binding material (cement), fine aggregate (sand), coarse aggregate (gravel), Admixtures in some cases, and water, in a predetermined proportion. Since concrete is made from different materials which form different parts, it is known as a composite material. The cement and water form a paste that hardens and bonds the aggregates together into a coherent solid mass. Performance of concrete depends on the quality of the constituent materials as well as on their proportion and on the process of construction that comprises: placing, compaction, and curing (Chen, Li et al. 2022).

2.2.1. Aggregate

Aggregates, both fine and coarse, take about 65-75% by volume of concrete and are important ingredients in concrete production. Aggregates are generally divided into two groups: fine and course. Fine aggregates consist of natural or manufactured sand with particle sizes ranging up to 9.5 mm (3⁄8 in.); coarse aggregates are particles retained on the 1.18 mm (No. 16) sieve and ranging up to 150 mm (6 in.) in size. The maximum size of coarse aggregate is typically 19 mm or 25 mm (3⁄4 in. or 1 in.). An intermediate-sized aggregates, around 9.5 mm (3⁄8 in.), are sometimes added to improve the overall aggregate gradation. Aggregates may be broadly classified as natural or artificial, both with respect to source and method of production (Dinku, Adamu et al. 2002).

Natural sands and gravels are the product of weathering and the action of wind or water, while stone sands and crushed stone are produced by crushing natural stone. Screening and washing may be used to process aggregates from either of these categories. Aggregates may be produced from igneous, sedimentary, or metamorphic rocks, but the presence or absence of any geological type does not, by itself, make an aggregate suitable or unsuitable for use in concrete. The acceptance of an aggregate for use in concrete on a particular job should be based upon specific (Noh, Mohamad et al. 2021).

Information obtained from tests used to measure the aggregate quality, or upon its service record, or both. The gravel part of aggregates forms the skeleton of the concrete, providing its compression strength. The smaller sized aggregate fills the voids between the large particles, while the cement paste fills the smallest spaces, coats the aggregate particles and glues them together. The very fine cement particles also fill the smallest empty spaces, thereby giving the concrete its high density and impermeability (Coutts and Ni 1995).

2.2.2. Cement

Cement is a material with adhesive and cohesive properties which make it capable of binding two or more materials together into a solid mass. Cement when mixed with water form a paste which sets and hardens by means of chemical reaction called hydration, and retains strength and stability. There are generally two types of cements; non-hydraulic and hydraulic cements. Hydraulic cements are types of cements which are able set and harden in water and give a solid mass; which doesn’t disintegrate (remain stable in water) (Aweke and Mohammed 2020). The great majority of Portland cements made throughout the world are designed for general constructional use. The specifications with which such cements must comply are similar, but not identical in all countries and various names are used to define the material, such as OPC

(Ordinary Portland Cement) in the UK, or Type I Portland Cement in the USA (Kumarasamy, Shyamala et al. 2020).

2.2.3. Water

Water is an important constituent in concrete. It chemically reacts with cement to produce the desired properties of concrete. Mixing water is a quantity of water that comes in contact with cement, impacts slump of concrete, and is used to determine water to cementitious materials ratio of concrete mixtures (Akinyemi, Omoniyi et al. 2020).

Strength and durability of concrete is controlled to a greater extent by water cement ratio. Concrete strength increases when less water is used during preparation of the mix. Although the hydration process consumes a certain amount of water, wet concrete actually contains more water than required for the hydration reactions. The excess water is added to provide the wet mix with sufficient workability (Dewi and Wijaya 2017). Concrete needs to be workable so that it can be molded into the desired shape and consolidated to the required density. The quantity of water used divided by the amount of cement gives the water to cement ratio. Low water-cement ratio leads to high strength but low workability while a high water to cement ratio produces a low strength concrete but good workability (Lokesh, Kumari et al. 2020). A careful balance of cement to water is therefore required when preparing the mix. Good quality water is required for the mixing of concrete.

Natural water that is drinkable and has not pronounced taste or odor can be used as mixing water for making concrete. Salt water should not be used for mixing concrete as it causes a significant reduction in strength and large variations in setting time (Ahmad, Zhou et al. 2023).

2.3. Reinforced Concrete Material

2.3.1. Fibers

Fibers are small discrete reinforcing inputs produced from various materials like steel, glass, carbon and natural sources in various shapes and sizes. It has been found that addition of small closely spaced and uniformly dispersed fibers to concrete would act as crack arrestors and substantially improve the tensile strength and other properties of concrete. This type of concrete is called as fiber reinforced concrete. ―Fiber reinforced concrete (FRC) can be defined as a composite material consisting of mixture of cement mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers (Okubo, Fujii et al. 2004).

2.3.1.1. Steel fibers

Steel fibers are short, discrete lengths of steel with an aspect ratio (ratio of length to diameter) from about 20 to 100, and with any of several cross sections. Volumes of more than 2% generally reduce workability and fiber dispersion and require special mix design or concrete placement techniques (Zatul, Kim et al. 2017).

2.3.1.2. Glass fibers

The first research on glass fibers was in the early 1960’s used as conventional borosilicate glass (E-glass) and soda-lime-silica glass fibers (A-glass). Glass fibers have high modulus and high strength to develop strong bond with the concrete (Mousavi, Zamani et al. 2022).

2.3.1.3. Synthetic fibers

Synthetic fibers are man-made fibers resulting from research and development in the petrochemical and textile industries. These fibers are derived from organic polymers which are available in a variety of formulations (Ramaswamy, Ahuja et al. 1983).

2.3.1.4. Natural fibers

Natural fibers are fibers that are found in nature. Natural fibers can be classified as Organic or In-organic fibers. Natural organic fibers are derived from either plant or animal sources (Kim, Okubo et al. 2013). The majority of useful natural textile fibers are plant derived with the notable exceptions of wool and, to a lesser extent, silk. Natural-inorganic fibers are discontinuous short fibers widely used to reinforce concrete. Many natural reinforcing materials can be obtained at low levels of cost and energy using locally available manpower and technical know-how. According to American Concrete Institute (ACI) natural fibers can be either processed or unprocessed (Rai and Joshi 2014).

Unprocessed natural fibers are available in reasonably large quantities in many countries and represent a continuously renewable resource. Unprocessed natural fibers require relatively small amounts of energy and technical know-how for their production compared to some other types of fibers. Coconut coir, sisal, sugarcane bagasse, bamboo, jute, wood, and vegetable fibers are typical examples of unprocessed natural organic fiber (Mousavi, Zamani et al. 2022).

Wood cellulose is the most frequently used processed natural fibers, where it is obtained using Kraft process. This process involves cooking wood chips in a solution of sodium hydroxide. Cellulose, hemicellulose and lignin can be obtained by bleaching (Zatul, Siow et al. 2017).

2.4. Bamboo plant

Bamboo is neither grass nor wood, while it has two of their characteristics. It belongs to the family of the Bambusoideae. It is estimated that 60–90 genera of bamboo exist, encompass approximately 1100–1500 species and there are also about 600 different botanical species of bamboo in the world. Bamboo mainly grows in tropical and sub-tropical regions of Asia, Latin America and Africa (Ramaswamy, Ahuja et al. 1983).

Bamboo, itself is very strong in its longitudinal direction due to strong fiber bundles penetration. The bamboo culm, in general, is a cylindrical shell, which is divided by transversal diaphragms at the nodes. Bamboo shells are orthotropic materials with high strength in the direction parallel to the fibers and low strength perpendicular to the fibers (Terai and Minami 2012). The thickness and strength of bamboo, however, decreases from the base to the top of the bamboo culm.

It is obvious that ecological materials satisfy fundamental requirements like pollution prevention and cost minimization. The use of agricultural byproducts such as rice husk, coconut fibers, and sisal and bamboo fibers plays a great role in minimizing energy consumption, conserving non-renewable natural resources, reducing pollution and maintaining a healthy environment. Bamboo is the core of these materials that fulfills these advantages (Guo, Chen et al. 2001).

Different researchers conduct tests on the mechanical properties for different species of bamboo fibers as a function of age, moisture content, density, etc. The optimum strength value occurs between 2.5 to 4 years of bamboo age (Besi 2013). The Ethiopian natural bamboo forest covers about 1 million hectares, which is about 7% of the world total and 67% of the African bamboo forest area. Different bamboo species are available in Ethiopia. Ethiopia has Africa‟s biggest bamboo resources and this plant can be harvested in sustainable cycles on 30%-40% of the mature culms every two years (Aweke and Mohammed 2020).

The total resource base of Ethiopia is confined to two indigenous bamboo species out of more than 1500 species of bamboo in the world and 43 species in Africa. The highland bamboo (Yushania Alpina), covers 15% and the monotypic genus lowland bamboo (Oxythenantera Abyssinica), covers 85% (GELAN 2019).

2.4.1. Highland Bamboo (Yushania Alpina, Arundinaria Alpina)

The highland Bamboo species is botanically known as Yushania alpina. The species was formerly classified under genus Arundinaria, and older literatures refer to this bamboo species using the name Arundinaria alpina. The local name for this bamboo species in Amharic is known as kerkeha (Aweke and Mohammed 2020).This species grows naturally in ecological zones of the country between 2200 – 4000 meters above sea level. The coverage of this species in Ethiopia was roughly estimated in 1997 to be about 130,000 hectares.

Y. alpina grows with Podocarpus falcatus in upland and with Juniperus procera in drier forests. The distribution of Y. alpina natural forests and manmade plantations in Ethiopia includes major places/localities of central and southern, south-western and north-western parts of the country namely Hagere Selam, Injibara, Gojam, Shewa, Kefa, Gamo-Gofa, Sidamo and Bale Southern Nations, Nationalities and Peoples (SNNPRS) Jima (Agaro, Gera) Bore/Gujji (Geremew, De Winne et al. 2021).

Y. alpina occurs in scattered populations on mountains from southern Sudan and Ethiopia southwards to Malawi. Out of Ethiopia, it is available in Kenya, Southern Sudan, Congo, Zaire, Rwanda, Uganda, Burundi, Tanzania, Cameron, Malawi and Zimbabwe (Aweke and Mohammed 2020).

Highland bamboo has the following properties: - It grows at an altitude of 2200-4000m above MSL, It needs 1500-2000mm rainfall, Grows in 10-20oC temperature, It attains mean height and base diameter of 12-20m and 8-20cm respectively, Hollow, monopodial and evergreen, It is single stemmed form and Culms are fully mature after 3 years of emerge from the soil (Dessalegn, Singh et al. 2022).

Grows with a density of 6000 stems/ha under natural conditions (without management interventions) and having about 51 tone/ha above ground biomass with mean annual increment of about 8.6 tones/ha oven-dry matter and mass flowering occurs 15-40 years (Cao and Wu 2008). Hollow Monopodial, Evergreen, (leptomorph-spreading/running and single-stemmed form Culms of Y. alpina are fully mature 3 years after they emerge from the soil

2.4.2. Lowland Bamboo (Oxytenanthera Abyssinian)

O. abyssinica natural forests of Ethiopia are available in Gambella, Asossa, Dedessa, Pawe West Walega (Begi, Nejo, Gimbi, Guten, Didessa Valley, Kelem) North of Nekemte/Hinde and the western parts of the country along major river valleys and in areas bordering the Sudan and include major places and localities namely Tigray, Gonder, Gojam and Welega. O. abyssinica is distributed throughout tropical Africa outside the humid forest zone, from Senegal east to Eritrea, and south to Angola, Mozambique and northern South Africa. Thus, out of Ethiopia, it is available in Senegal, Eritrea, Malawi, Angola, Mozambique, South Africa, Zimbabwi and Zambia (Aweke and Mohammed 2020).

Oxytenanthera Abyssinica grows within deciduous, savanna woodlands of western Ethiopia associated with grasslands. These bamboo species have the following properties (Akinyemi, Omoniyi et al. 2020): - It grows at an altitude of 500-1600 above MSL, it needs 1150mm rainfall and 20-27oC temperature, these bamboo species can even grow on poor volcanic soils where the rainfall is only 600mm and the temperature is above 35oC, It attains a mean height and base diameter of about 6-8m and 4-8cm; respectively, It is monotypic species of clumping form (Dessalegn, Singh et al. 2022).

In Ethiopia, in the past and even in present, the economic potential of bamboo has not been explored and the role of bamboo resources in national economies is negligible. However, now a day, bamboo has been used in traditional ways in the country side a little bit for the scaffolding, construction of houses, fuel feed houses, feed fodder, beehives, hats, mats, baskets, handicrafts, small furniture and other numerous products (Noh, Mohamad et al. 2021).

2.4.2. Bamboo Fiber

Bamboo fibers are natural fibers that are extracted from the bamboo tree and are focused as one of substitution for natural plant fiber having many advantages such as low cost, low density, ecologically friendly, sustainability and biodegradability (Akinyemi, Omoniyi et al. 2020).

Bamboo (Bambusa vulgaris) is the fastest growing natural construction material with 1250 species at an estimated annual production of 20 million tons worldwide. Several studies on the use of bamboo as a substitute to reinforcement steel have been found. Bamboo reinforced concrete cannot be an alternate to steel reinforcements (Ban, Zhi et al. 2020). The surface treatment for enhancing the bonding is labor intensive, costly and uses toxic materials. So, bamboo fibers can be utilized to reinforce concrete, along with the steel reinforcements. Alkali treatment of the bamboo fibers increases the thermal stability and surface area of the fibers, and the incorporation of 0.5 wt.% increased the toughness and reduced the elastic modulus of cement concrete and also Gradual reduction in the workability with an increment in the quantity of bamboo fibers (Akinyemi, Omoniyi et al. 2020).

In developing countries, bamboo has great economic potential because it can be replenished in a very short time. It is also known as an environmentally-friendly material for building since the cost of bamboo as an economical material is lower than other building materials, such as steel. It also has comparable strength and less energy is required for harvesting and transporting bamboos. Thus, the cost of manufacturing the bamboos will be much lower compared to steel. It has been proven that bamboo has a high tensile strength (Besi 2013).

Bamboo is claimed to have a tensile strength of about 193 MPa, which for mild steel is on par with a tensile strength of 159 MPa. This desirable performance of bamboo has enabled it to be entitled as "green steel". Bamboo is also known as an excellent carbon sequestration agent since it can sequester up to 12 tons of carbon dioxide (CO2) per hectare (Cao and Wu 2008). Moreover, it also produces about 35 percent more oxygen which is equivalent to trees. From this, it is assumed that bamboo can play a role in mitigating and protecting the environment from climate change (Noh, Mohamad et al. 2021).

2.4.2.1. Physical and mechanical properties

A) **Specific gravity**: it is a measure of density of a substance in comparison with density of water. Specific gravity of bamboo varies between 0.4 and 0.8 depending mainly on anatomical structure. The outer part of the bamboo culm has a higher specific gravity than the inner part. Specific gravity increases along the culm from bottom to the top (Ahmad, Raza et al. 2014).

B) **Moisture content**: Moisture of bamboo varies vertically from the bottom to the top portion and horizontally from the outer layer to the inner layers. Bamboo possess very high moisture content and green bamboo may have 100% moisture content (oven-dry weight basis) and can be as high as 155% for the innermost layers and 70% for the peripheral layers (Kwiecień, Hebel et al. 2015).

C) **Wettability: -** is the ability of a liquid to form a coherent film on a surface, owing to the dominance of molecular attraction between the liquid and the surface over the cohesive force of the liquid itself. Wettability of bamboo has a significant influence on adhesion and other related properties. In terms of adhesion theory, bond formation involves wetting, adsorption, and inter diffusion of the resin with the respect to the adhered substrate (Guo, Chen et al. 2001).

D) **Age of bamboo**: Fiber length and fiber diameter increases with increases of age of bamboo and strength of bamboo increases with an increment of age. The optimum strength value occurs between 2.5 and 4 years and decreases at the later ages.

2.4.3. Chemical Composition of Bamboo Fiber

The main chemical constituents of bamboo culms are cellulose, hemi-cellulose and lignin; minor constituents consist of resins, tannins, waxes and inorganic salts. Composition varies according to species, condition of growth, age of bamboo plant and part of the culm. Bamboo has 60% cellulose and considerably about 32% of lignin. The bamboo fiber is often brittle compared with other natural fibers, because the fibers are covered with lignin. Therefore, a devised process should be adopted to extract the bamboo fibers for reinforcement of composite materials (Dewi and Wijaya 2017). Bamboo is a lingo-cellulosic bast fiber. Chemical composition and properties are similar to theother bast fibers like jute, flax. It contains cellulose (70-74)%, hemicellulose(12-14)%, lignin(10- 12)%, extractives like protein, pectin, wax (2- 3)% (Besi 2013).

