

Experimental Investigation on Morphological and Mechanical
Behavior of Glass Fibered Concrete with Partial Replacement of
Cement by Bentonite



Ethiopia Yirgawesen Yemariamwork

A Thesis Submitted to Department of Civil Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirements for the Degree
of Master's Science in Civil Engineering (Specialization in
Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

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Adama, Ethiopia

Experimental Investigation on Morphological and Mechanical
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DECLARATION

I hereby declare that this master thesis entitled “Experimental Investigation on Morphological and Mechanical Behavior of Glass Fibered Concrete with Partial Replacement of Cement by Bentonite.” is my original work, prepared under the guidance of Fikreyesus Demeke (Ph.D.). All sources of material used for organizing this research have been dually acknowledged by proper citation. Moreover, this work has not been submitted by any other person in any university or Higher Educational Institute for an award of a degree.

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LISTS OF ACRONYMS

ACI	American Concrete Institute
ASTM	American Standard for Testing Material
BN	Bentonite
F	Feldspar
FM	Fineness modules
GF	Glass fiber
GFRC	Glass fiber reinforced concrete
GGBFS	Ground granulated blast-furnaces slag
Gt	Giga tons
I	Illite
OPC	Ordinary Portland cement
Q	Quartz
LOI	Loss of ignition
M	Montmorillonite
MJ	Mega joule
Rep	Replacement
SCM	Supplementary cementitious materials
SSD	Saturated Surface Dry
STS	Split tensile strength
TAB	Thermally activated bentonite
XRD	X-ray diffraction

LIST OF CHEMICAL FORMULAS

Al_2O_3	Aluminum Oxide
$\text{Ca}(\text{OH})_2$	Calcium hydroxide
CaO	Calcium Oxide
Ca^{2+}	Calcium ion
Ca_3SiO_5	Alite
Ca_2SiO_5	Belite
$\text{Ca}_2\text{AlFeO}_5$	Ferrite
$\text{Ca}_3\text{Al}_2\text{O}_6$	Aluminate
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_3S	Tricalcium Silicate
CaCO_3	Calcium Carbonate
C-A-H	Calcium aluminat hydrate
C-H	Calcium hydroxide
C-S-H	Calcium Silicate Hydrate
CO_2	Carbon Dioxide
Fe_2O_3	Iron Oxide
H_2O	Water
K_2O	Potassium oxide
MgO	Magnesium Oxide
Na_2O	Sodium oxide
OH^-	Hydroxide ion
O_2	Oxygen
SiO_2	Silicon dioxide
SO_3	Sulfur Trioxide
TiO_2	Titanium dioxide

ABSTRACT

Glass fiber reinforced concrete is a type of concrete incorporates thinly chopped glass strand to improve the strength of concrete. For further enhancement of durability and sustainability pozzolanic materials used as cement partial replacement in concrete. Therefore, the current study aimed to investigate incorporation of glass fiber as a reinforcement agent and bentonite as pozzolanic supplementary cementitious material along with its effect on workability, compressive strength, flexural strength, split tensile strength and microstructure of concrete with its environmental and economic implications. The amount of glass fiber is determined by altering the glass fiber with 0.3%, 0.5%, 0.7% and 1% by weight of concrete material. Maximum compressive and flexural strength obtained at 0.5% addition of glass fiber as result 1.5 % increment in compressive strength and 29.4 % enhancement in flexural strength achieved. Then it hybrid with calcined bentonite calcined at 700⁰c which have silicon content of 65.34 %. The control mix was made from a mixture of cement, water, glass fiber, fine and coarse aggregate to attain 25 MPa according to ACI standard, whereas the replacement mix was made with 0.5% glass fiber and 5%, 10%, and 15% and 20% bentonite by the weight of cement. Maximum compressive strength obtain at 10%BN replacement which yield 3.94% improvement and the flexural strength improved by 0.88 after 56 day of curing. Therefor 0.5% GF with 10% BN taken as the optimal replacement amount to enhance both compressive strength and flexural strength. In micro structural analysis additional secondary cementitious materials called Pumpellyite observed due to the pozzolanic reaction between silicon in bentonite and calcium hydro oxide in cement. The SEM shows compacted dens and less cracked with high C-H and C-S-H amount in replaced mix. As conclusion, 0.5% glass fiber with 10% bentonite replacement of cement can collaborate together to enhance the strength of concrete while reducing the environmental impact of cement manufacturing and the replacement reduce initial production cost of glass fiber concrete by 3.72%.

Key words:- Glass fibered concrete, Bentonite, Compressive strength , Tensile strength, concrete morphology

1 INTRODUCTION

1.1 Back ground of the study

One of the largest industries in the world is the construction sector. (Pheng et al., 2019). Now a days most of construction structure are made of concrete accounting for 12 billion tone of concrete material produced annually.(Amran et al., 2022). Concrete consists of a hard, chemically inert particular substance known as an aggregate bonded by cement (Babor et al., 2009). High compressive strength, rigidity, and durability in typical environmental conditions are only a few desirable characteristics of concrete. However concrete is also fragile and tension-sensitive. Low tensile strength and low strain at fracture are the two main drawbacks of plain concrete. Reinforcement are typically used to address these problems (Chawla et al., 2013). These inherent flaws can be significantly improved using the idea of micro-level reinforcement or by adding different discontinuous chopped fibers to concrete (Yuan et al., 2021). Fibers like glass, carbon, steel, polypropylene, and aramid makes concrete stronger and more serviceable by increasing concrete's fatigue properties, impact resistance, tensile strength and loadbearing capacity after crack (Raval et al., 2017).

Fibers are divided into metallic and non-metallic categories based on the materials used to make them; metallic fiber include low carbon steel, stainless steel, galvanized iron, and aluminum. Mineral fibers are the other categories, such as glass, carbon, and asbestos. (Murthy et al., 2012). Various studies have shown that glass fibers can significantly improve engineering properties of concrete such as the split tensile strength, flexural strength, impact, fatigue and abrasion resistance, deformation capability, toughness and load bearing capacity after cracking (Alsayed et al., 2000; Benmokrane et al., 2002; Kene et al., 2012; Ruben et al., 2021; Shafei et al., 2021; W.-C. Wang et al., 2020). In this regard, reinforcing fiber applied in the current study is glass fiber, it is a well-known fiber that have great potential for concrete reinforcement because to its low specific weight, low water absorption, high elastic modulus, and high tensile strength (Kizilkanat et al., 2015).

In fiber reinforced concrete Cement is used as mineral glue to binds sand, coarse aggregate and glass fiber together (Habert et al., 2020). Yearly worldwide cement production is around 3.6 billion metric tons (J. Ahmad, Kontoleon, et al., 2022). Cement production

involves the consumption of large quantities of raw materials, energy and releasing a significant amount of solid waste and gaseous emissions which are harm full to the environment (Stajanča et al., 2012). Due to the aforementioned drawbacks, Supplemental cementitious materials (SCM) is often urged to utilize as cement substitute alternatives due to the environmental benefits achieved from their derivation from the waste stream and decrease in energy needed for their repurposing, and the conservation of raw resources.

Supplemental cementitious materials, such as soluble siliceous, alumino siliceous, or calcium alumino siliceous powders, have been successfully used in concrete over the years as partial replacements of clinker in cements or as partial replacements of portland cement in concrete mixtures (Juenger et al., 2019). The use of such materials do not require additional clinkering process, which result a significant reduction in CO₂ emissions per ton of cementitious materials. (Lothenbach et al., 2011). Pozzolans are silicate and aluminous based materials used as a supplementary cementitious material in concrete production. Pozzolan by itself possesses little or no cementitious value but in the presence of water chemically react with calcium hydroxide generated by hydration of cement to form additional cementitious products.(Aprianti et al., 2015). According to Wi et al. (2018), from those pozzolanic material bentonite is suitable to replace cement because it containing high amount of siliceous and aluminous content and shows excellent ability to reduce the alkali-silica expansion and yields almost equal strength to Portland cement at later ages . Bentonite is a clay that is usually formed by altering volcanic ash that is mostly composed of montmorillonite. According to Gilg et al. (2021), bentonite comes in three primary varieties: calcium bentonite, which has minimal swelling, high swelling sodium bentonite, and sodium-calcium bentonite, which has intermediate swelling. Various researchers have determined the appropriateness of calcined bentonite clay to use in the construction of concrete. A part from investigating the impact of such clay elements on the mechanical characteristics of concrete is delightful. In addition, chemical resistance of concrete to sulphate, carbonation, and chloride exposure as well enhanced (Andrade Perdreix et al., 2021). The use of bentonite clay may aid to maintain the compressive strength of concrete. The early-age compressive strength of the concrete with additional bentonite did not demonstrate a substantial improvement. However, it increases to a level that is much greater than that of the control concrete specimen when the specimen is aged longer. (Aravindhraj et al., 2016; Karthikeyan et al., 2015; Sarikaya et al., 2000; Sudheer et al., 2017), from another researches with the maximum

bentonite replacement mechanical performance of concrete decreased (Farhan Mushtaq et al., 2022; Lima-Guerra et al., 2014; Penson, 2019; G. V. K. Reddy et al., 2017; Sudheer et al., 2017). The reason behind is with a high percentage of bentonite replacement cement content is reduced since cement is the primary binding agent in concrete, and a reduction in cement content can lead to a decrease in compressive strength. The second reason is bentonite reduce the hydration rate, bentonite is a low-reactivity material and does not contribute significantly to the cement hydration process at early ages. The other reason is bentonite have a lower specific gravity than cement, which means that the overall density of the concrete can decrease with a high percentage of bentonite replacement. A reduction in density can lead to a decrease in compressive strength. In addition, those studies claims that bentonite based concrete needs more curing time to obtain strength.