2.4.3.1. Cellulose

Cellulose is mainly composed of three elements such as carbon, hydrogen, and oxygen, and it is the material basis that forms the cell wall of bamboo fiber. Typically, cellulose remains in the form of micro fibrils within the cell wall of plant. Cellulose is the main factor affecting the tensile strength along the grain of bamboo fiber and the cellulose content is closely related to the bamboo age. It is worth noting that the cellulose content of the same bamboo material decreases with the increasing age of bamboo (Chen, Li et al. 2022).

2.4.3.2. Hemicellulose

Hemicellulose is an amorphous substance offering a low degree of polymerization and it exists between fibers. Hemicellulose is a complex polysaccharide with xylan as the predominant chain, and the branches mainly include 4-O-Methyl-D-glucuronic acid, L-arabinose, and D-xylose. The polysaccharide fraction of Phyllostachys makinoi extracted with 5% and 17.5% NaOH and observed that its main component was arabinoxylan, and the ratio of xylose to arabinose was 17–18:1 (Chen, Guo et al. 1998). The bamboo polysaccharide components extracted by two different methods and reported that most of the polysaccharide components after extraction with distilled water were glucose, while the content of xylose was higher after extraction with alkaline (Kumarasamy, Shyamala et al. 2020).

2.4.3.3. Lignin

Lignin is a kind of polymer with complex structures and of many types. The basic units of lignin mainly include guaiacyl, syringyl monomers, and p-hydroxyphenyl monomers. The structural units in lignin are mainly connected by ether bonds and carbon-carbon single bonds. Lignin is not evenly distributed in the bamboo fiber secondary wall. Generally, the concentration of lignin in the broad layer is lower, while the concentration of lignin in the narrow layer is higher. The presence of lignin also gives bamboo material a certain degree of stability. The lignin content also varies with the age of the bamboo. The basic skeleton of lignin can be roughly divided into three types (Chen, Guo et al. 1998).

In addition to the three main components, lignin often contains various sugars, fats, and protein substances and a small amount of ash elements. These chemical compositions affect not only the properties of bamboo, but also the application of bamboo fiber (Kim, Okubo et al. 2013)

2.4.4. The Basic Structure of the Bamboo Fiber

The cells of bamboo are mainly composed of fiber cells, parenchyma cells, ducts, epidermal cells, sieve tubes, companion cells, and some other cells.

According to previous studies, bamboo fiber cells have no inner wall, but the middle layer of the secondary wall has a multi-layer structure. The orientation of microfibers varies between layers of the bamboo fiber cell wall, as well as between different types of bamboo (Kwiecień, Hebel et al. 2015). The direction of microfibers in the narrow layer is a near-horizontal spiral arrangement, whilst the direction of microfibers in the wide layer is a near-axial spiral arrangement. Due to the different fiber orientations of the narrow layer and the wide layer, bamboo is anisotropic. The different distribution of vascular bundles leads to different longitudinal permeability of bamboo fibers, which in turn affects the penetration of chemical reagents and has a certain impact on the composition analysis and production of bamboo fibers (Kim, Okubo et al. 2013).

2.4.5. Extraction process of bamboo fiber

The chemical constituents of bamboo are primary cellulose, hemi-cellulose and lignin. The bamboo has 60% cellulose and a considerably high percentage of lignin (about 32%). The bamboo fiber is often brittle compared with other natural fibers, because the fibers are covered with lignin. Therefore, a devised process should be adopted to extract the bamboo fibers for reinforcement of composite materials. Bamboo fibers can be extracted in different ways. Some of them are explained below (Kwiecień, Hebel et al. 2015).

2.4.5.1. Chemical processing

It is basically hydrolysis alkalization. The crushed bamboo is cooked with the help of Sodium hydroxide (NaOH) into a form of regenerated cellulose fiber. Hydrolysis alkalization is then done through carbon disulfide combined with multi-phase bleaching. Due to high consumption of energy, health problems and pollution aspects; chemical processing is not environmental friendly, since it is preferred by many manufacturers as it is a less time consuming process (Radzi, Zaki et al. 2022).

2.4.5.2. Mechanical processing

In this method, the crushed bamboo is treated with biological enzymes. This breaks the bamboo into a mushy mass and individual fibers are then combed out. Although expensive, this process is eco-friendly (Zhang, Wang et al. 2018).

2.4.5.3. Steam-explosion processing

Raw bamboo was first cut into bamboo culms with 70-80cm in length by saw machine, and put into an autoclave with over-heated steam at 1750C and at a pressure of 0.7-0.8 MPa for 60 minutes. Then, the steam was suddenly released for 5 minutes and the cycles of sudden-steam release were continuously repeated for 9 times to assure the complete facture of cell walls. Finally, they were washed in hot water with addition of soap at 90-950C for 15 minutes to remove ash and dried in the oven for 24 hours at 1050C (Zhang, Wang et al. 2018).

2.4.6. Application of Bamboo Fiber

Bamboo fiber is currently used in the textile, papermaking, and construction industries in various formats. Recently, bamboo fiber has attracted the attention of composite material researchers and has been gradually making its way into the composite material industry (Lokesh, Kumari et al. 2020).

2.4.6.1. Textile Industry

Compared to other fibers, bamboo fiber has good hygroscopicity, can reflect light, and reduce the absorption of heat radiation, and can be used for clothing production. At the same time, bamboo fiber has a strong antibacterial effect and can be used in the production of medical supplies, such as masks and medical gauze. In the textile industry, bamboo fiber can be utilized on its own or in combination with other materials such as silk and cotton fibers (Cao and Wu 2008). Despite the potential and widespread application of bamboo fiber in the textile industry, some of its shortcomings, such as the short length of single bamboo fiber and the easy water absorption of bamboo fiber fabrics should be addressed through fundamental research (Chen, Li et al. 2022).

2.4.6.2. Papermaking Industry

Since bamboo fiber has an antibacterial effect and its length is close to coniferous trees, it can be used in the papermaking industry. China has a long history of using bamboo for papermaking. Bamboo was utilized in the papermaking industry as early as 1700 years ago. And the use of bamboo for machine-made paper production in China began in the 1940s. In recent years, due to the shortage of wood fiber, bamboo fiber has become an indispensable raw material for papermaking (Coutts and Ni 1995). It should be noted that although bamboo fiber is a good papermaking material, compared to wood, the cost of bamboo planting, storage, and transportation is higher, and the price of bamboo fiber is easily affected by the market.

2.4.6.3. Construction Industry

Studies have shown that in the production of some building materials, natural fibers can replace traditional steel and synthetic fibers, and improve their mechanical properties. Bamboo fiber is a natural fiber with excellent mechanical properties, and incorporating it into concrete leads to better physical and mechanical properties. (Terai and Minami 2012) studied the effect of adding 0%, 1%, and 2% (by volume) bamboo fiber on the mechanical properties of concrete and found that the flexural strength, tensile strength, and compressive strength of bamboo fiber reinforced concrete increased with the increase in bamboo fiber content.

(Ramaswamy, Ahuja et al. 1983) studied the deformation properties of bamboo fiber concrete and reported that the addition of bamboo fiber could reduce the shrinkage deformation of coagulation. (Chin, Tee et al. 2020)conducted experiments on bamboo fiber composite plate (BFCP) reinforced concrete beams, and the results showed that its structural bearing capacity increased by 10–12% compared to unreinforced beams.

Bamboo fiber can also be added to the cement paste to develop bamboo fiber reinforced cement. Studies have shown that adding an appropriate amount of bamboo fiber can enhance the toughness of cement, but if the amount of bamboo fiber is excessive, it can cause fiber agglomeration and, hence, cannot enhance the maximum flexural strength and impact resistance of the composites. (Akinyemi, Omoniyi et al. 2020) studied the effects of different pre-treatment methods on bamboo fiber cement composite materials and observed that microwave-assisted alkali treatment enhanced mechanical properties.

(Sanchez-Echeverri, Ganjian et al. 2021)compared the performance of bamboo fiber reinforced cement made from treated and untreated bamboo fibers and reported that the applied alkali treatment produced enhanced flexural strength. They also observed that after alkali treatment, the impurities on the surface of the bamboo fiber were significantly reduced giving a cleaner surface. Huang et al. analyzed the applicability of bamboo fiber and bamboo charcoal resources as building fillers in tropical and subtropical regions through the hygrothermal properties test as well as through simulation of the building component and the enclosed space.

2.5. Fiber Aspect ratio

Fiber is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat. The fiber is often described by a convenient parameter called ―aspect ratio‖. The aspect ratio of the fiber is the ratio of its length to its diameter. Increase in the aspect ratio of the fiber usually segments the flexural strength and toughness of the matrix. However, fibers which are too long tend to ―ball‖ in the mix and create workability problems (Ramesh, Deepa et al. 2021)

Fibre volume fraction and the interfacial adhesion between the fibre and matrix had been favourite effect study in most of the researcher as its ensure on the effectiveness of stress transfer. However, the fibre orientation and the fibre aspect ratio (l/d) was being understand that it also plays a very important role in mechanical properties of composites (Yu, Wang et al. 2014).

(Wang, Ren et al. 2012) conducted a study on the effect of fibre aspect ratio on mechanical properties of steel fibre reinforced concrete (SFRC) and reported that the fibre aspect ratio is being a very important parameter than going to affect the mechanical properties of steel fibre reinforced concrete. Based on the findings, optimum aspect ratio is existing for the SFRC in view of mechanical performance. Toughness was found to be enhanced rather than the strength as the volume of steel fibres added in the concrete are increasing. However, higher fibre aspect ratio was also found to be high energy absorption and better in restraining crack propagation due the enhancement of toughness and maximum strain of SFRC are being increased but it may cause the compressive strength and the modulus of elastic to be lower in overall.

While according to (Gao, Zhu et al. 2022) it states that the fibre aspect ratio (l/d) is directly proportional increment with the deflection limit corresponding to the ultimate load which can say the effect of steel fibre on the flexural behaviour is highly prominent. The shape of the descending branch of load-deflection curves tended towards gently, and flexural fracture toughness was largely improved because the fibre pull-out and debond increased the value of the fracture energy required.

2.6. Orientation of fibers

Fiber reinforced concrete is the composite material containing fibers in the cement matrix in an orderly manner or randomly distributed manner. Its properties would obviously, depends upon the efficient transfer of stress between matrix and the fibers. One of the differences between steel reinforcement and fiber reinforcement is that in steel reinforcement, bars are oriented in the direction desired while fibers are randomly oriented (Hoda, Patil et al. 2018).

Eventhough its difficult to align fibers parallel or perpendicular to the direction of load application, fibers aligned parallel to the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibers (Jayakumar, Jagadheshwran et al. 2020).

2.7. Fibre Length

Other than the fibre aspect ratio, fibre length are also an important parameter than will effect on the overall fibre tensile strength and its capability to resistance. (Radzi, Zaki et al. 2022) indicates that the fibre length and fibre content are strongly affecting the mechanical properties of the composite. The trend is the increase of fibre length leads to the increase of flexural strength.(Hoda, Patil et al. 2018).

While for team (Zhang, Wang et al. 2018) they used 3 different kind of fibre length which is 22.5mm, 45mm and 67.5mm respectively in their research. Research finding shows that the compression strength of the concrete in overall have no contribution form the fibres but the split tensile property of the concrete had been significantly enhanced with the fibre induction and the optimum length they found is 45mm.

While (Zhang, Wang et al. 2015) found that the concrete cube compression strength are actually decreasing with the increasing length of bamboo fibre used regarding the fibre content remain constant in the experiment. However, the trend is follow the increasing of length leads to increasing of strength in flexural and it starts to drop as it reached its optimum length.

2.8. Clays

Clay is a fine-grained natural material (soil or rock) comprising one or more minerals with small amounts of organic materials and metal oxides. Geologic clay deposits are mostly composed of phyllosilicate minerals, depending on the composition of the original materials. Clay can have different colors: white, gray, brown, orange, or red (Sposito, Beuntner et al. 2020). Clay minerals are formed by weathering of a variety of minerals. It is made through two main processes that may involve physical and chemical modifications or decomposition and recrystallization (Ilić, Radonjanin et al. 2017).

Table 2.1: Clay mineral groups (Sposito, Beuntner et al. 2020)

Group	**Types of chemical formula**
Kaolinite	$(Si4)A_{l4}O_{10}(OH)_8.nH_2O$(n=0 or 4)
Illite	$Mx[Si_{6.8}Al_{1.2}]Al_3Fe_{.025}Mg_{0.7}5O_20(OH)_4$
Vermiculite	$Mx[Si_8]Al_{3.2}Fe_{0.2}Mg_{0.6}O_20(OH)_4$
Smectite	$Mx[Si_8]Al_{3.2}Fe_{0.2}Mg_{0.6}O_20(OH)_4$
Chlorite	$(Al(OH)_{2.55})4[Si_{6.8}Alo_{1.2}]Al_{3.4}Mg_{0.6})20(OH)_4$

2.8.1. Sources of kaolin clay

Kaolin mines can be found in different counties including the Indian subcontinent, South East Asia, China, South America, North America, Australia, and many European countries. Among the different sources of kaolin, the Chinese clay is considered to be very pure. It is composed chiefly of the mineral Kaolinite, which occurs in the deposits of China clay rock, a mixture of 15% china clay and 10% mica, and the remainder is quartz (Narmatha, Felixkala et al. 2016).

2.8.2. Thermal treatment of kaolin clay

MK is mainly produced by calcination (i.e., thermal treatment) of kaolin clays within a temperature ranging from about 600C- to 800C (Ilić, Radonjanin et al. 2017). The treatment process calcination is important for the production of highly reactive pozzolanic material. The water is driven off from the kaolinite clay ($Al_2O_3.2SiO_2.2H_2O$) and the material structure collapses, resulting in an amorphous alumino-silicate ($Al_2O_3.2SiO_2$) referred to as metakaolin or metakaolinite. The process is named dehydroxylation, and may be expressed by the following equation (Trivunac, Kljajević et al. 2016): $Al_2O_3.\ 2SiO_2.\ 2H_2O$ $Al_2O_3U2SiO_2$ 1 $2H_2Om$

The thermal conversion of kaolinite has been a research topic for a large number of studies. It was found that the main parameters that significantly influence the dehydroxylation process are heating temperature, heating duration and rate, cooling rate, and ambient conditions. The loss of mass resulting from the dehydroxylation of pure kaolinite (39.5% Al_2O_3, 46.5% SiO_2, and 14% H_2O) at ambient atmosphere is about 14% (Sposito, Beuntner et al. 2020).

2.9. Meta kaolin

Meta kaolin is a pozzolanic additive/product which can provide many specific features. Meta kaolin is available in many different varieties and qualities. The purity will define the binding capacity or free lime. Some of them also provide special reactivity. Usually 8% - 20% (by weight) of Portland cement is replaced by Meta kaolin. Such a concrete exhibits favorable engineering properties. The pozzolanic reaction starts soon and continues between 7 to 28 days (Narmatha, Felixkala et al. 2016) Metakaolin differs from the other cement replacement materials (CRM) (supplementary cementitious materials; SCMs) in that it is not a waste product resulting from industrial activities nor is it completely natural. It is originated from kaolinite clay mineral and is processed for different uses and applications including cementitious systems (Trivunac, Kljajević et al. 2016).

Meta kaolin is not a by-product. I t is obtained by the calcinations of pure or refined Kaolinite clay at a temperature between 6500 C and 8500 C, followed by grinding to achieve a finesse of 700-900 m2 /kg. It is a high quality pozzolonic material, which is blended with cement in order to improve the durability of concrete. When used in concrete it will fill the void space between cement particles resulting in a more impermeable concrete (Hameed, Usman et al. 2023).

Meta kaolin is a relatively new material in the concrete industry, is effective in increasing strength, reducing sulphate attack and improving air-void network. Pozzolanic reactions change the microstructure of concrete and chemistry of hydration products by consuming the released calcium hydroxide (CH) and production of additional calcium silicate hydrate (C-S-H), resulting in an increased strength and reduced porosity and therefore improved durability (Trivunac, Kljajević et al. 2016).

2.10. Environmental Benefits of Metakaolin on Concrete

The manufacturing process of Portland cement often creates a large amount of carbon dioxide emissions, a known greenhouse gas. By replacing just a portion of the Portland cement in the overall cement mixture with Metakaolin, companies are actively reducing the amount of CO2 emissions while adding several performance-enhancing benefits (Hameed, Usman et al. 2023). When scaled up to the size and scope of infrastructure projects, the addition of metakaolin to cement or concrete significantly reduces the carbon footprint. Furthermore, the improved water and thermal resistance of metakaolin-enhanced concrete leads to reduced erosion and potential catastrophic defects that necessitate repairs or total replacement (Narmatha, Felixkala et al. 2016).