By keeping those concepts in consideration this research was experimentally conducted by varying percentage of bentonite clay with fixed amount of glass fiber. The glass fiber content was independently determined to get the optimum amount to blend with bentonite. Their effect on workability, compressive strength, tensile strength, some durability characters, morphology and formation of hydration products are studied well.

1.2 Statement of the problem

Concrete have high compressive strength but low tensile force resistance due to small fissures microscopic cracks throughout its structure. These fissures lengthen when tensile pressures are applied to concrete it become elongated and eventually the concrete breaks apart. (Abdelrazik et al., 2020). Incorporating different reinforcing elements into concrete is a good option to maintain this issue. Recently, it was discovered that inclusion of hybrid fibers improve behavior of concrete. Like steel and polypropylene (Afroughsabet et al., 2015) bamboo and glass fiber (Mathew et al., 2022), steel carbon and palm fibers (Hidayat et al., 2021). Only a few researcher have conducted studies concerning hybrid fibers with pozzolanic materials to attain both economic and strength advantage of concrete because cement production and raw material extraction pose to the pre-existing ecosystem in extraction and manufacturing sites. There are two major hagridden situations with respect to sustainability. The first one is about 1.5 tons of raw materials are needed in the production of every ton of cement which is non-renewable. At the same time a high amount of carbon dioxide about one tone of CO₂ is released into the

environment to produce one ton of cement (K. Wang, 2004). It accounts approximately 7% of the world's CO₂ emissions annually (Amran et al., 2022). To make it cost-efficient and environmentally friendly, it is mandatory to use other materials as partial replacement of cement like bentonite. Large quantities of bentonite resources are available worldwide also in Ethiopia. Bentonite is hydride with different cementitious material such as bentonite with marble (Laidani et al., 2022), bentonite with gypsum (Tilak B et al., 2015), bentonite with glass powder (Al-Soud et al., 2022), bentonite with lime (Taher, 2003) Etc. However, still, there is limited knowledge of concrete properties resulting from using bentonite and glass fibers as a hybrid reinforcing and cementitious material. This study was done to fill the gap in knowledge of the effect of using hybrid bentonite as a cement and glass fibers as a reinforcement. The morphological behavior, mechanical property, and hydration process of concrete containing bentonite and glass fiber is not studied at all. In this experimental study, glass fiber was used as a reinforcing material to overcome the tensile resistance problem of concrete, whereas bentonite was used as a cement substitute to minimize cost of cement.

1.3 Objectives

1.3.1 General objective

The main objective of this research to conduct experimental investigation on morphological and mechanical behavior of glass fibered concrete with partial replacement of cement by bentonite.

1.3.2 Specific objectives

- 1) To assess physical and chemical characterization of concreting materials and bentonite.
- 2) To find the optimum percentage of glass fiber as a reinforcement additive and bentonite as a cement substitute to achieving the desire strength.
- 3) To analyze the effects of bentonite and glass fiber on morphology of concrete.
- 4) To evaluate cost effectiveness of partially replacing cement by bentonite and adding of glass fiber in concrete.

1.4 Significance of the study

This research gives new insight on the usage of bentonite as a supplementary cementitious material and ways to enhance the weak tensile properties of concrete by adding glass fiber, which is much cheaper than steel reinforcement. There are many diverse opinions regarding the use of bentonite clay as a cement substitute, but this knowledge is scattered, and no one can easily judge the suitability of bentonite as a binding material. Accordingly, this experimental research gives valuable information on the suitability of combining bentonite and glass fiber as a cementitious and reinforcing material by studying the physical, mechanical, durability, and morphological behavior of concrete made with bentonite and glass fiber. Moreover, give information on how to incorporate glass fiber and use bentonite in concrete works. On another stage, it paves the way for new researchers to investigate more, and for cement manufacturers, it indicates new sources of material for silica and alumina.

1.5 Scope of the study

The scope of this research work is limited to the following structural considerations: investigating mechanical properties like compressive and tensile strength and morphological behavior, including XRD and SEM image tests of C-25 concrete grade.

At the first stage, a preliminary test of the concrete is performed to determine the glass fiber content, which blended with bentonite. To get the optimum amount of glass fiber content, four different trials are taken: 0.3%, 0.5%, 0.7%, and 1% of glass fiber by percentage weight of concrete. Compressive strength and flexural strength tests are used as selection criteria. The bentonite is added to the concrete in percentage weights of 5%, 10%, 15%, and 20 percent of the cement weight. In addition, the amount of glass fiber added was constant 0.5% by weight of concrete, which was obtained from the preliminary test of concrete based on their flexural and compressive strength. The main experiment process includes collecting, preparing, proportioning, mixing, casting, curing, and investigating the effect on concrete. The tests that are conducted here are workability, compressive strength, split tensile strength, flexural strength, morphology, and mineralogical analysis.

1.6 Organisation of the thesis

The presentation of this thesis work is organized in five parts. The first part gives a brief description of thesis background, statement of the problem, objective of the research, significance of the study and scope of the study adopted. In the second section presents literature review on supplementary cementitious material and concrete reinforcing material as general. More over focus on bentonite clay as a cement replacement and glass fiber as a reinforcing ingredient also its effects on mechanical properties of fresh and hardened concrete and on morphology of concrete assessed on a previous work. The third section discuss the general experimental methodology that followed to conduct tests in ASTU construction material laboratory, biology laboratory, material engineering laboratory and at Addis Ababa geological survey institute. Detail procedures of the material preparation, mix proportions, mixing process, and workability tests, casting process and curing process of various concrete mixes used in this investigation is presented. The fourth section consists the test result and discussion. The last section presents conclusions and recommendations depending on this research finding.

2. LITERATURE REVIEW

2.1 Introduction

The general purpose of this chapter is to provide an extensive review of recent papers and knowledge regarding fiber-reinforced concrete and cement replacement mechanisms and alternatives in concrete. Moreover, it focuses on reinforcing concrete with glass fiber and replacing cement with bentonite. The studies analyzed in this review had to meet specific criteria that included relevant information in the area to identify research gap and to determine the research methodology. The eligible works were searched through databases like Scopus, Google Scholar, and Research Gate. First, titles and abstracts were taken into consideration, and afterward, the full paper was examined for suitability. Finally, from selected articles, the appropriate data were extracted and subjected to further analysis. From around 123 references, including articles, conference papers, and books, almost 85% were published between 2000 and 2022.

2.2 General over view about concrete

The most popular building material is cement concrete because of its exceptional qualities, including strength, longevity, mold ability and resilience to high temperatures (Z. Li et al., 2022). In order to replace cement or aggregate in concrete, a variety of industrial wastes, agricultural wastes and natural minerals can be recycled and incorporate (Chinnu et al., 2021). This comprises materials like waste glass, fly ash, rice husk ash, ground vehicle tires, granulated blast-furnace slag, maize cob, etc. (Pellegrino et al., 2019). Environmental effects from the manufacture of cement can be greatly reduced by using recycled materials or supplementary cementitious materials. The quantity of cement decreased by using these ingredients, and the quality of the construction is not affected. Thus, the strength of concrete is dependent on the strength of the aggregate matrix bond and the hydration product of cement. The entire mass of the concrete is deposited or placed in a plastic state and almost immediately begins to develop strength a process under proper curing conditions may continue for years. The disadvantage of concrete in construction industry relative to other construction materials is its weakness in tensile strength, poor crack resistance, low flexural strength, weak plastic deformation capacity, and brittle character. The tensile response of conventionally reinforced concrete improved only in the one direction of the reinforcement (Yoo et al., 2019).

2.3 Ingredients of concrete

2.3.1 Aggregates

Aggregates are the filler component of concrete, accounts for a sizable amount of the concrete volume roughly 70–75 percent. Aggregate can be found in both natural and manmade sources. Natural aggregate taken from quarries without changing their nature with the exception of crushing, size, or grading during production (John et al., 2018). Aggregates are often described using words like:

- 1 Fine aggregate- aggregate particles passing 4.75mm sieve and retained on 75- μ m sieve.
- 2 Coarse aggregate- aggregate predominantly retained on the No.4 (4.75mm) sieve.

2.3.2 Water

Water has two purposes in production of concrete. First it makes the mixture fluid and workable then triggers cement to hydrate. It's critical to use clean water since contaminants weaken the bond between the paste and aggregate. Concrete should be produced using water that is safe to drink (Kucche et al., 2015). Water with a noticeable taste or odor should not be used until it is tasted for organic impurities. Impurities in mixing water cause any one or all of the following:- abnormal setting time, decreased strength, volume changes, efflorescence, corrosion of reinforcement.

2.3.3 Cement

Usually ordinary Portland cement is specified for general concrete construction work. Portland cement is primarily made of calcium and aluminum silicates, which react with water to generate a new chemical capable of giving stone-like qualities. Setting and hardening are caused by hydration, which is a chemical reaction between the cement components and water that produces submicroscopic crystals or a gel-like substance with a large surface area. Cements even set and solidify in water due to their hydrating qualities.

2.4 Fiber reinforced concrete

2.4.1 Introduction to reinforced concrete

Fiber Reinforced Concrete (FRC) is a composite material that contains short discontinuous fiber material that is equally dispersed and randomly orientated to strengthen the structural integrity of concrete (Ravikumar et al., 2015). Steel fibers, glass fibers, synthetic fibers, and natural fibers

are examples of fibers. When compared to lengthy fibers, these short fibers are incredibly thin and numerous. This allows them to more efficiently bridge micro fractures. With stress, these micro fractures expand into bigger macro cracks; in this case, the hooked-end fibers bridge the micro fissures more efficiently and prevent from failure (Ravikumar et al., 2015).

Fibers are also utilized in concrete to prevent cracks caused by plastic and drying shrinkage. They also lower the permeability of concrete with less water bleeding (Yousefieh et al., 2017). In the underground construction fiber reinforced concrete has totally replaced bar, such as in tunnel segments, where practically all tunnel linings are fiber reinforced rather than rebar reinforcements. Some fibers do, in fact, diminish the compressive strength of concrete (Li et al., 1992). The amount of fibers added to a concrete mix is stated as a percentage of the composite's total volume, which is known as the "volume fraction" (V_f). V_f is normally between 0.1 and 3% (Ravikumar et al., 2015).