Making concrete with metakaolin is a more proficient process as it diminishes the consumption of Portland cement as well as strengthens the desired properties of the concrete. Thanks to the added strength provided by metakaolin to concrete projects, fewer additional support structures may be required to achieve the same results (Trivunac, Kljajević et al. 2016). Additionally, considering the impact metakaolin has on the composition of concrete it becomes far less susceptible to chemical attack that leads to cracking. Ultimately creating a more efficient infrastructure that necessitates far less maintenance and leaching of material into the surrounding environment. Lastly, metakaolin differs from other SCMs as it is not an industrial by-product and is instead manufactured by heating the naturally occurring clay mineral kaolin (Sposito, Beuntner et al. 2020).

2.11. Applications of Metakaolin

Metakaolin is ideally suited for a wide variety of cementing applications due to it being a reactive amorphous pozzolanic material that contains latent hydraulic properties and an overall finer particle size than cement. The finer particle size is exceptionally useful in creating additional surface area for chemical reaction sites within the concrete mixture. An increased number of beneficial chemical changes creates concrete with improved structural integrity and greater resistance to the harsh environmental conditions infrastructure projects typically encounter (Hameed, Usman et al. 2023).

These properties provide good particle packing capabilities. Because these properties are particularly desired in the oil and gas industry, these companies will utilize metakaolin in their cementing mixture to increase the hardening strength of the cement to withstand compressive forces and reduce the loss of both liquids and gases to permeability (Narmatha, Felixkala et al. 2016). The use of metakaolin is not restricted to infrastructure projects and oil industry applications. Thanks to the impressive enhancements provided by metakaolin as a supplementary cementitious material it can be extremely beneficial to a variety of other unique applications (Trivunac, Kljajević et al. 2016).

2.12. Reviews on Bamboo Fiber and Meta kaolin Concrete

(Zhang, Pan et al. 2012) Investigated the effect of bamboo fiber on the compressive and split tensile strength of concrete: They conducted a compressive strength test on standard cubical specimens of 150mm*150mm*150mm and tensile strength test on cylindrical specimens of 150mm diameter and 300mm height as per ASTM C39/39M and ASTM C 496 respectively. The results of this experiment reported that both compressive and tensile strengths of the concrete were enhanced by the addition of the fibers.

(Terai and Minami 2012) Conducted experiments to investigate the mechanical characteristics of bamboo fiber reinforced concrete; the tests were carried out after 28 and 56 days of curing. The variables were fiber dosages (0%, 1%, 2% and 3% by volume of concrete) and compressive strength of concrete (C-10 and C-20). The results of this study showed that the slump, specific gravity and modulus of elasticity of the BFRC specimens decreased as the fiber volume fraction increased. And the flexural and compressive strength of the concrete are not significantly affected by the bamboo fiber volume fraction. But the split tensile strength of the specimens increases significantly with an increase of fiber volume fraction. For all types of tests, the 56th -day strength is more than the 28th -day strength.

(Ahmad, Raza et al. 2014) Conducted experiments to study the effect of bamboo fiber on the compressive and flexural strength of the concrete; BFRC cubes have been tested and results compared with plain concrete. Additionally, singly and doubly reinforced beam with bamboo fibers have been cast and tested in flexure. It was reported as the compressive strength of the concrete with bamboo fibers does not show much improvement when tested after 28 days of curing but surprisingly the strength becomes double after 50 days of curing. And additions of the fibers improve the flexural strength and static modulus of elasticity of the composite.

(Ferreira, Tavares et al. 2017) Investigated the mechanical strength of natural fiber reinforced concrete; the variables were types of fibers (sugarcane and bamboo) and volume fraction of the fibers (2% and 5%). They conducted compressive strength, tensile strength in bending (flexural strength), tensile strength in diametrical compression (split tensile strength) and water absorption tests using cylindrical and prismatic specimens of standard dimension. It was reported that no significant variation of water absorption was noticed when compared with the standard concrete. But the fibers enhanced the compressive and tensile strength of the concrete. BFRC which have a fiber volume fraction of 2% showed better mechanical strength than sugarcane FRC and plain concrete.

(Zatul, Kim et al. 2017) Studied the effect of fiber treatment and loading on the mechanical properties of bamboo/cement composite by conducting compressive strength and flexural strength tests on bamboo fiber reinforced cement specimens after 10- day aging. The variables were type of bamboo fiber (treated in hot water and untreated) and fiber loading (0%, 0.25% and 0.5% by weight of cement). It was concluded that the compressive strength and modulus of elasticity of cement composites reinforced with untreated fibers were lower than those of pure cement specimens. In contrast, the treated bamboo fibers enhanced the compressive strength of cement composites. Both the treated and untreated fibers enhanced the flexural strength of the composite.

(Dewi and Wijaya 2017) investigated the use of bamboo fiber to improve the performance of bamboo reinforced concrete beam at the tension crack area; the only variable was fiber volume fraction (40g/m3 and 150g/m3). They conducted experiments on the beam having a dimension of 15cm x 20cm x 160cm with reinforcement of bamboo. The results showed that the increase of bamboo fiber volume fraction reduced the slump or workability and quality of concrete. However, the addition of fibers reduces crack width of concrete and its post cracking load-carrying capacity. And the fibers increase the first crack load capacity of the reinforced concrete beam. Fiber volume fraction of 40g/m3 was found the optimum fiber content that can be used in the mix.

(Ramaswamy, Mathew et al. 2017) Studied the mechanical properties of bamboo and glass fiber reinforced concrete; the variables were fiber content (0% and 1% by weight of cement) and hybridization ratio of glass fibers to bamboo fibers which is varied as 0:0, 25:75, 50:50 and 75:25. It was reported that the maximum compressive strength is obtained on the concrete having fiber dosage of 1% by weight of cement and hybridization ratio of 75:25 (glass fiber to bamboo fiber). For the split tensile strength test, maximum strength increment is obtained on the concrete which has fiber dosage of 1% by weight of cement and hybridization ratio of 75:25 (glass fiber to bamboo fiber). The flexural strength test results show that the fibers enhanced the flexural strength of the concrete.

(Gupta and Singh 2018) Conducted a series of experiments to investigate the mechanical behavior of BFRC; the only variable was fiber volume fraction of 0%, 0.5%, 1% and 1.5%. It was concluded that the workability of the concrete reduces as the fiber volume fraction increases. The optimum increment in the compressive strength was found on BFRC having a fiber volume fraction of 0.5%; increasing the fiber volume fraction beyond this percent reduces the strength of the concrete. The flexural and split tensile strength test results show the strengths increased as fiber volume fraction increases; the optimum strength increment was found on the concrete having fiber volume fraction of 1.5%. In addition to this, the fibers act as a crack resistor; hence, BFRC bears more load with reduced crack-width and deflection as compared to the conventional concrete.

(Hoda, Patil et al. 2018) Investigates the mechanical strength of bamboo and sisal fiber reinforced concrete; the variables were fiber dosage (0%, 0.5%, 1%, 1.5%, 2%, 2.5% and 3% by weight of cement) and compressive strength of concrete (C-30 and C-35). It was reported that workability of the concrete reduces as the fiber volume fraction increases. For the C-35 grade concrete, the optimum split tensile strength, compressive strength and flexural strength increment was found on BFRC having fiber dosage of 1%, 1.5% and 1% by weight of cement respectively. Similarly, for the C-30 concrete the optimum split tensile strength, compressive strength and flexural strength increment was found on the concrete having fiber dosage of 1.5%, 2% and 1% by weight of cement respectively.

(GELAN 2019) conducted a series of experiments on the shear and other mechanical strength of bamboo fiber reinforced concrete; To study the effect of fiber volume fraction on the mechanical strength of the concrete flexural and split tensile strength tests were conducted on the concrete having fiber volume fraction of 0%, 0.5%, 1% and 1.5% and aspect ratio of 63.63. To investigate the effect of fiber volume fraction and aspect ratio on the shear strength of the concrete the direct shear strength test was conducted on the concrete which have fiber volume fraction of 0%, 0.5%, 1% and 1.5% and aspect ratio of 63.63, 90.91 and 118.18. For the flexural and split tensile strength tests, optimum strength increment was found on the concrete having a fiber volume fraction of 1%. For all test types, fiber volume fraction of as much as 1% changes the failure mode from brittle to ductile.

Rebekah, D et al. (2019) investigation the concrete using bamboo fibre and metakaolin, the variables were fiber dosage (1%, 2%, 3%) and metakaolin (0%, 5%, 10%). The compressive strength of cubes is increased with addition of bamboo fibre at 1% and further any addition of bamboo fibre decreases the compressive strength of concrete. The addition of metakaolin along with the cement has increased the compressive strength when compared to the bamboo fibre concrete at addition of bamboo more than 1%. Partially replacement of cement with metakaoklin has increased the split tensile strength when compared to addition of bamboo fibre in concrete. The problem of decreases in compressive strength of concrete is increased 40% by using of metakolin.

(Jayakumar, Jagadheshwran et al. 2020) studied on bamboo fibre reinforced hollow concrete block. The block were casted in M5 grade of concrete using processed bamboo fibre at 0.5%, 1.0%, 1.5% of cement weight as additional reinforcement, 10% of Alccofine as replacement of fine aggregate. The study shows that block reinforced with bamboo fibre and Alccofine has a mild improvement in compressive strength when compared to conventional hollow concrete block. The strength properties of BFRHC blocks containing bamboo fibre of 0.5%, 1.0%, 1.5% were investigated. Modulus of elasticity of concrete was increased by the addition of bamboo fibres. The compressive strength of blocks is increased with the addition of bamboo fibre up to 1.0% and further any addition of bamboo fibre the compressive strength decreases. For 1.0% replacement in the 7 days, the compressive strength is 3.27 N/mm2 and for 28 days is 8.17 N/mm2.

(Aweke and Mohammed 2020) Studied the mechanical properties of fly ash concrete reinforced with bamboo fibers; percentage replacement by weight of fly ash (0%, 15%, 20%, 25% and 30%) with and without bamboo fiber for addition of different percentages by weight (0.1%, 0.2% and 0.3%).There was a significant increase of mean split tensile strength of a bamboo fiber reinforced fly ash concrete of 5.81% by 28th day at 0.1% bamboo fiber addition. The split tensile strength of BFRFAC with 0.20% bamboo fiber showed an increment of 0.12% which was almost insignificant compared to a non-fibrous fly ash concrete. The 28th day test results of BFRFAC incorporating 0.1%, 0.2% and 0.3% bamboo fiber showed flexural strength increment by 2.48 %, 5.98% and 7.80%

(Althoey, Hakeem et al. 2022) This research was carried out to study the basic concrete properties such as compressive strength, split tensile strength and Flexural strength by adding in volume of concrete at 0%, 0.5%, 1.0%, 1.5%,2.0% and 2.5% with concrete. The compressive strength, split tensile strength and flexural strength of bamboo fiber reinforced concrete have been tested for the various proportion of bamboo fiber concrete. The outcomes obtained specify the strength of bamboo fiber reinforced concrete that increases with an addition of fiber up to 2% and slightly decreases after that. The test result obtained from the flexural strength shows that the bending strength increases with addition of bamboo fiber in the concrete up to 2% and slightly decreases after that. From the results its concluded that bamboo fiber reinforced concrete provides added strength than conventional concrete.

(Atima 2022) conducted the experiment on effect of bamboo fiber on the mechanical properties of fiber reinforced concrete. The 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, compressive and tensile strengthen gained. 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/mm2 at 28 days. The optimum bamboo fiber proportion for concrete strength improvement was at 1% and gave 19.4 and 2.7 N/mm2 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%.

2.13. Research Gap

A detailed report is written by gathering a variety of study publications. It is discovered by doing a thorough literature review that several experiments on the basic properties of concrete have been undertaken by adding bamboo fiber and chemical admixtures. Even though a lot of research has been done on the mechanical properties of bamboo fiber reinforced concrete using molds, there hasn't been any relevant work done on the durability of bamboo fiber reinforced concrete and a comparative study on the Meta kaolin with bamboo fiber reinforced concrete over conventionally concrete. It is vital to examine the behavior of the concrete in terms of durability and conduct a comparative study.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1. Introduction

Concrete is a composite material composed of cement, sand as fine aggregate, crushed rock as coarse aggregate, water and admixture. It's obvious that, concrete can be produced through mixing of concrete ingredients, but the important point to bear in mind is producing acceptable concrete quality with a reasonable economy (Ramesh, Deepa et al. 2021). In this research, the materials used in the examination will be discussed in relation to their origins as well as their mechanical and durability properties. All material-related laboratory experiments will be conducted in the laboratory of the ASTU Department of Civil Engineering. The study will use a mixed methodology, referring to extracted and evaluated secondary data from earlier investigations.

3.2. Materials

3.2.1. Cement

Cement from different sources may have different properties which in turn will influence properties of concrete mix. Ordinary Portland cement is designed for a general use of construction work throughout the world. From locally produced cements Mugher Ordinary Portland Cement has been used in this specific research.

Figure 3.1: OPC cement

3.2.2. Fine aggregate

In this specific research work, local river sand was used as fine aggregate. Physical properties of fine aggregates like specific gravity and absorption capacity (ASTM C 128), fineness modulus (ASTM C 136), silt content and moisture content (ASTM C 566) are determined.

3.2.3. Coarse aggregate

Crushed natural stone was used as coarse aggregate in sample preparation for this specific experimental study. The maximum aggregate size of coarse aggregate is 20 mm. Physical properties of coarse aggregate; like specific gravity and absorption capacity (ASTM C 127), moisture content (ASTM C 566) and sieve analysis (ASTM C136) are determined.

3.2.4. Water

Tap water from the city's Adama water supply system is used during the investigation. This water will be used for both mixing and curing purposes. Water is primarily utilized for the hydration reaction, which causes cement to gradually harden. Water for concrete mix to be potable water which is drinking water which will free from all impurities was as per ASTM C1602 for the entire work of concrete preparation and curing.

3.2.5. Bamboo Fiber

For this study, the bamboo plant samples were collected from the Adama city region. The specific bamboo species used was the Lowland bamboo (Oxytenanthera Abyssinian). This species is known to be native to the local Adama area.

Figure 3.2: Bamboo fiber

3.2.6. Meta kaolin

For the purposes of this research investigation, the metakaolin powder utilized was procured from a commercial supplier. Metakaolin is a pozzolanic material derived from the thermal activation of kaolinitic clay minerals. The specific metakaolin powder employed in this study was obtained from the local market.

Figure 3.3: Metakaolin Powder

3.3. Research Design

The logical flow of the actions and methods required to achieve a research's goals is represented by the research design. Experimental research type will use as the design and process present graphically in figure below.

Research Methods (Procedure)

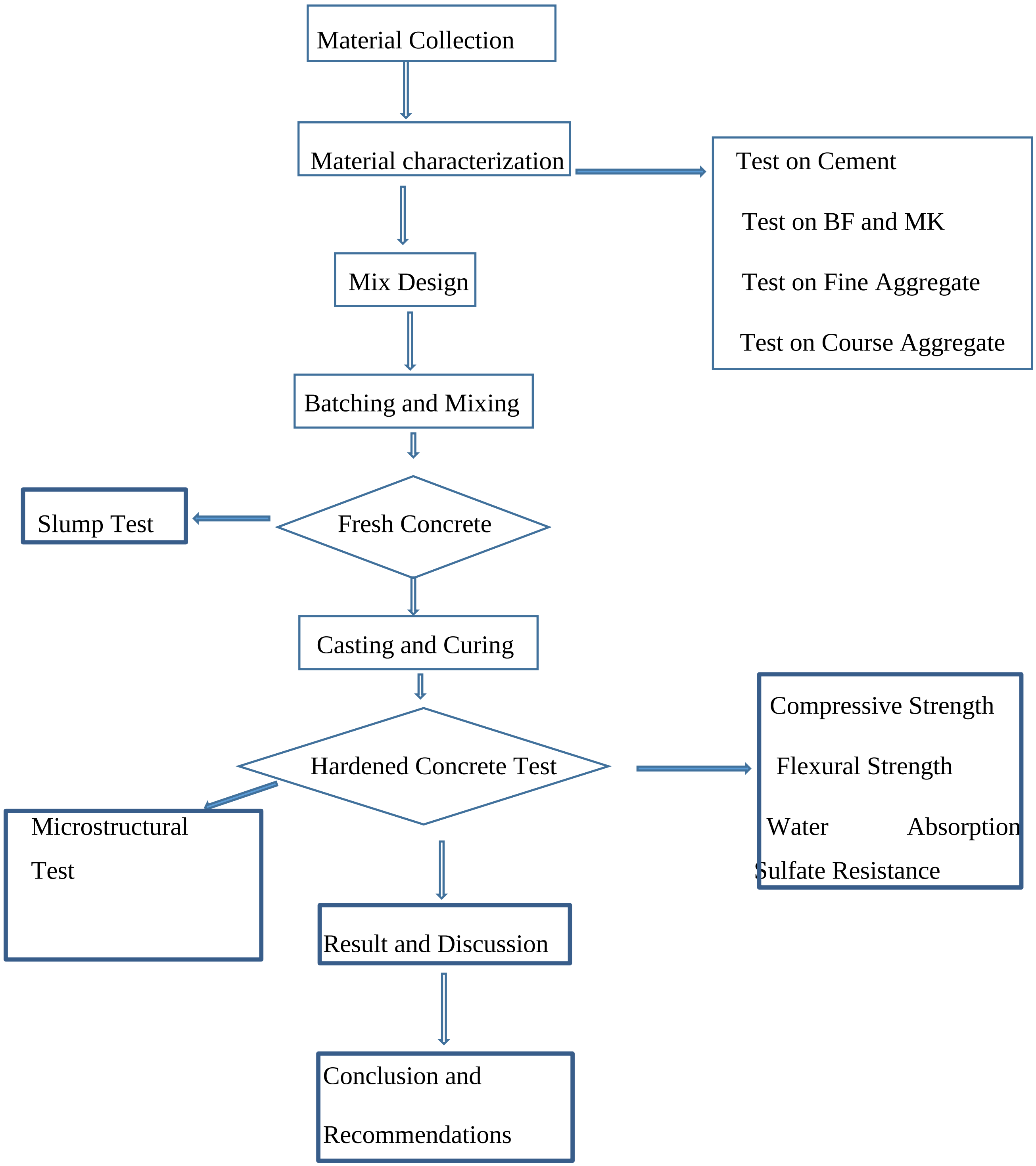

Figure 3.4: Schematic Diagrams for Research Procedure

3.3.1. Extraction process of bamboo fiber

Procedures to extract fiber from bamboo culm is summarized as below

Step-1 By using local harvesting method, 3.5 years lowland bamboo culm cut down by knife.