Individual fiber slenderness is measured by the fiber aspect ratio. It is calculated by dividing the fiber length by the equivalent fiber diameter for each individual fiber. The aspect ratio of fibers in concrete can range from 40 to 1000, but is normally better to be less than 400. This value is also used to calculate fiber stiffness (Thomason, 2023). If the modulus of elasticity of the fiber is greater than that of the matrix concrete or mortar binder, they aid to carry the load by enhancing the material's tensile strength. Increasing the aspect ratio of the fiber typically segments the matrix's flexural strength and toughness (Klyuev et al., 2019). It is advisable to utilize fibers that are longer than the aggregate's maximum size to guarantee that each fiber strand is effective, However, fibers that are too long and not properly treated at time of processing tend to "ball" in the mix and create workability problems (Abdelrazik et al., 2020).

2.4.2 Types of Fiber reinforced concrete

FRC is a composite material composed of hydraulic cements, water, fine and coarse aggregate, and dispersed discontinuous fibers. The length of conventional fiber ranges from 0.2 to 2.5 inches. ASTM C116/116M specifies four categories of FRC.

Type I Steel Fiber reinforced concrete:- employs steel bars that are put into the fresh mortar or concrete, which needs a large deal of prep work but allow for a considerably stronger concrete (Kaur et al., 2017). This confers the concrete with enhanced structural strength, prevents

cracking and helps defend against extreme cold. Steel fiber is commonly used in combination with rebar or one of the other fiber types (Van Chanh, 2004).

Type II is Glass Fiber reinforced concrete:- Glass fibers ranging in length from 10mm to 50mm and their diameter is in microns and can be added up to 5% by volume of concrete and premixed with cement and water. The glass fiber insulates the concrete while also strengthening it. Glass fiber also aids in the prevention of cracking in concrete owing to mechanical or thermal stress (Ragavendra et al., 2017). Furthermore, unlike steel fiber reinforcement, glass fiber does not interfere with radio transmissions. It has a very high tensile strength of 1020 to 4080 N/mm² and E-glass fiber has comparable endurance and durability from other glass fiber types (Kaur et al., 2017). Glass fibers in concrete are utilized to create lighter, more contemporary constructions such as architectural claddings on buildings and for under ground tunnel works.

Type III Synthetic Fiber reinforced concrete:- Synthetic fiber-reinforced concrete include plastic and nylon fibers to increase concrete tensile strength. While they are not as sturdy as steel, they do aid the cement pump ability by keeping it from being stuck in the pipes. Synthetic fibers do not expand in hot weather or compress in cold weather, which helps to avoid cracking. Finally, synthetic fibers aid in the prevention of concrete spalling after impacts or fires (Wilson et al., 2014).

Type IV Natural Fiber reinforced concrete, historically, fiber-reinforced concrete have used natural fibers, such as hay or hair such as bamboo, coir, jute, sisal, wood, sugarcane bagasse. While these fibers help, the concrete's strength they can also make it weaker if too much is used. In addition if the natural fibers are rotting when they are mixed in then the rot can continue while in the concrete. This eventually leads to the concrete crumbling from the inside, which is why natural fibers are no longer used in construction (Ragavendra et al., 2017).

2.4.3 Glass fibered concrete

Glass fiber reinforced concrete (GFRC) is a type of concrete that incorporates glass fibers into the mix to enhance its strength and durability. The glass fibers are typically made of alkali-resistant glass, which is designed to withstand the alkaline environment of the concrete mix. GFRC is typically made by mixing cement, sand, water, and glass fibers together. The resulting mix is then poured into molds and allowed to cure. GFRC can be cast into a wide range of shapes

and sizes, making it a versatile material for architectural and decorative applications (Benmokrane et al., 2002).

GFRC has several advantages over traditional concrete the first one is strength addition of glass fibers to the mix improves the tensile strength of the concrete, making it less prone to cracking and more durable. GFRC is lighter than traditional concrete, which makes it easier to handle and install. GFRC can be cast into a variety of shapes and sizes, allowing for a greater degree of design flexibility. It is also highly resistant to weathering and can withstand exposure to the elements without deteriorating. another advantage is fire resistance GFRC is non-combustible and can be used in fire-resistant construction. Overall, GFRC is a versatile and durable material that offers many advantages over traditional concrete, making it a popular choice for architectural and decorative applications (Senthil Kumar et al., 2014).