Step-2 Internodes of bamboo culm had been prepared by removing the node. The internodes have sliced in longitudinal direction by using circular band saw.

Step-3 the sliced bamboo stick was soaked in caustic soda and water for 5 days in order to soften them. Then remove the bamboo stick from water and hand peeling of very thin layer of outer covering parts.

Step-4 bamboo sticks were beaten at slow constant load using hammer in order to make them loosen, then combing using wire comb in order to remove fats and to separate individual fiber. The process of beating and combing continued until the individual fiber were separated.

Step-5 the extracted bamboo fiber dried on sun and cut the fiber with a length of 5cm.

Figure 3.5: Extraction process of Bamboo Fibers

3.3.1. Tests on Cement

3. 3.1.1. Normal Consistency Test for Cement

The test was conducted in a laboratory or on the construction site and has a straightforward method. Based on how deeply the plunger of the Vicat device penetrated the cement mixture, the test findings were analysed. The test was conducted per the guidelines in (ASTM C 187). **Apparatus**: Vicat Apparatus, Graduated Cylinder, Mixing Dish, Trowel, Weighs, And Weighing Apparatus Test Procedures for Consistency

i. 400 grams of cement were measured.

ii. Water amounting to a percentage of cement (22-30%) was added to cement and mixed.

iii. Within 3-5 minutes, properly combine the paste; gauging time wes the time it took to got cement paste after adding water.

iv. Filled the paste in the Vicat mold appropriately, level the paste and lower the plunger gently removed any surplus paste with a trowel.

v. Then, set the Vicat mold on the glass plate, making sure the plunger lightly touches the surface of the Vicat mold.

vi. Allow the plunger to sunk into the test mold after it had released.

vii. Took note of the plunger's penetration from the bottom of the mold as indicated on the scale.

viii. Repeat the experiment with varied percentages of water until the Vicat apparatus scale reading became between 5-7 mm.

ix. The water added was right and the penetration was between 5 mm and 7 mm.

The amount of water required for normal consistency then expressed as a percentage weight of the dry cement.

$$\text{Water} = \frac{weight\ of\ water\ in\ gm}{weight\ of\ cement\ in\ gm}\ \text{x}\ 100\% \text{ ----------------------------- Equation 3.1}$$

The results of the consistency test of cement are interpreted based on the depth of penetration of the Vicat apparatus plunger into the cement paste. The different types of consistency and their corresponding depth of penetration are dry or stiff consistency. In this research, the impact of BF and MK on the normal consistency of cement paste was examined. Normal consistency refers to the proportion of water needed to create a paste with a standard fluidity level. This consistency is reached when the plunger goes through 10 ± 1 mm from the paste's initial surface. This aspect is crucial, as it influences the workability and strength of the concrete.

3.3.2. Tests for Fine Aggregate

3.3.2.1. Silt content

Finding out how much silt was in the sand was the main objective of this test. The test was conducted under the guidelines in (ASTM C 117). Apparatus**:** sample sand, clean water, a graduated jar, a spoon, a dish for taking a sand sample, and a funnel

Procedure for the Silt Content Test

- **i.** The researcher used a graduated cylinder with a 1000-ml capacity.
- ii. 300 ml of sand was added to the cylinder.
- iii. The jar was filled with water to approximately 3/4 of its capacity.
- iv. For almost a minute, the jar was shaken vigorously.
- v. Leaving the jar unattended for an hour allowed the silt to accumulate on the layer of
- vi. The amount of fine that separated into a layer on top was measured.
- vii. The silt content was computed using Equation 3.1 below.

A = amount of silt deposited above the sand

B = amount of clean sand

Silt content = $\frac{A}{B}$ x 100% ---------------------------- Equation 3.2

The distinction between silt & clay can’t be based on particle size because both are microscopic having sizes finer than No. 200 (0.075mm) sieve and hence the significant physical properties of the two materials are related only indirectly to the size of particles.

3.3.2.2. Sieve analysis

Objective: To determine Particle Size of the fine aggregate. Apparatus ¬ Balance ¬ Series of sieves ¬ Shovel and sieve brush

Procedures (Dinku, (2002)).

1. Weight 2Kg of a sample fine aggregate.

2. Select representative sample by riffle box.

3. From the quartered sample take 500gm.

4. Weight the empty sieves and record the data.

5. Place the500gm sample on the top sieve.

6. Shake about 2minttes in the sieve shaker.

7. Weight each sieve together with the aggregate retained on.

8. Calculate weight retained on each sieve.

9. Fill the gradation chart and calculate fines modulus.

3.3.2.3. Specific gravity and absorption capacity

Objective: to determine bulk and apparent specific gravity, and absorption of fine aggregate. Apparatus ¬ Balance ¬ Pycnometer ¬ Tamper and ¬ Mold. Sample Preparation 1000gm of fine aggregate was taken by quartering. It was dried it to constant weight at a temperature of 110 ±5 oC, cool in air at room temperature and then immerse in water at room temperature for a period of 19hrs. The sample was removed from the water and spread to flat surface and allow it to dry in the sun, then a portion of dried aggregate was placed in a mold and the surface was lightly tamped 25 times; then the aggregate slumps slightly it reaches of SSD condition.

Procedure

1. Immediately introduce into pycnometer 500g of fine aggregate.

2. Roll invert agitate the pycnometer to remove air bubbles.

3. Determine the total weight of pycnometer, sample and water.

4. Remove the fine aggregate from pycnometer, dry to constant weight at a temperature of 105 ±5 oC, cool in air at room temperature for ½ & 1½ hrs. And weight.

5. Determine weight of pycnometer filled in water.

The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. This definition assumes that the substance is solid throughout. Aggregates, however, have pores that are both permeable and impermeable; whose structure (size, number and continuity pattern) affects water absorption, permeability and specific gravity of the aggregates (Dinku, (2002)).

The specific gravity and absorption capacity of the coarse and fine aggregates used in this study were determined as per ASTM C 127 and ASTM C 128 respectively. And the values are summarized as follows: For the fine aggregate; Bulk specific gravity= 2.6, Bulk specific gravity SSD= 2.66, Apparent specific gravity= 2.75, Absorption capacity= 2.04%

3.3.2.4. Moisture content

To determine the moisture content, 500g fine aggregate sample was weighed and oven dried for about 24hrs to remove moisture contained in the sample with a temperature of 105oC- 110oC. The sample was then removed from the oven and placed on a desiccator for about an hour in order to cool without absorbing water from the atmosphere. The sample was then weighed (oven dry weight).

3.3.3. Tests for Coarse aggregates

In this specific research, basaltic crushed rock aggregates having nominal maximum size of 19mm were made use of through blending in order to keep gradation in the range specified on Ethiopian Standard. Physical property tests; like gradation, specific gravity, water absorption, moisture content and unit weight of the aggregates were conducted.

3.3.3.1. Sieve analysis

The purpose of this test is to ascertain the fineness modulus of coarse aggregate. To do so, a variety of equipment was used, including 2,000 g of coarse aggregate, a balance, sieve shaker, shovel, and sieve brush, as well as a series of IS sieves with the following sizes: 20 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, and pan. The test protocol that was used complied with ASTM C136.

Sieve Analysis for Coarse Aggregate: Weighed 20 kg of coarse aggregates, A representative sample was obtained through quartering, Extracted 2 kg from the quartered sample, The empty sieves were weighed, and the data was accurately recorded, Positioned the 2 kg sample on the top sieves, which featured larger opening sizes, Subjected the sample to sieving for approximately 10 minutes using a sieve shaker, Each sieve, along with the retained aggregate, was measured, and the weight retained on each sieve was calculated, Completed the gradation chart and computed the fineness modulus using Eqn. 3.2.

Fineness modulus = %cum.retained 100 -------------------Equation.3.3

3.3.3.2. Specific gravity and absorption capacity

To carry out this test, sample was taken by using a sample splitter and sieved with 20 and 4.75 mm sieves to ignore materials retained on sieve opening 20 mm and passed through a sieve opening 4.75 mm. Then the sample was washed to remove dust particles and put in the oven at 110oC for 24 hours. After that, the sample was allowed to cool after being removed from the oven and its weight was measured. The sample was submerged in the water for 24 hours. After the sample was removed from the water, it was rolled in a large absorbent cloth until all visible films of water were removed, and the required weight of the saturated surface dry sample was taken. After being weighted, immediately S.S.D sample was placed in the wire basket, and its weight in the water was determined. Finally, the sample dried to constant weight at a temperature of 110oC, and cooled in the air for 2 hours.

Overall calculations were done using equations 3.3 to 3.5. Density, specific gravity and water absorption tests were done according to ASTM C127 (2007) standard.

Bulk specific gravity = A/ (A+S-C)……………………………….…..Equation 3.4

Apparent specific gravity = A/ (B+A-C)…………………………...Equation 3.5

Absorption capacity = ((S-A)/A) * 100…………………………..…Equation 3.6

Where, A: Weight of oven dry specimen in oven, (g) B: Weight of wire basket with water, (g). S: Weight of saturated surface dry specimen, (g). C: Weight of wire basket with specimen in the water, (g).

3.3.3.3. Moisture content of coarse aggregates

Moisture content of coarse aggregate samples has to be determined as it affects workability and water-cement ratio in the mix design. A design water-cement ratio is usually specified based on the assumption that aggregates are inert (neither absorbs nor gives water to the mixture) and hence aggregates from different sources do not comply with this assumption of water cement ratio. To determine moisture content, 2 kg coarse aggregate sample was weighed and oven dried for about 24hrs at a temperature of 105oC-110oC.

The sample was then removed from the oven and placed on a desiccator for about an hour in order to cool without absorbing water from the atmosphere. The sample was then weighed (oven dry weight).

3.3.3.4. Unit weight of coarse aggregates

The unit weight measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. The unit weight is simply measured by filling a container of known volume and weighing it. Oven-dried coarse aggregate samples were used in this specific test. In determining unit weight of coarse aggregate, rodding procedure was followed where it is applicable to the aggregates of 20 mm maximum size. Normal crushed rocks and gravels have bulk unit weight of 1520-1680kg/m3 and produce normal weight concrete.

3.4. Batching and Mixing

3.4.1. Batching

Batching refers to the procedure of measuring the appropriate amounts or ratios of materials, such as cement, fine and coarse aggregates, and water, for creating a concrete mix. This can be completed either through weight or volume-based measurements. Batching by weight and volume method is used for this specific study. Bamboo fiber (BF) at dosage of (0.5%, 1%, 1.5%) by volume of concrete and Metakaolin (MK) is used to replace OPC at dosage of (10%, 15%, 20%) by weight of (cement) referring table below. Additionally, 0% of BF and MK is used as a control mix.

Taking these established benchmark values from the table below, the experimental investigation evaluated the effects of BF addition from 0.5-1.5% by volume of concrete, and MK replacement levels between 10-20%. This range of dosages for the two materials was selected to assess their influence on the concrete performance characteristics.

Table 3.1: Optimum Percentage Addition of BF by Past Studies

Authors	(Gupta and Singh 2018)	(Rebekah, D et al. 2019)	(Althoey, Hakeem et al. 2022)	(Hoda, Patil et al. 2018)
BF	0.50%	1.%	1.5%	1.50%

Table 3.2: Optimum Percentage Replacement of MK by Past Studies

Authors	Kumar, A. S., et al. (2014)	Gowram, I., et al. (2021)	Narmatha, M., et al. (2016)	Nikhila, C., et al. (2015)
MK	10.00%	10.00%	15%	20.00%

3.4.2. Concrete Mixing

There is no standard mixing method provided for bamboo fiber reinforced concrete. However, ACI 544.3R-89 (Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete) specifies ways of the mixing, compaction and curing of steel fiber reinforced concrete. According to the specification, fibers can be mixed with the concrete in three ways. Those are: 1st Add the fibers to the truck mixer after all other ingredients including the water have been added and mixed, 2nd Add the fibers to the aggregate stream in the batch plant before the aggregate is added to the mixer and 3rd Add the fibers on top of the aggregates after they are weighed in the batch. The normal flow of the aggregates out of the weigh batch will distribute the fibers throughout the aggregates. From those methods of mixing the first one is recommended by the report.

Standard weight balance measuring all the ingredients of concrete needed for the mix as per the mix ratio. The concrete ingredients cement, fine aggregate (sand), coarse aggregate, mixing water and admixture was measured by weight balance. Concrete mixtures with various proportions of bamboo fiber, ranging from 0.5% to 1.5% by volume of concrete and Metakaolin powder, ranging 10% to 20% by weight of cement was made and tested. ACI 211.1 concrete mix design manual was used to design for C-25 concrete grade as control.

Table 3.3: Percentage Replacement of Cement with MK and Percent Addition of BF

Batch	**Mix code**	**Bamboo Fibre (BF)**	**Metakaolin (MK)**
1	mix 1 (0,0)	0	0
2	mix 2 (0.5,10)	0.5	10
3	mix 3 (0.5,1 5)	0.5	15
4	mix 4 (0.5, 20)	0.5	20
5	mix 5 (1,10)	1	10
6	mix 6 (1,15)	1	15
7	mix 7 (1,20)	1	20
8	mix 8 (1.5, 10)	1.5	10
9	mix 9 (1.5, 15)	1.5	15
10	mix 10 (1.5, 20)	1.5	20

3.5. Fresh Properties

When concrete is in its plastic state it is known as a fresh concrete. Fresh concrete can be easily moulded to a durable structural member. Workability indicates the ease or difficulty with which the concrete is handled, transported and placed. The amount of water present in concrete should be in proper ratio. Workability of concrete can be measured using slump cone test. For each mix of different aspect ratio slump test were conducted.

3.5.1. Workability/Slump Test

Slump test is the simplest and common test used for finding the flow ability of the concrete. Flow ability of concrete is defined as the ability of the concrete to flow freely in a horizontal surface in the absence of obstacles without segregation. It also gives an assessment of filling ability. The apparatus consists of Abrams cone, which is a truncated cone having a base diameter of 200mm, top diameter of 100mm and a height of 300mm, a base plate, measuring tape and a trowel. The procedure consists of firstly the inside portion of the cone made wet and is placed at the centre of base plate Then the concrete is filled inside using a trowel with compaction to concrete. Concrete is filled in 4 layers and after each layer compaction is given. When the concrete is fully filled the cone is vertically lifted up. If there is no deformation the slump value will be zero.

Figure 3.6: Slump test

3.6. Concrete Casting and Curing

Activities of cleaning of the mold, oiling the surface, casting after thoroughly mixing the inner cubes molds cleaned and lubricated with mold oil to facilitate easy molding and smoother surface. Three (150mmx150mmx150mm) concrete cube samples for each sample number (Mix-1 – Mix 10) is casted and Water tank curing method adopted as all the specimens wholly submerged in water tank for continuous water curing and cured in the open tank for 7th and 28th and test for compression strength of concrete.

Table 3.4: Number of Sample Preparation

Mix Code	Compressive Strength		Flexural Strength		Water Absorption	Sulphate Attack
	7 Day	28 day	7Day	28 day	28 Day	28 Day
Mix 1 Control	3	3	3	3	3	3
Mix 2	3	3	3	3	3	3
Mix 3	3	3	3	3	3	3
Mix 4	3	3	3	3	3	3
Mix 5	3	3	3	3	3	3
Mix 6	3	3	3	3	3	3
Mix 7	3	3	3	3	3	3
Mix 8	3	3	3	3	3	3
Mix 9	3	3	3	3	3	3
Mix 10	3	3	3	3	3	3
Total	30	30	30	30	30	30

Three (500mmx100mmx100mm) concrete beam samples for each sample number (Mix-1 – Mix 10) is casted and Water tank curing method adopted as all the specimens wholly submerged in water tank for continuous water curing and cured in the open tank for 7^{th} and 28^{th} for flexural strength of concrete. Three concrete cube samples for each mix casted then cured in the open tank for 28th day and tested for water absorption. Three concrete cube samples for each mix casted then cured in the open tank for 28th day and tested for sulphate attack.


Figure 3.7: Curing of the specimens

3.7. Hardened Properties

3.7.1. Compressive Strength Test

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. (Ramesh, Deepa et al. 2021).

The compressive strength of concrete could be obtained from the equation below:

Compressive Strength = Load / Cross Sectional Area

The compressive strength of concrete could be obtained from laboratory compressive cube tests. These tests have carried out to assess the strength of concrete after seven (7) days, twenty-eight (28) days of casting. The cubes that will be used in this research are of dimensions 15cm x 15cm x 15cm. The results of the compressive strength test will be the average of the three specimens required for each curing day.

In order to evaluate the internal curing effect of Bamboo Fiber reinforced concrete and MK, concrete samples were prepared by adding different weights of Bamboo fiber at percentages of 0.5%, 10%, and 1.5% in the concrete mix with 15% cement replacement of MK. The curing duration for the samples was varied, with subsets of 24 samples, each subjected to different curing periods: 7 days, and 28 days. The samples were exposed to standard laboratory conditions throughout the curing process, maintaining a relative temperature of 23 degrees Celsius. Once the designated curing period for each sample was completed, they were removed from the soaking tank and placed in the open laboratory environment, marking the initiation of the internal curing process. At the end of the 28-day curing period, the compressive strength test was conducted on all the samples. The variation in compressive strength among the samples was then analyzed to determine the extent of the internal curing effect provided by BFRMC.

Figure 3.8: Compressive Strength Test

3.7.2. Flexural strength test

The flexural strength of bamboo was also tested using the manual universal testing machine using the three-point bending test on whole bamboo. The force at which failure occurred was recorded and flexural strength calculated from the formula (Ramesh, Deepa et al. 2021).

Flexural strength = M/S

And; $S = \pi (D2^{4} - D1^{4})/32D^{2}$

Where;

M is the failure load applied to the specimen

Flexural force, also known as bend strength, fracture force, or modulus of rupture, was a mechanical characteristic for brittle materials that describes a material's ability to resist deformation under load. To determine flexural strength, beams of the dimensions 10cm*10cm*50cm were cast. The test was conducted on the beams at the age of 7 and 28 days, and the specimen was placed in the machine following ASTMC78. The load was applied at an increasing rate of 108KN/min, and the load at which the specimen fails was recorded.

The beam specimens were put through a two-point loading test on flexural testing equipment to create pure bending. The specimen's surface should be free of any unnecessary debris, such as sand, on the bearing surface of the flexural testing equipment. The applied two-point bending load was raised progressively and steadily until the specimen could no longer resist it. The maximum load placed on the specimen was recorded. The modulus of rupture was given by the equation.

Rupture (R) = $(3Wa) / (bd^2)$

W = load at failure L = specimen's length b = specimen width d = specimen depth.

Figure 3.9: Flexural Strength Test

3.7.3. Water Absorption Test

This research examined the water absorption of conventional and BFRMC concrete at curing periods of 28 days to determine the water tightness of concrete. The water absorption test procedure followed was: after 28 days of curing, the samples were taken out of the curing water and dried at a temperature of 105°C for 24 hours, weighed, then immersed in curing water for 24 hours, weighed again, based on (ASTM, C1585), and the highest water absorption limit is 10%. The increase in weight as a percentage of the original weight is expressed as water absorption. The water absorption and percent reduction can be computed based on the formula:

Water absorption % $= \frac{S-H}{H}*100\%$

Reduction % $= \frac{\text{H−S}}{H} * 100\%$

Where, S= Submerged sample H= Oven Dry sample

3.7.4. Sulfate Attack Test

The test method is applicable to concretes that are to be exposed to sulfate –rich environments and not applicable to concretes that are to be exposed to environments that are highly acidic or alkaline. The sulfate attack index should not exceed 0.5% and concrete cubes with a sulfate attack index greater than 0.5% are considered to be suspected to be sulfate attack. The test was conducted as per ASTM C1260-22

Apparatus: Balance, Mold, Stirrer, Container, Graduated Cylinder

Procedure for the Sulfate Attack

i. The concrete cubes prepared in accordance with the requirements of ASTM C1260 standard.
ii. The sulfate solution prepared by dissolving50g of sodium sulfate (NA2SO4) in 1000ml of water.
iii. Immerse the concrete cubes in the sulfate solution so that all six sides were exposed to the solution.
iv. The concrete exposed cubes to the sulfate solution for a period of 14 days.
v. Removed the concrete cubes from the sulfate solution and weigh them.
vi. Calculated the mass loss of the concrete cubes by subtracting the weight of the dry concrete cubes from the weighted of the wet concrete cubes.
vii. Calculated the sulfate attack index by dividing the mass loss of the concrete cubes by the original mass of the concrete cubes.

Loss in Kg = W_1-W_2

% of Loss= $\frac{W_1 - W_2}{W_1} * 100\%$

Where, W1= weight of the concrete before exposure to sulfate solution

W2 = weight of the concrete after exposure to the sulfate solution

3.7.5. XRD Test

Microstructures for bamboo fiber reinforced concrete were studied by conducting XRD test to determine the mineral, compounds and crystalline phases present in the sample. A piece of the concrete from the 1% BFRMC was removed, specimens were cured for 28 days before being analyzed using XRD. The specimens' top, middle, and bottom halves were used to create the parts. The pieces were subsequently crushed to a powder and brought to the XRD lab. After examination, the peaks were produced using the Origin Software utilizing the gathered XRD data in terms of diffraction intensity and degree. After that, the peaks were analyzed with the help of the X'pert High Score plus programmed.

3.7.6. SEM Test

SEM was done for the face identification of bamboo fiber reinforced concrete and Metakalolin concrete. These tests are non-destructive in nature and can be conducted by taking small sample of specimen. The SEM scans the specimen with a concentrated electron beam and records any signals created by the beams interactions with the sample. Topography photos are used to examine a surface's size, form, surface roughness, and fracture. To undertake an SEM study of the concrete, samples from the 15% MK concrete mix and 1% BFRMC were taken after 28 days of curing. At first, the samples were made by taking a piece of the cured specimen and taking it down to size.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Introduction

The previous chapter discussed the research methodology adopted in this study. This chapter presents the test results of cement, Fine Aggregate, and Coarse Aggregate. As well as The characteristics of the materials employed in this investigation were discussed. Additionally, the concrete's workability, compressive strength, water absorption, sulfate attack, and microstructure were discussed.

4.2. Material characteristics

4.2.1. Normal Consistency of Cement

The consistency of cement paste was evaluated using the Vicat equipment, following the ASTM C-187 standard. As the Vicat plunger immersed about 9 mm into the material, it penetrated 28%. This shows that 28% of the weight of cement is made up of water to create a cement paste.

4.2.2. Bamboo Fiber Characterization

4.2.2.1. Tensile Strength

Bamboo fibers used for concrete reinforcement have a tensile strength of 430-930 MPa.

4.2.2.2. Fiber Length and Width

The bamboo fibers utilized in this research have diameters ranging from 0.4 to 0.9 mm, with an average diameter of 0.65 mm and an average length of 5 cm.

4.2.2.3. Water Absorption:

The water absorption of the bamboo fibers used in this research ranges between 5-13%.

4.2.3. Metakaolin Characterization

4.2.3.1. Chemical Characterization of MK

The chemical characterizations of the materials used for the MK are presented in Table 4.1 below.

Table 4.1: Oxide Composition of MK

Chemical Composition	Metakaolin %
SiO_2	54.5
Al_2O_3	38.3
CaO	0.39
Fe_2O_3	4.28
MgO	0.08
K_2O	0.5
Na_2O	0.56
SO_4	0.22
LoI	0.68
Specific gravity	2.5
$SiO_2+Al_2O_3$ + Fe_2O_3	97.08

The result indicates that the combined oxide components (SiO_2 + Al_2O_3 + Fe_2O_3) of Mk exceeded the 70% minimum requirement for classes N pozzolans, as specified by ASTM C 618-08 (2008). ASTM C 618-08 (2008) classifies MK as a class N pozzolan. Similarly, the standard sets a maximum loss on ignition (LOI) limit of 10% for class N pozzolans. MK met this specification, showing a LOI of 0.68%, which is well below ASTM C618's maximum threshold of 10%.

4.2.3.2. Fineness of Metakaolin

Fineness is an important property of cementitious materials that affects their hydration rate, strength development and durability. Fineness can be measured by various methods, such as sieving, air permeability, laser diffraction and image analysis. The fineness of the MK retained on 45 µm (No. 325) sieves is 29.1% and 70.9% passed which is less than the maximum value of 34% retain as specified per ASTMC 618.

4.2.4. Test on Fine Aggregate

i. Silt content

Silt content (%) = 3.45 < 6 $\ldots.\ OK!$

According to the Ethiopian Standard, if the silt content of the sand is more than 6% it is recommended either to wash or to reject the sand. The sand in this specific research can be used without washing since silt content is less than 6%, the detail is in the appendix.

ii. Sieve analysis

Figure below summarize the particle size distribution as per the Ethiopian Standard for the grading of fine aggregate.

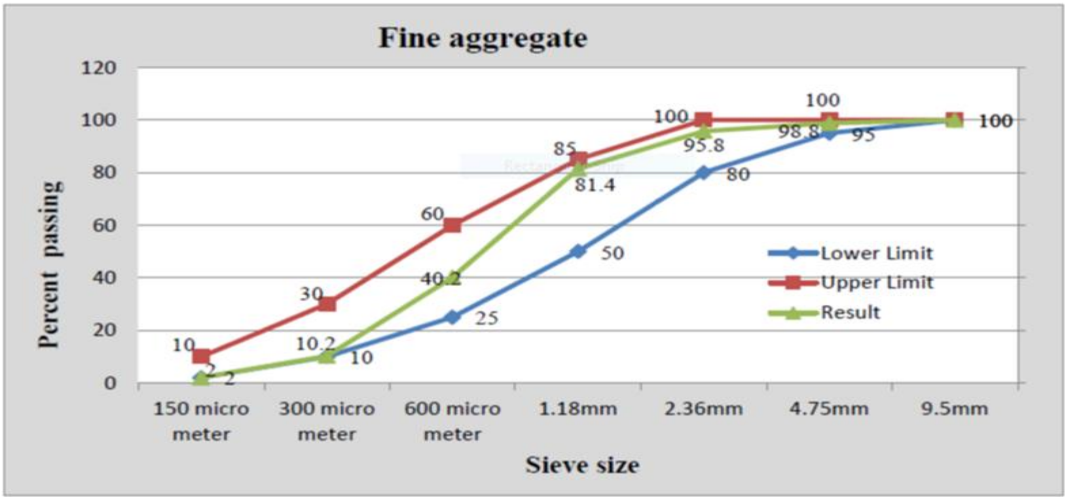

Figure 4.1: Gradation curve for fine aggregate

iii. Specific gravity and absorption capacity

Results

Bulk specific gravity, Bulk sp.gr =2.6

Bulk specific gravity (SSD), Bulk sp.gr = 2.66

Apparent specific gravity, Apparent sp.gr = 2.75

Absorption capacity, Absorption (%) =2.04%

iv. Moisture content

$\boldsymbol{w}$ (%) = $\mathbf{3}$. 31%

4.2.5. Tests for Coarse aggregates

i. Sieve analysis

Sieve Analysis is a procedure for the determination of the particle size distribution of aggregates using a series of square or round openings starting with the largest. According to the Ethiopian Standard coarse aggregates are those between 75 and 4.75 mm in size.

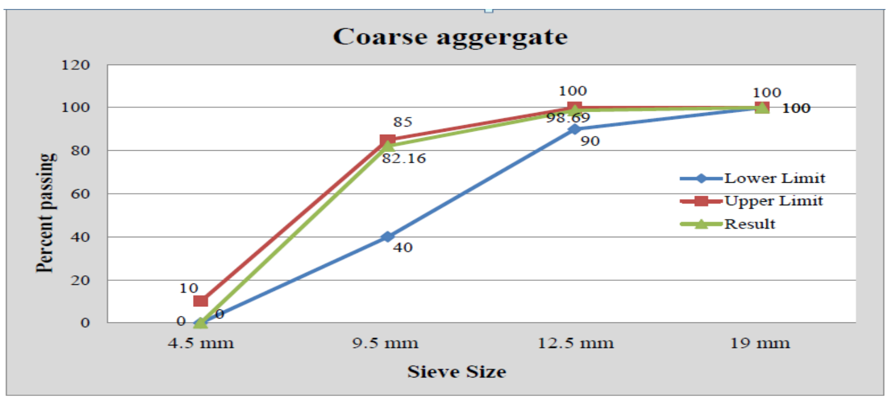

Figure 4.2: Gradation curve for coarse aggregate

The aggregate for a specific use should satisfy the gradation requirement of the ES. Table in the appendix gives the percentages passing required as per ES.

ii. Specific gravity and absorption capacity

Bulk Specific Gravity (Bulk sp. Gr) = 2.78

Bulk Specific Gravity (Saturated – Surface –Dry basis): Bulk sp. gr (SSD basis) = 2.8

Apparent Specific Gravity (Apparent sp. Gr) = 2.89

Absorption Capacity (Absorption Capacity: (%)) = 1.84%

iii. Moisture content of coarse aggregates:

w (%) = 1.63%

Comment: Aggregates were washed to remove dirt particles, and hence well dried in the sun. Moisture content and absorption capacity of coarse aggregate sample are used in concrete mix design to specify the amount of mixing water and water cement ratio.

iv. Unit weight of coarse aggregates

Unit weight of coarse aggregates = 1679.67kg/m3

4.3. Fresh concrete properties

4.3.1. Workability of the Concrete

The study focused on investigating the fresh concrete properties of various concrete mixtures, with a particular emphasis on conducting slump tests. The concrete mixtures incorporated a range of mix proportions, including Mix 1 (0, 0), Mix 2 (0.5, 10), Mix 3 (0.5, 15), Mix 4 (0.5, 20), Mix 5 (1, 10), Mix 6 (1, 15), Mix 7 (1, 20), Mix 8 (1.5, 10), Mix 9 (1.5, 15), and Mix 10 (1.5, 20). The results of the slump tests for each of these concrete mixtures are presented in the table below.

Table 4.2: Result of Slump Value of Fresh Concrete

Mix code	% Added	% Replaced	Slump (mm)	Slump Range
	BF	**MK**		
mix 1	0	0	4.9	3_10
mix 2	0.5	10	4.8	3_10
mix 3	0.5	15	4.6	3_10
mix 4	0.5	20	4.4	3_10
mix 5	1	10	4.2	3_10
mix 6	1	15	4	3_10
mix 7	1	20	3.7	3_10
mix 8	1.5	10	3.4	3_10
mix 9	1.5	15	3.2	3_10
mix 10	1.5	20	3	3_10

The results of the slump tests conducted on the various concrete mixtures provide valuable insights. The slump results for Mix 2, Mix 6, and Mix 10 were reduced by 2.04%, 18.37%, and 38.78%, respectively, compared to the control mix. However, the slump results for all the mixes presented in the table comply with the originally assumed slump range of 3-10 cm, indicating that the amount of bamboo fiber and Metakaolin used in the experiment did not cause any significant workability problems.

The fresh concrete test results reveal that increasing the volume fraction of both bamboo fibers and Metakaolin tends to reduce the workability of the mix. The control mix, with no bamboo fibers or Metakaolin, had a slump value of 4.9 cm. As the fiber and Metakaolin volume fractions increased, the reduction in slump varied accordingly. Mix 2 showed the least change, with a 2.04% reduction in slump, while Mix 10 had the highest reduction of 38.78%. Mix 6 exhibited a reduction of 18.37% in slump compared to the control mix; see Figure below.

4.4. Test Result for Hardened Concrete Property

4.4.1. Compressive strength test

Three 150mm sized cube samples were tested for each percentage addition of bamboo fiber And Metakaolin, The results of the compressive strength tests conducted on concrete cubes containing Bamboo fiber and Metakaolin powder, along with the corresponding curing days and percentages of replacement, are presented in Table 4.10. The detail of the compressive strengths of three replicate samples of blended cement concrete cubes, as well as the mean compressive for 7 day and 28 day curing periods are presented in the appendix.