2.4.3.1 Chemical composition of glass fiber

Glass fiber is a yarn or thread that is made from molten glass with a certain composition. Glass fibers are mostly comprised of silica, calcium, aluminum, sodium, boron, magnesium, and iron oxide (Amer et al., 2018). It is known that the uses of glass fibers in composite materials are based on chemical reactions that result in distinct composites with favorable or unfavorable properties. For example, zirconium dioxide (ZrO_2) can be added to the mixture before melting and fiberizing the raw materials to make the glass fiber more resistant to the lime created when setting the Portland cement. These zirconium-containing glass fiber architectures are known as Alkali-Resistant (AR) glass fibers (Lalinde et al., 2022).

Table 2.1 shows the oxide percentage for different types of common and commercial glass fiber materials. For instance, E-glass, which was primarily used for electrical applications and was composed of Al_2O_3 , SiO_2 , CaO and MgO , was initially developed as an alkali-resistant substitute for soda lime glass. In addition, the high-strength S-glass fibers are composed of aluminium oxide and magnesium oxide, and a high concentration of silica, which increases its tensile strength (Chawla et al., 2013).

Table 2.1 Chemical compositions of different glass fiber types

Type of GF	Percentage composition (%)						
	SiO ₂	Al ₂ O ₃	B ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O
A	67.5	3.5	1.5	6.5	4.5	13.5	3
C	64.3	4.1	5	11.4	3.3	9.6	0.5
D	74	1.2	22.5	-	-	1.5	2.0
E	55	14	7	22	1	0.5	0.3
R	60	24	0.3	9	6	0.5	0.1
S	65	25	-	-	10	-	-
ECR	58.2	11.6	-	21.7	2.0	0.1	0.2
AR	61	1.0	-	5	1	1.4	3

2.5 Previous Studies on glass fiber as a concrete reinforcing material

Many researcher perform studies on glass fiber concrete this review portion included crucial concrete characteristics including fiber content, flow ability, crack limitation and shrinkage, compressive, flexural, and tensile property of concrete investigated by previous researchers.

2.5.1 Fiber content

The quantity of fiber added to a concrete mix is expressed as a volume fraction (vf) of the total volume of the composite concrete. (Vf) is commonly 3% to 10% by volume of concrete. and increased the tensile strength by roughly two times, and the impact resistance by about 10 times. When the fiber content is measured in terms of weight ranges from 0.1 to 3% by weight of concrete (Ravikumar et al., 2015). Further, the mixture constitution and the type of concrete grade influences the maximum possible fiber amount (El-Dieb et al., 2012). Moreover, for concrete with higher fiber consumptions, the fibers tend to form balls during the mixing process, thus the desired workability of FRC cannot be easily obtained (Jiao et al., 2019). Although fiber kinds and aspect ratios have a large effect on fiber content, all slump values reduced as fiber content increased. According to the study Alsayed et al. (2000), the study revealed that the flexural capacity of concrete beams reinforced by different amount of glass fiber can be accurately estimated using the ultimate design theory. the flexural capacity of concrete beams reinforced with varying amounts of glass fiber may be reliably calculated using the ultimate design theory.

2.5.2 Slump Flow

Laura et al.(2002), reported that when he compared the slump of glass fibered concrete to the slump value of plain concrete, there was no discernible decrease in slump when the glass fiber dose reached till 0.5%.The droop of concrete slump was only approximately a fifth of that of ordinary concrete when the fiber dose was increased to 1.0%. The variations in workability were less prominent when GF reinforced mortar mixes were utilized. Slump flow by another study found that slump flow for fiber reinforced mixes was 97%, 95%, and 92% when compared to plain concrete for additions of 0.5%, 1%, and 1.5% glass fiber (Sanjeev et al., 2020). Song et al. (2005), Was revealed that short length fibers have a lesser flow ability than longer length fibers. Fibers with a shorter length have a bigger surface area, which improves the binding of fiber cement paste. The slump flow of glass fiber-reinforced concrete was somewhat greater than that of nylon fiber-reinforced concrete. In addition, because glass fibers are less ductile, they give more resistance to concrete flow, resulting in less workable concrete (J. Ahmad, González-Lezcano, et al., 2022).Slump values rose at a scope of 5-10 mm, and workability dropped as the fiber dose increased, with 1.5 percent fiber prescription having the lowest flow value.

2.5.3 Compressive Strength

Most researchers agreed up on that glass fibers have a negligible impact on the compressive capacity of concrete. The use of glass fibers boosted the final, binding strength of concrete (Alsayed et al., 2000; Chawla et al., 2013; George et al., 2019).

According to Abdollahnejad et al. (2017), they stated that with the increase in fiber length, the reduction of compressive strength was greater. Regarding to Fang et al.(2018),the early age strength of mixture with GF exhibited higher values than plain mortars. Findings by the other authors shown that GFRC behaved comparable or in many cases significantly better compressive strength than plain concrete. As conclusion, less or negligible percentage improvement of compressive strength can be obtained when we add glass fiber in concrete. Furthermore, in many cases, the positive influence of simultaneous incorporation of two types of fibers on compressive strength of concrete instead of one was highlighted (Ganta et al., 2020; Liu et al., 2019).

2.5.4 Crack Limitation and Shrinkage

According to different researchers GF were able to limit shrinkage cracking, change the failure mode into multiply cracking, as well as decrease crack width. In inclusion of GF the maximum crack width decreased from around 2 to 12 times depending on the number of fibers (Abdollahnejad et al., 2017; Jiao et al., 2019; Kene et al., 2012; Lalinde et al., 2022; Murthy et al., 2012). Similarly, regarding average crack width, the enhancements were even more significant and the best performance was obtained with 1.3 % of GF the crack was about 0.15 mm wide which gave 27 times smaller value compared with PC (Enfedaque et al., 2010). According to Rahmani et al. (2012) The plastic shrinkage test results performed in revealed that the maximum and average crack width for GFRC was equal to 1.123 and 0.379 mm which was 57 and 50% less than PC, respectively. Furthermore, the total crack area underwent a reduction since it decreased from 253.90 mm² for PC to 109.24 mm² for GFRC, decreased by 57%.

2.5.5 Splitting tensile and flexural strength

The examination of failure pattern in tensile load unlike conventional concrete GFRC specimens did not separate out after first cracking. This improvement can be attributed to the enhanced ductile behavior provided by the fiber. It was noted that fiber addition also resulted in an increase in the splitting tensile strength of concrete. The highest splitting tensile strength observed for GF was 27% at 0.75% fiber inclusion. Study by Kizilkanat et al. (2015), reported that the addition of GF to concrete and mortar increased the splitting tensile strength by up to 12.5% and 17% for concrete and mortar respectively.

Kene et al. (2012), conclude that the increase in GF content increased the splitting tensile strength of concrete up to about 24%. The increase was attributed to the bridging action of the fibers across the cracks which restrained the propagation of micro cracks at the inception only. The stress is transferred to the bridging fibers after the flexural failure, which contains the crack propagation for some time and thus splitting tensile strength is enhanced. However, no significant increase in strength was observed after 0.50% dosage of GF.

The mechanical performance of glass fibered concrete depends up on the fiber content and concrete grade some of mechanical test results from different researchers is summarized below in table 2.2

Table 2.2 Summary of Mechanical performance of concrete with Glass Fibers

Reference	Glass fiber content	Compressive strength	Split Tensile Strength	Flexure Strength
Ali et al. (2019),	0 %	38.94	3.14	3.58
	0.25 %	42.71	3.57	4.59
	0.5 %	42.26	3.71	4.47
	0.75 %	41.46	3.65	4.39
(Kizilkanat et al. (2015),	0 %	33	3	5
	0.25 %	32	3.5	6.5
	0.5 %	32	7.7	6.5
	0.75 %	37	3.8	6
	1 %	34	3.4	6.3
Sivakumar et al. (2017)	0 %	72	5.7	5.9
	0.3	68	6.1	6.3
	0.5 %	66	6.2	6.6
	0.7 %	52	6.5	6.7
Ali et al. (2020),	0 %	34		3.6
	0.25 %	35		4.2
	0.5 %	37		4.9
	1 %	35		4.8

2.5.6 Morphological properties of concrete with glass fiber

The concrete structure consists of three components: cement paste, pore structure, and the interfacial transition zone between the cement paste and aggregates. It has a heterogeneous microstructure. Improving these three components enhances the mechanical strength and durability of concrete. Based on reviewed research, the scanning electron microscopic test was conducted after 28 days of curing as per ASTM C1365-18, which shows a good-quality bond is present between binder matrix, aggregate, and glass fiber. Yet, in control sample clear cracks in the binder matrix can be noted but they blocked in fiber reinforced concrete. The SEM images of the concrete sample with glass fibers identify multi-phase, multi-interface, and multi-element composite material, glass fiber-reinforced concrete behavior mostly relies on the properties between the binder matrix and the glass fiber. The binder matrix and glass fiber are very strong

bonded, which can be clarified by the fact that glass fiber has improved hydrophilicity and mineral fiber material. The quality of bonding between binder-matrix and glass fibers provides enhanced strength and reduced the water absorption of the concrete. This is also because glass fibers played a filling role and decreased the concrete porosity leading to denser and less porous concrete (Zaid et al., 2021).

2.6 Hybrid effect of glass fiber with supplementary cementitious material in concrete

Aside from compressive strength, one of concrete's most crucial characteristics is durability and economic effectiveness. Many researchers are now working to build concrete that is stronger and more durable by including fibers and other cementitious materials including fibrous material improves the structural stability of concrete. A recent study displays that the stresses like tensile and shear that emerge at a various cross-section of concrete might be reduced by strengthening concrete with glass fiber. Thus, the successful usage of agricultural wastes, natural cement supplementary material and industrial waste with combination of glass fiber as a substitute of cement contributes to the preservation of depleting resources which is non-renewable, decreases utilization of energy, and also decreases the expenses of construction materials. researchers has utilized a few scrap matters in concrete, with supplementary cementitious material which are hydride with glass fiber like fly ash and glass fiber (Ali et al., 2018), silica fume and glass fiber (Zaid et al., 2021), metakaolin with glass fiber (Sivakumar et al., 2017) and GGBFS and glass fiber (Qu et al., 2021). Moreover, coconut shell and rice husk ash hybrid with glass fiber (Patil et al., 2022) to deliver better concrete in terms of cost as well as strength. From those concrete containing glass fiber and fly ash have reported to exhibit excellent mechanical and durability properties. Nevertheless, reviewer cannot get research on glass fiber and bentonite combination.