Table 4.3: Compressive Strength of the Concrete with Different Replacement Percentage at 7and 28 Day's Age

Compressive Strength					
	7th Day		28th Day		
Mix Code	**Ult.Load (KN)**	**Stress (Mpa)**	**Ult.Load (KN)**	**Stress (Mpa)**	**% Incremental**
Mix 1	490.67	21.84	731.7	32.517	
Mix 2	522.33	23.21	800	35.567	9.379
Mix 3	546	24.28	812.33	36.133	11.123
Mix 4	528	23.453	809.1	35.96	10.59
Mix 5	556.95	24.75	839.467	37.31	14.74
Mix 6	**587.62**	**26.12**	**879.753**	**39.11**	**20.246**
Mix 7	603.525	26.823	864.375	38.417	18.145
Mix 8	546	24.58	812.33	36.267	11.532
Mix 9	530.553	23.447	803.667	35.897	10.395
Mix 10	511.75	22.743	773.103	34.36	5.669

Replacement levels Mix (BF: MK) %

Mix 1(0, 0): Mix 2(0.5,10): Mix 3(0.5, 15): Mix 4 (0.5, 20)): Mix 5 (1, 10): Mix 6(1,15): Mix 7(1,20): Mix 8(1.5,10): Mix 9(1.5, 15): Mix 10 (1.5, 20).

The data shown in Table 4.10 indicate that at 7 days, the compressive strength of Mix 6 (BF1% and MK 15%) was recorded as having the highest value (39.11Mpa). This is because, in comparison with conventional concrete, Bamboo Fiber and Metakaolin-containing concrete achieves early strength due to the availability of water, which enables the hydration to continue and increase the setting. Because Metakaolin is pozzolanic material it reacts with calcium hydroxide in the presence of water to form calcium silicate hydrate (C-S-H) jell which is additional cementetious compound and combined with properties of bamboo fiber leads to accelerated strength. The 1% BF and 15% MK mixs compressive strength was 26.12Mpa and 39.11 Mpa, respectively, at its greatest points for the corresponding curing days of 7 and 28 days.

Mean compressive strength of BFRMC with 0.50% addition of bamboo fiber by volume of concrete and 10 % Metakaolin showed an increment of 9.38% compared to control sample. The optimum value of BFRMC is with 1.0 % bamboo fiber and 15% Mk which showed compressive strength incremental of 20.25%, while BFRMC with 1.50% bamboo fiber and 20% MK showed the lowest compressive strength incremental of 5.67%.

It can be concluded that the incorporation of Bamboo fiber and Metakaolin leads to improvements across all mixes when compared to conventional concrete. While the peak performance is observed in mix 6, it is noteworthy that all tests exhibit a progressive enhancement in results.

Mix 6 stands out as the blend that demonstrates the highest level of improvement among the tested combinations. This mix likely represents the most effective balance of Bamboo fiber and Metakaolin for achieving the desired properties in the concrete.

4.4.2. Flexural strength test

Flexural strength test gives another way for estimating tensile strength of concrete. During pure bending the member resisting the action is subjected to internal stresses (shear, tensile and compressive). For a bending force applied downward for a member simply supported at its two ends, fibers above the neutral axis are generally subjected to compressive stresses and those below the neutral axis undergo tensile stresses. For the sake of testing three prismatic samples each for percentage addition of bamboo fiber by volume of concrete namely; 0.5%, 1% and 1.5% and Metakaolin with (5%, 10% and 15%) replacement of cement were tested with center-point loading in accordance with ASTM C293 standard. Typical failure loads and bending strength of 7th and 28th day BFRMC samples under center-point loading are presented in the Tables as shown below.

Table 4.4: Results of the Flexural Strength Test

Flexural Strength					
	7th Day		**28th Day**		
Mix Code	**Ult.Load (KN)**	**Stress (Mpa)**	**Ult.Load (KN)**	**Stress (Mpa)**	**% Incremental**
Mix 1	8.77	2.63	11.8	3.538	
Mix 2	9.624	2.87	12.1358	3.684	4.098
Mix 3	10.373	3.116	13.38	4.014	8.97
Mix 4	11.86	3.39	14.496	4.354	23.05
Mix 5	12.046	3.655	15.726	4.708	33.044
Mix 6	**12.199**	**3.669**	**16.557**	**4.972**	**40.496**
Mix 7	12.13	3.62	16.168	4.851	37.095
Mix 8	11.944	3.49	15.72	4.695	32.67
Mix 9	11.733	3.318	15.175	4.54	28.363
Mix 10	11.523	3.208	14.251	4.31	21.807

Replacement levels Mix (BF: MK) %

Mix 1(0, 0): Mix 2(0.5, 10): Mix 3(0.5, 15): Mix 4 (0.5, 20)): Mix 5 (1, 10): Mix 6(1, 15): Mix 7(1, 20): Mix 8(1.5, 10): Mix 9(1.5, 15): Mix 10 (1.5, 20).

The table above presents the flexural strength results for different concrete mixes containing bamboo fiber and metakaolin powder at various percentages and curing days. The data analysis demonstrates that the incorporation of these materials into the concrete mixture has led to improvements in the flexural strength properties. Specifically, the mean flexural strength of mix 2 shows an increment of 4.098% compared to the control concrete. However, the optimal composition appears to be mix 6, which exhibits the highest flexural strength increment of 40.496% among all the mixes. Conversely, mix 2 shows the minimum incremental value of 4.098% compared to the other mixes.

Bamboo fibers can improve the flexural strength of concrete by providing tensile reinforcement and bridging cracks. However, if the fiber content is too high, it can lead to poor workability and fiber balling, reducing the overall strength. Moreover, elevated metakaolin levels might obstruct the hydration process and the proper dispersion of bamboo fibers due to an excess of fine particles, diminishing their reinforcing impact on the concrete.

If the metakaolin content is raised beyond a certain point, the excess metakaolin might not adequately engage in the pozzolanic reaction due to a potential lack of available calcium hydroxide. This scenario could result in decreased efficiency within the pozzolanic reaction, potentially restricting further strength enhancements.

4.4.3. Water Absorption Test

Water absorption test is a test conducted over 24 hours to determine the quantity of water absorbed by a sample. The water absorption measures the unit’s total capacity to absorb moisture.

Table 4.5: Water Absorption of Conventional and BFRMC

Average water absorption and reduction in percentage				
Mix Type	Dry Block Weight(kg)	Immersed Block Weight(kg)	Water Absorption (%)	% reduction or incremental
Mix 1	7.354	7.675	4.18	
Mix 2	7.37	7.6891	4.15	0.717
Mix 3	7.368	7.685	4.12	1.435
Mix 4	7.285	7.64	4.29	2.632
Mix 5	7.359	7.71	4.129	1.22
Mix 6	7.367	7.681	4.09	2.2
Mix 7	7.464	7.8	4.31	3.055
Mix 8	7.38	7.73	4.53	9.104
Mix 9	7.05	7.43	5.02	21.845
Mix 10	7.149	7.55	5.311	27.057

Replacement levels Mix (BF: MK) %

Mix 1(0, 0): Mix 2(0.5, 10): Mix 3(0.5, 15): Mix 4 (0.5, 20)): Mix 5 (1, 10): Mix 6(1, 15): Mix 7(1, 20): Mix 8(1.5, 10): Mix 9(1.5, 15): Mix 10 (1.5, 20).

The durability of the concrete was evaluated using a water absorption test. It quantifies the amount of water absorbed by the concrete under ASTM C1585. The Table above, depicts the water absorption percentages after 28 days of curing for ten different concrete mixes, identified as Mix-1(control mix) to Mix-10 at different percentage of replacement. These percentages provide valuable insights into the water absorption characteristics of each mix.

The addition of bamboo fiber and metakaolin results in a decrease in water absorption compared to the plain concrete control mix, from Mix 2 to Mix 6, except for Mix 4. The reduction in water absorption ratio is due to the beneficial effect of the filling effect of ultrafine metakaolin as well as due to its pozzolanic reaction (Nour Eldin, Sharobim et al. 2021). However, water absorption begins to increase from Mix 7 onward. With a lowering percentage, the rate of water absorption falls. This might be because the inclusion of bamboo fibers percent increases the space and cavities in the materials (Ahmad, Zhou et al. 2023). If the metakaolin content exceeds a certain level, the excess may not effectively participate in the pozzolanic reaction due to a potential shortage of available calcium hydroxide (Saand, Keerio et al. 2017).

At the optimal composition (Mix 6), the water absorption is the lowest compared to all the other mixes. This finding highlights the importance of the specific ratio of fiber and filler components in shaping the water absorption characteristics of the composite material. A well-balanced combination of these components not only enhances the material's performance but also plays a critical role in determining how effectively the composite resists water penetration. Ultimately, achieving the right proportions is essential for optimizing the overall durability and functionality of the concrete mix.

4.4.4. Sulfate Attack Test

To determine the weight loss of various types of concrete, tests were conducted in accordance with ASTM C1260 to determine the weight loss of various types of concrete. Results of the sulphate attack test are shown in Table below. According to the results, weight loss on different percentages of BFRM concrete as compared to conventional concrete is reduced by 30 days of sulphate attack solution to the concrete.

The incorporation of bamboo fiber and metakaolin powder into C25 concrete mixes significantly improved their resistance to sulfate attack. This enhancement was clearly reflected in the notable decrease in weight loss percentages observed when bamboo fiber and metakaolin were added in varying proportions. The pozzolanic reaction between the MK and calcium hydroxide released during the hydration of cement, which consumes part of the calcium hydroxides. Thus, the quantity of expansive gypsum formed by the reaction of calcium hydroxide will be less in MK concrete than in plain concrete (Al-Akhras and research 2006). In all instances, the values consistently exhibited a reduction compared to the control mix, emphasizing the positive influence of these additives on the sulfate resistance of concrete formulations.

Metakaolin inhibit harmful ettringite formation by using up calcium hydroxide, while bamboo fibers block pores and add strength. Together, they boost concrete durability in sulfate-rich areas and lessen sulfate damage, like ettringite buildup.

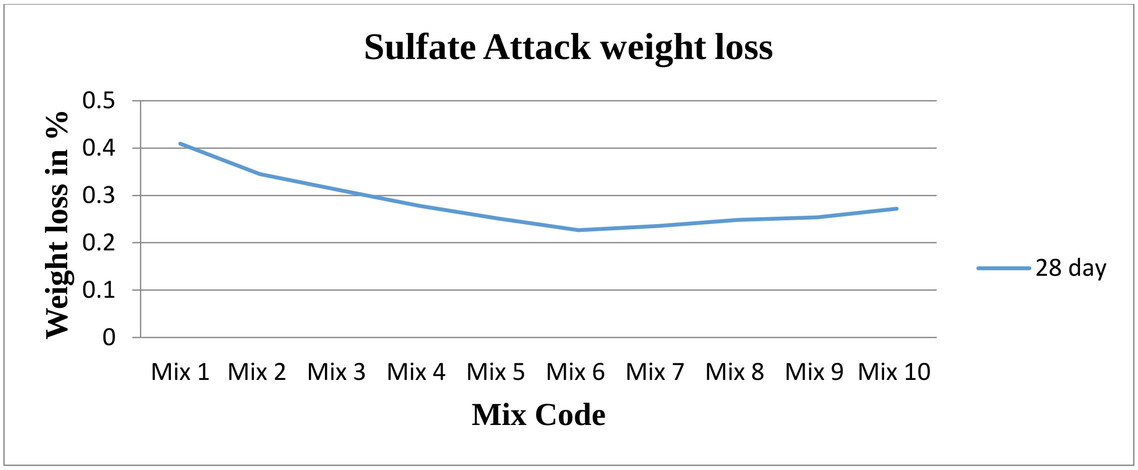

Figure 4.3: Sulfate attack Weight loss

4.4.5. X-Ray Diffraction (XRD) Test

X-ray diffraction (XRD) is an invaluable analytical technique used to identify the crystalline phases present in various materials. When applied to concrete, the XRD pattern reveals a composite of the diffraction patterns from its different components. The XRD patterns of the concrete samples are presented in Figure 4.10A. The peaks reflect the presence of various compounds, with their positions corresponding to the 2θ angles. In the control concrete, sharp peaks signify the presence of calcium silicate hydrate (CSH) and calcium hydroxide (CH). On the other hand, lower intensity peaks indicate calcium hydroxide (CH) and a certain amount of Ettringite.

The XRD patterns of the modified concrete samples are shown in Figure 4.10B. In the resulting XRD pattern, sharp peaks signify the presence of specific minerals like Albite (NaAlSi3O8) and CSH, whereas lower intensity peaks indicate the presence of calcium hydroxide (CH) and calcium silicate hydrate (C-S-H). Albite is crucial in pozzolanic reactions within concrete. During cement hydration, calcium hydroxide (CH) is generated, which then reacts with albite. This reaction facilitates the formation of additional calcium silicate hydrate (C-S-H) gel, essential for improving the strength and durability of concrete structures. Thus, XRD not only aids in the identification of materials but also provides insights into the chemical interactions that contribute to the performance of concrete.

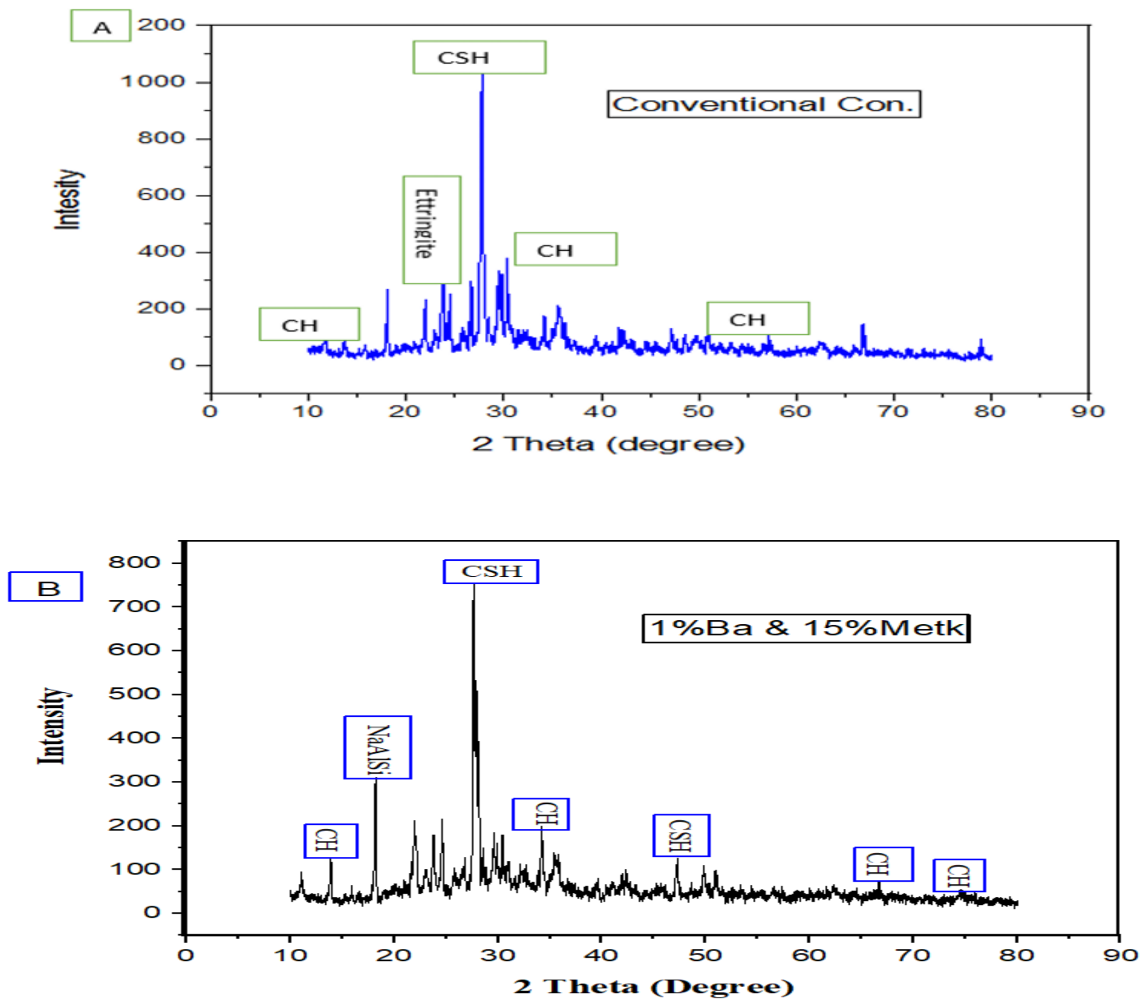

Figure 4.4: X-Ray Diffraction (XRD) test result of (A) conventional and (B) modified concrete

4.4.6. Scanning Electron Microscope (SEM) Test

Scanning Electron Microscopy (SEM) analysis plays a vital role in the detailed investigation of materials, allowing researchers to study surface morphology, elemental composition, and microstructure at high magnifications. In this study, SEM was utilized to examine the microstructural and phase characteristics of concrete, with a specific focus on how fiber orientation affects these properties.

At optimal fiber content, the bamboo fibers are distributed uniformly throughout the concrete matrix, which enhances the material's overall performance. However, when the fiber content reaches 1.5%, the excessive amount negatively impacts the orientation of the fibers. This overabundance can lead to the fibers clustering together, forming balls within the concrete, rather than maintaining an even distribution. Such changes in fiber orientation can significantly affect the mechanical properties and durability of the concrete, highlighting the importance of carefully controlling fiber content in composite materials.

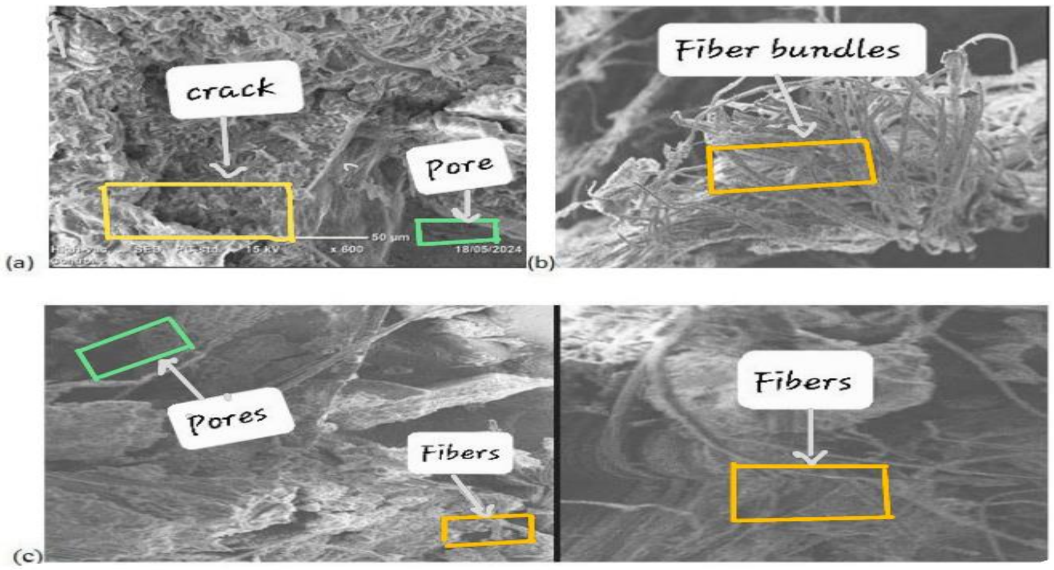

Figure 4.5: Scanning Electron Microscope (SEM) images at 28 days, for (a) control, (b) 1.5 BF% 10%MK and (c) 1%BF 15% MK

4.5. Cost comparison between convectional and modified concrete

To assess the economic implications of using BFMC, we estimated the material costs for producing both BFMC and conventional concrete (CC). This analysis was based on current market prices for construction materials.

Table 4.6: Material cost for producing one cubic meter of conventional concrete

Ingredients	Cement	Fine Aggregate	Coarse Aggregate	Water	Bamboo
Quantity (Kg/m3)	377	822	1045	177	7.95
Ratio	1	2.18	2.78	0.47	
Sum of ratios	5.96				

The cost of C-25 Plain concrete

- The cost 100Kg Mugher OPC is 2200 birr. Hence for 377 Kg it becomes 8294 birr.

- To investigate the volume of fine and coarse aggregates the dry volume of concrete assumed as 1.54m3.

Then the volume of fine aggregate (m3) = 2.18/5.96 * 1.54 = 0.56.

In parallel, the volume of coarse aggregate (m3) = 2.78/5.96* 1.54 = 0.72.

-The cost of 1m3 fine aggregate is 1565 birr; for 0.56 m 3 it becomes 876.4 birr.

- The cost of 1m3 coarse aggregate is 2500 birr; for 0.72 m 3 it becomes 1800 birr.

Cost of 1m3 C-25 conventional concrete =8294+876.4+1800 = 10970.4 birr.

The cost of Bamboo fiber and Metakaolin for 1 m3 concrete

From Table 4.6, 7.95Kg bamboo fiber is required to produce 1m3 BFMC which has a fiber volume fraction of 1%. To obtain 1Kg bamboo fiber 5m long bamboo plant is required then for 7.95Kg bamboo fiber 39.75m bamboo plant is required. The length of a single bamboo plant used in this study ranges 5.5-7m; it has an average value of 6.5m. The cost of the plant is 15 birr, for 39.75m it becomes 90.27birr. The extraction (labor) cost estimated as 400birr; then the total cost of 7.95Kg bamboo fiber becomes 400.27birr. For Metakaolin 15% cement replacement 0.15x377=56.35kg~56, 200x56 = 11200 birr and cement = 7049.9birr. Therefore, the cost of 1m3 C-25 concrete with bamboo fiber and Metakaolin =8294+876.4+7049.9+11200+400.27 = 27820.57 birr. While bamboo fibered Metakaolin concrete is generally more expensive than control concrete, it provides significant benefits in terms of sustainability, improved mechanical properties, and lower maintenance costs over time. Although it may not be the most economical choice in initial cost, its long-term advantages should be taken into account when making a decision.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The research study has drawn the following comprehensive conclusions based on the major findings:

- The addition of Bamboo Fiber and Metakaolin in blended concrete reduced its workability. However, since the slump results for all the mixes comply with the slump range of 3-10 cm, indicating that the amount of BF and MK used in the experiment did not cause any significant workability problems.
- On the 28th day of curing, the compressive strength of concrete made with the addition of BF and MK at Mix 6 was greater than that of all other mixes, including the control mix. This indicates that the optimal combination of BF and MK at Mix 6 resulted in the highest compressive strength. However, the study also found that any further increase in the addition of BF and MK beyond Mix 6 would lead to a reduction in compressive strength.
- The flexural strength of concrete with the addition of bamboo fiber and partial cement replacement with metakaolin increases with percentage up to an optimal point, after which it gradually decreases.
- The addition of BF and MK in the blended concrete improved water absorption compared to the control mix at Mix 6. However, the study also observed that further increasing the percentage of Bamboo fiber and Metakaolin beyond Mix 6 led to an increase in water absorption of the concrete.
- The incorporation of BF and MK in concrete improved its resistance to sulfuric acid attack, and all the tested mixes showed a reduction in sulfate attack compared to the control sample. This indicates that the addition of BF and MK can enhance the concrete's durability and resistance to chemical attack.

5.2. Recommendations

Recommendations of the Research

- It is recommended that bamboo fiber metakaolin concrete be employed in the construction of high-rise buildings. This innovative material offers substantial benefits, including improved durability and strength. By using this concrete mix, architects and engineers can design taller and more resilient structures.
- The research indicates that bamboo fiber metakaolin concrete is ideal for heavy load-bearing structures due to its high compressive and flexural strength. This makes it suitable for applications such as bridges, large commercial buildings, and industrial facilities, enhancing their durability and safety.

Recommendations for Future Research:

- Future research should explore the various methods of bamboo fiber extraction, such as mechanical, chemical processes, and the subsequent effects of these different approaches on the durability and mechanical properties of bamboo fiber reinforced concrete (BFRC).
- It is recommended to conduct long-term studies on the mechanical properties of BFRMC, including its behavior under thermal loading and dimensional stability (shrinkage).
- Future research should investigate how different environmental factors, such as temperature, humidity, precipitation, and exposure to UV radiation, affect the physical, mechanical, and durability properties of bamboo fiber metakaolin concrete.

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APPENDIX

Appendix A: Mix design of conducted C-25 concrete according to ACI 211

Step 1: Calculating the required mean compressive strength based on the characteristic strength of 25 Mpa. which gives; fck = f'ck + 8.5 = 25 + 8.5 = 33.5 Mpa

Table A.1 Average Compressive Strength Conversion

Characteristics strength (f'ck, Mpa	Mean strength (fck, Mpa)
< 21	F'ck + 7
21-35	F'ck +8.5
>35	1.1 x F'ck + 5

Hence, by referring the above table our average compressive strength become

fck = f'ck + 8.5 = 25 + 8.5 = 33.5 Mpa

Step 2: Determining the minimum cement content

From a durability point of view, the minimum cement content was taken as 300 Kg/m3.

Step 3: Choose a slump Value

It is recommended to use concrete with a slump of 3-10 cm for C-25

Step 4: Choose the maximum aggregate size.

For higher compressive strength, a reduced maximum size aggregate was selected; in this case, the maximum size aggregate was 20mm, and the nominal size aggregate was 19 mm.

Step 5: Mixing water and air content determination

The Amount of Water per unit volume of Concrete required for the required slump value depends on aggregate grading, amount of entrained air, and maximum size aggregate.

Table A.2 Mixing water for different slumps and Maximum size aggregate

Slump (cm)	Water (Kg/m3) of concrete for indicated maximum size aggregate in mm							
	10	12.5	20	25	40	50	70	150
	Non-air entrained Concrete							
3 - 10	205	200	185	180	160	155	145	125
8 - 10	225	215	200	195	175	170	160	140
15 - 18	240	230	210	205	205	185	180	170
Amount of entrapped Air (%)	3	25	2	15	1	0.5	0.3	0.2

In Table A.2 above, with a slump of 3-10 cm and a maximum size aggregate of 20 mm, the water content becomes 185 Kg/$\boldsymbol{m3}$ And 2%, or 20 liters, and entrapped air.

Step 6: Determine the water-cement ratio

In a concrete mix, the water-cement ratio is the Weight of Water to the Weight of cement.

Table A.3 Average Compressive Strength with Water Cement Ratio

Compressive strength at 28 days (Mpa)	Water cement ratio (by mass)
45	0.38
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69
15	0.79

In the case of concrete with a mean strength of 33.5 MPa, the ACI table above cannot provide a precise water-cement ratio. It can be calculated by interpolating the above and below values: 33.5 MPa.

35 0.47

33.5 x

30 0.54, by interpolation,

$33.5 - 35 / 30 - 35 = x - 0.47 / 0.54 - 0.47$

x=0.491 Hence, the minimum water-cement ratio is 0.491

Step 7: Determination of mix cement content

Cement content = water content/ water cement ratio= 185/ 0.491 = 376.78 Kg/m3 ≈ 377kg/m3

Since the mix cement content is higher than the minimum cement use.

Step 8: Estimating the Bulk volume per unit volume of Concrete

Concrete's bulk volume per unit volume depends on the fineness modulus, which is 2.716, and the maximum size aggregate of 20 mm.

Table A.4 Volume of coarse aggregate per unit volume of Concrete

Maximum size of aggregate	The volume of coarse aggregate per volume of Concrete different fitness modules			
	2.4	2.6	2.8	3
10		0.5	0.46	0.44
12.5		0.59	0.55	0.53
20		0.66	0.62	0.6
25		0.71	0.67	0.65
40		0.76	0.72	0.7
50		0.78	0.74	0.72
70		0.81	0.77	0.75
150		0.87	0.83	0.81

In the above table, it was not possible to determine the bulk volume of dry-rodded aggregate directly. In the case of a 20 mm aggregate with a fineness modulus of 2.716, it is possible to calculate the fineness modulus by interpolation since it lies between 2.6 and 2.8.

2.6	0.66	by interpolation, 2.6-2.716/0.66-x= 2.716-2.8/x-0.62
2.716	x	solving equation, x = 0.637
2.8	0.62	

Hence, the dry volume of aggregate per volume of concrete is 0.637

Step 9: Calculate the Weight of coarse aggregate (WCA) per m3 Of Concrete.

WCA= bulk volume x bulk density of coarse aggregate

WCA= 0.637*1614.44 = 1028.139kg

Step 10: Determine the solid volume of coarse aggregate

The solid volume of coarse aggregate = WCA/Specific gravity= 1028.139/2.78= 369.834 Kg/m3

Step 11: Calculating the solid volume of cement, Water, and air

The volume of cement (VC) = Weight of cement / Specific gravity of cement

= 376.78/3.15= 119.612 Kg/m3

Volume of Water (VW) = 185 Kg/m3 ,Volume of Air (VA) = 20 Kg/m3

Step 12: Calculating the Volume of Sand

Solid volume of Sand = 1000 - (VCA + VC + VW + VA)

= 1000 – (369.834 +119.612 + 185 + 20) = 1000 – 694.446 =305.554 Kg/m3

Solid Weight of Sand = dry volume * specific gravity

= 305.554 * 2.6 = 794.4404 Kg/m3 ≈ 795kg/m^3

Step 13: Adjustment for moisture in the aggregate.

Adjust the proportions of fine & coarse aggregate and the mixing water quantity based on the surface moisture and absorption capacity in the aggregate. Both fine and coarse aggregates contain surface moisture; therefore their weights must be adjusted.

Thus, the weight of fine aggregate = 795 + 3. 31% (795) = 821.3145 kg ≈ 822kg

And, the weight of coarse aggregate = 1028.139 + 1.63% (1028.139) = 1044.898 ≈ 1045 kg

Similarly, the required adjusted amount of water will be calculated as follows:

Water from fine aggregate = 822 x (3.31-2.04) % = 10.45 kg

Water from coarse aggregate = 1028.139 x (1.84-1.63) % = 2.16 kg

Therefore, the required adjusted amount of water= 185 – 10.45+ 2.16= 176.71 ≈ 177 kg

Final Mix Proportions

Table A.5: Ingredients for 1m3 C-25 Concrete

Ingredients	Cement	Fine Aggregate	Coarse Aggregate	Water	Bamboo
Quantity (Kg/m3)	377	822	1045	177	7.95
Ratio	1	2.18	2.78	0.47	

Appendix B: Tests for Materials

1. **Test on Fine Aggregate**

v. Silt content

The objective of this test is to determine the silt (finer than No. 200 sieve) content in sand.

Test results: A = 10ml, B = 290ml

Where: A = amount of silt deposited above the sand, B = amount of clean sand Calculation:

Silt content (%) = $A\ B * 100\ Silt\ Content$ (%) = 10 290 X 100 = 3.45 < 6 …. . OK!

According to the Ethiopian Standard, if the silt content of the sand is more than 6% it is recommended either to wash or to reject the sand. The sand in this specific research can be used without washing since silt content is less than 6%.

vi. Sieve analysis

The objective of the test is to determine the particle size distribution of fine aggregates. Table A.1 and Figure A.1 below summarize the particle size distribution as per the Ethiopian Standard for the grading of fine aggregate.

Table 4.1: Gradation of the Fine Aggregate

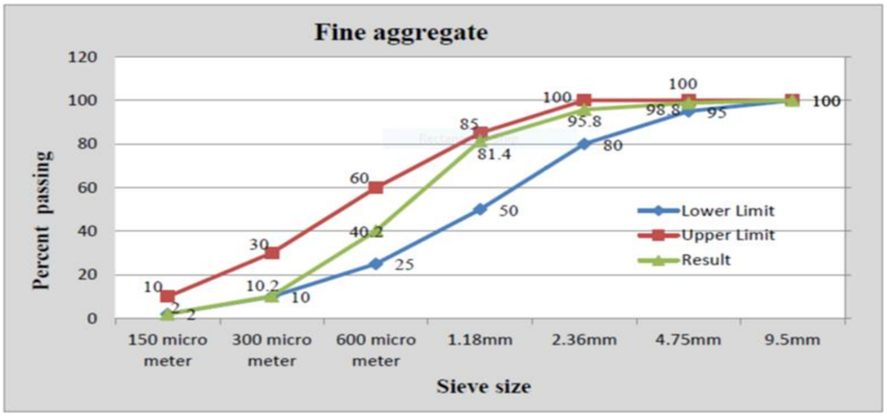
Fine Aggregate							
sieve size mm	wt. of sieve gm.	Wt. of sieve & retained gm.	wt. of retained gm.	%age retained	Cumulative coarse %	Cumulative passing %	standard Limit %
9.5							
4.75	427	433	6	1.2	1.2	98.8	95-100
2.36	387	402	15	3	4.2	59.8	80-100
1.18	374	446	72	14.4	18.6	81.4	50-83
600	326	532	206	41.2	59.8	40.2	25-60
300	302	452	150	30	89.8	10.2	10 to30
150	269	310	41	8.2	98	20	2to10
pan	254	264	10	2			
Total			500		271.6		

FM=∑Cumulative coarse%/100

FM = 271.6/100 = 2.71

Table 4.2: Gradation of Fine Aggregate as per ES (Dinku, (2002))

Sieve size	9.5mm	4.75mm	2.36mm	1.18mm	600 mic.m	300 mic.m	150 mic.m
percentage passing	100	90-100	80-100	50-85	25-60	30-10	10--0



Figure; Gradation curve for fine aggregate

vii. Specific gravity and absorption capacity

Results

A= 490, B= 1474.2, C= 1786

Bulk specific gravity, Bulk sp.gr =A/ (B+500-C) =490/ (1474.2+500-1786) =2.6

Bulk specific gravity (SSD), Bulk sp.gr =500/ (B+500-C) =500/ (1474.2+500-1786) = 2.66

Apparent specific gravity, Apparent sp.gr = A/ (B+A-C) =490/ (1474.2+490-1786) = 2.75

Absorption capacity, Absorption (%) = (500-A)/A= (500-490)/490 =2.04%

viii. Moisture content

The objective of this test is to determine the moisture content of fine aggregate.

Test results: A = 500 g, B = 484 g

Where: A = weight of original sample [g], B = weight of oven dry sample [g]

Calculation:

$w\ (\%) = (A - B)/B * 100$

$\boldsymbol{w}\ (\%) = \mathbf{3}.31\%$

2. Tests for Coarse aggregates

I. Sieve analysis

Sieve Analysis is a procedure for the determination of the particle size distribution of aggregates using a series of square or round openings starting with the largest. According to the Ethiopian Standard coarse aggregates are those between 75 and 4.75 mm in size.

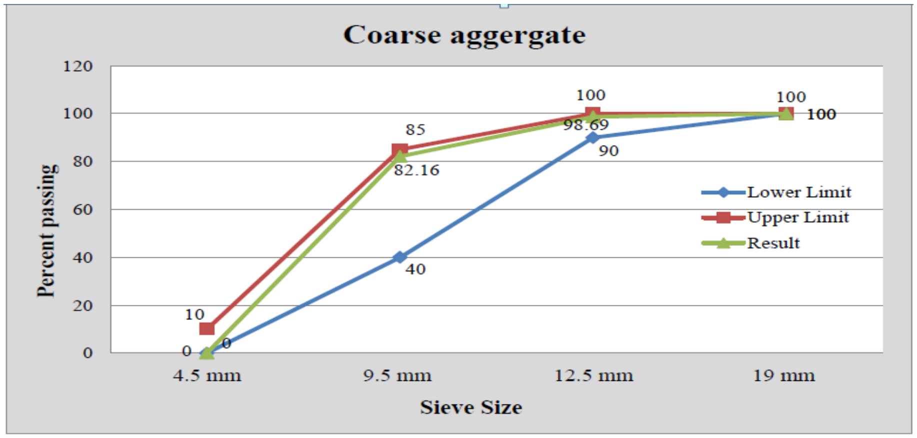
Test Results:

Table 4.3: Particle size distribution for coarse aggregate

Coarse aggregate						
sieve size mm	wt. of sieve gm.	Wt. of sieve & retained gm.	wt. of retained gm.	%age retained	Cumulative coarse %	cumulative passing %
37.5	1185	1185	0	0	0	100
19	1170	1190	20	1	1	99
12.5	1200	1870	670	33.5	34.5	65.5
9.5	1125	1705	580	29	63.5	36.5
4.5	1240	1940	700	35	98.5	1.5
pan	990	1020	30	1.5		
Total					197.5	

Fineness Modulus (FM) = ∑ (cumulative coarser /100)%

FM = ∑ 197.5/100 = 1.971%



Figure; Gradation curve for coarse aggregate

The aggregate for a specific use should satisfy the gradation requirement of the ES. Table below gives the percentages passing required as per ES.

Table 4.4: Ethiopian Standard for Grading of Coarse Aggregate (Dinku, (2002))

Nominal size of	Percentage passing through test sieves having square openings						
Aggregate, mm	75mm	63mm	37.5mm	19mm	13.2mm	9.5mm	4.75mm
38-5	100	_	95-100	30-70	_	10_35	0_5
19-5	_	_	100	95-100	_	25-55	0-10
13-5	_	_	_	100	90-100	40-85	0-10

II. Specific gravity and absorption capacity

The specific gravity of a substance is the ratio between the weight of the substance and that of the same volume of water. Absorption is the process by which water is drawn into and tends to fill the permeable pores in a porous solid body.

An approximate aggregate sample of 5kg was acquired, by using quartering from the mass sample. All aggregate materials passing N0. 4 (4.75 mm) sieve were rejected

Test Results: A = 4936 g, B = 5027 g, C = 3230 g

Where:

A = weight of oven-dry sample in air, [g]

B = weight of saturated-surface-dry sample in air, [g] and

C = weight of saturated sample in water, [g]

Calculation:

Bulk Specific Gravity

Bulk sp. gr = A /B – C, Bulk sp. gr = 4936 /5027 − 3230 = 2.78

Bulk Specific Gravity (Saturated – Surface –Dry basis):

Bulk sp. gr (SSD basis) = B/B-C, Bulk sp. gr (SSD basis) = 5027/5027 − 3230 = 2.8

Apparent Specific Gravity:

Apparent sp. gr = A/ A – C, Apparent sp. gr = 4936/ 4936 − 3230 = 2.89

Absorption Capacity:

Absorption Capacity: (%) = B – A/ A $*$ 100,

Absorption Capacity: (%) = (5027 – 4936/ 4936) x100 = 1.84%

III. Moisture content of coarse aggregates:

The objective of this test is to determine the moisture content of coarse aggregate.

Test Results: Where:

A = 2000 g A = weight of original sample [g]

B = 1968 g B = weight of oven dry sample [g], w = Moisture content (%)

Calculation:

w (%) = $(A-B)/B*$ 100 w (%) = (2000 – 1968)/ 1968 x100 = 1.63%

Comment: Aggregates were washed to remove dirt particles, and hence well dried in the sun. Moisture content and absorption capacity of coarse aggregate sample are used in concrete mix design to specify the amount of mixing water and water cement ratio.

IV. Unit weight of coarse aggregates

The unit weight measures the volume that the graded aggregate will occupy in concrete and includes both the solid aggregate particles and the voids between them. This method is applicable to aggregates of 40 mm maximum size.

Test Results:

Weight of the Measuring apparatus = 4841 gm.

Weight of sample + Measuring apparatus = 28054 gm.

Calculation:

Dimension of the measuring apparatus:

- Inside diameter = 253mm
- Inside height of the measure = 275mm

Volume of the measuring apparatus:

V= πD2/4=3.14*0.253^2*0.275/4=0.01382m^3

Unit weight of coarse aggregates = 28054 – 4841/ 0.01382 = 1679.67kg/m3

Appendix C: Detailed Test Results

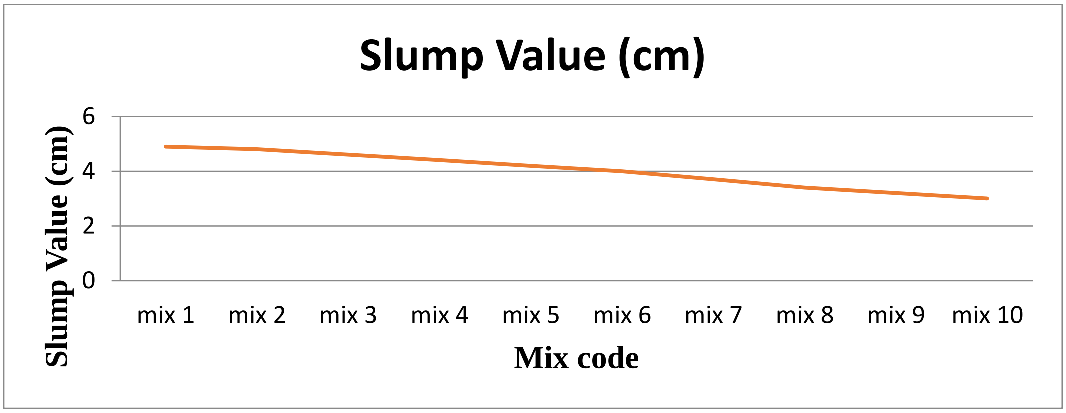


Figure: Workability of Bamboo Fiber Reinforced Concrete

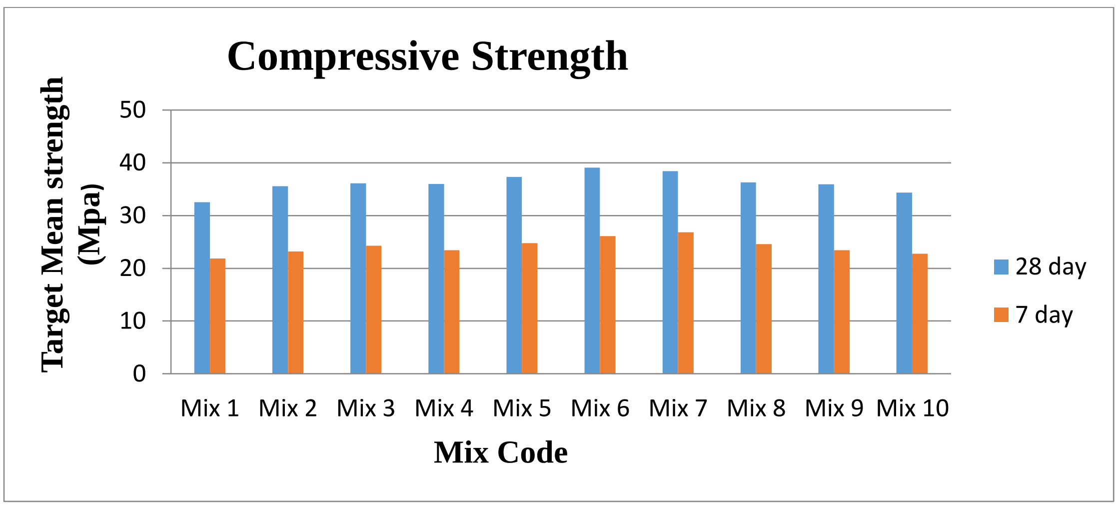


Figure: Compressive Strength of Bamboo Fiber Reinforced Metakaolin Concrete

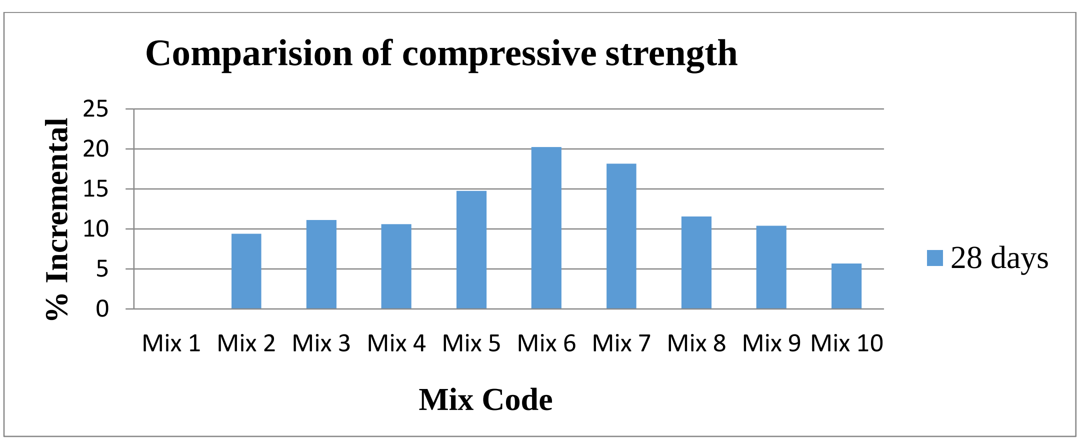


Figure: Compressive Strength Comparisons

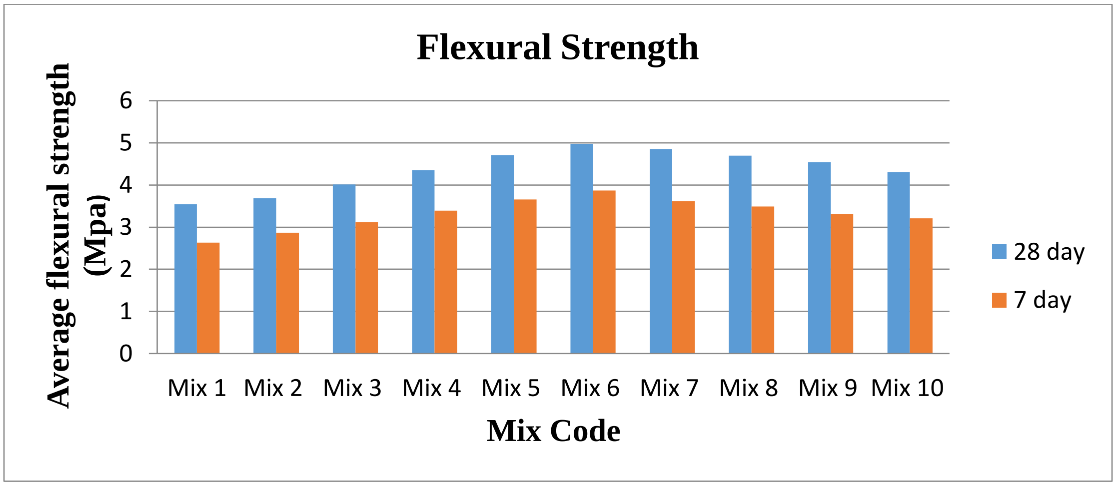


Figure: Flexural Strength of Bamboo Fiber Reinforced Metakaolin Concrete

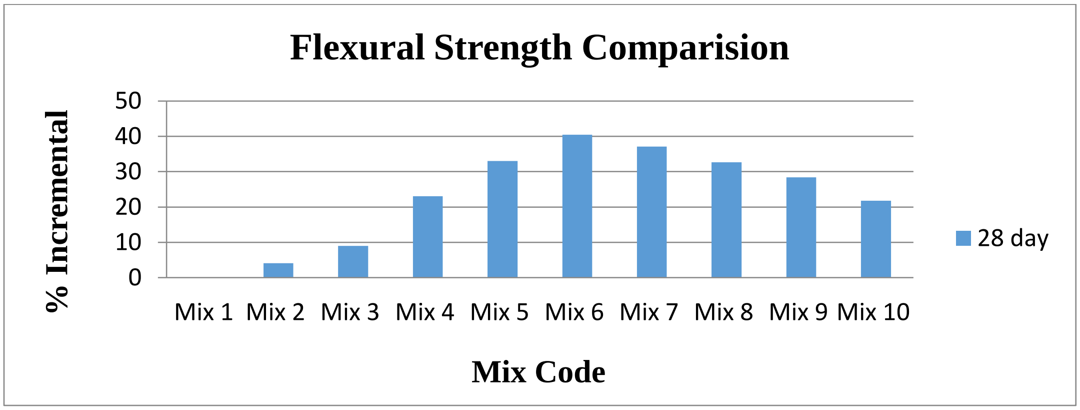


Figure: Flexural Strength Improvement

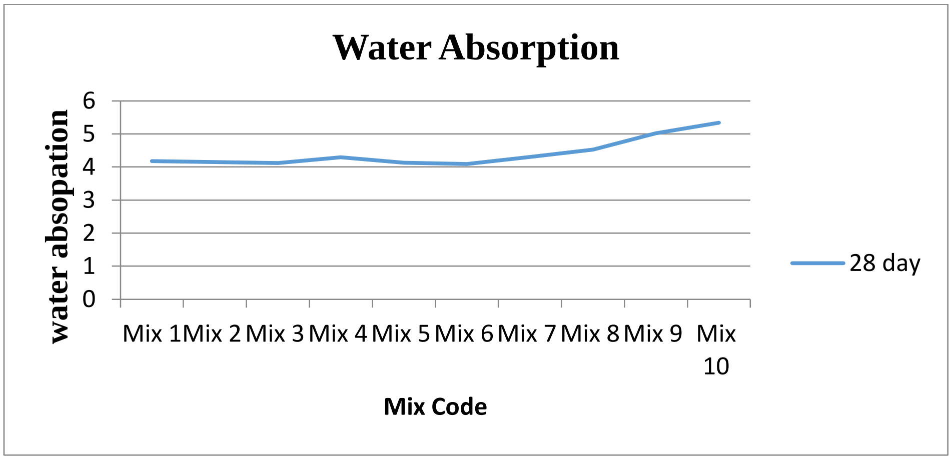


Figure: Water Absorption of Conventional and BFRM Concrete

Table: Sulfate attack and loss in percentage

Sulfate Attack and % of loss				
Mix Code	W1 (kg)	W2 (kg)	Wt. loss (kg)	% of loss
Mix 1	7.573	7.542	0.031	0.41
Mix 2	7.532	7.506	0.026	0.345
Mix 3	7.385	7.362	0.023	0.311
Mix 4	7.193	7.173	0.02	0.278
Mix 5	7.578	7.559	0.019	0.25
Mix 6	7.495	7.478	0.017	0.227
Mix 7	7.345	7.327	0.018	0.245
Mix 8	7.252	7.234	0.018	0.248
Mix 9	7.495	7.476	0.019	0.25
Mix 10	7.355	7.335	0.02	0.27

Appendix D Images from experimental work




AUTOMATIC COMP. STRENGTH
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