2.7 Replacement of cement by pozzolanic materials in a concrete

2.7.1 Introduction

Cement plays the role of a binder by forming reaction then sets, hardens, and might bind alternative materials along. But cement have negative impact on environment also in economy because it uses huge amount of energy during production the theoretical minimum energy use for dry production process of cement is 1.76 GJ per ton of cement while a wet kiln uses 5.3 to

7.1 GJ per ton of clinker (Taylor et al., 2006). The energy costs to produce cement constitute 50-75% of cement costs. Which make cement expensive and needed to be replaced by pozzolanic supplementary cementations materials. Pozzolanic materials are siliceous or aluminosilicates compounds, thus potentially exhibiting pozzolanic reactivity, aluminium and silicone in pozzolanic material react with calcium hydroxide generated by hydrating cement to form additional cementitious materials (Dodson, 1990) like calcium aluminosilicates hydrate (C-A/S-H). Owing to the additional C-A/S-H formed, which arise from the pozzolanic reaction. Cement replacement with pozzolanic SCM leads to strength enhancement but typically at later ages, regardless of the type of cement. The pozzolanic products also help in the refinement of capillary porosity, as well as the reduction in its inter connectivity, which improves durability (M. C. Juenger et al., 2019).

2.7.2 Properties of the main compounds in cement clinker

In the manufacture of Portland cement, the raw materials are ground then mixed to produce the desired proportion of minerals, and burned in large kiln. The temperature in the kiln reaches about 1200°C -1500°C. This drives off water and gases to produce new chemical compositions called clinker (Gao et al., 2016). The four major compounds of cement produced in the kiln are:

1. CaO. SiO₂ (Tri calcium silicate), abbreviated as C₃S
2. CaO. SiO₂ (Di calcium silicate), abbreviated as C₂S
3. CaO. Al₂O₃ (Tri calcium Aluminate), abbreviated as C₃A
4. CaO. Al₂O₃. Fe₂O₃ (Tetra calcium Alumino ferrite) abbreviated as C₄ AF

The relative amounts of these four chemicals in the final product varies the desired properties of cement such as rate of hardening, amount of heat given off, and resistance to chemical attack.

The four major compounds that exist in cement clinker are the following :- the first one is C₃S (Tri calcium Silicate) also known as alite, is the primary phase of Portland cement that sets and develops early strength because it hardens quickly when water is introduced to it. This quick reaction results in the following $2\text{Ca}_3\text{SiO}_5 + 6\text{H}_2\text{O} \rightarrow \text{C-S-H} + 3\text{Ca}(\text{OH})_2$ (Gartner et al., 2002) Water needed for hydrating the cement is about 25% of the mass of cement The range of C₃S is between 25 and 60%.

The second mostly abundant compound is C₂S (Di calcium Silicate) or Belite hardens slowly & contributes to strength increase at ages beyond one week. Belite reacts with water to form calcium silicate hydrates (C-S-H) and portlandite (Ca(OH)₂) (M. Juenger et al., 2011) according to the reaction $2\text{Ca}_2\text{SiO}_4 + 4\text{H}_2\text{O} \rightarrow 3\text{CaO} \cdot 2\text{SiO}_2 \cdot 3\text{H}_2\text{O} + \text{Ca}(\text{OH})_2$

C₃A (Tri calcium Aluminate) is also an other main component of cement which liberate a large amount of heat (heat of hydration) during the first few days of hardening. About 50% of the total heat of hydration is released in the first three days. It contributes little to early strength development. Tri calcium aluminate hydrates with water to form a hydrated tri calcium aluminate $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$. (C-A-H) If gypsum is added it acts as a retarder, and the heat of evolution is less and the setting occurs more slowly. The proportion of C₃A ranges from 5-15%(Gartner et al., 2002).

The last but not the least clinker compound is C₄AF (Tetra calcium Alumino ferrite) that is actually not a compound that aids in the strength of cement. During hydration reaction of cement, it forms a hydrated iron oxide gel in a fast reaction producing enough heat but the reaction slows down once calcium alumino ferrite crystals are formed (Bullard et al., 2011). The proportion of C₄AF ranges from 8-15%

Table 2.3 Characteristics of four compounds of cement clinker

Characteristics	C ₃ S	C ₂ S	C ₃ A	C ₄ AF
Rate of hydration	Medium	Slow	Fast	Slow
Early Strength	High	Low	Medium	Low
Ultimate Strength	High	High	Low	Low
Amount of heat liberated	Medium	Low	High	Low
Resistance to chemical attack	Good	Good	Poor	Good

2.7.3 Portland Pozzolana Cement (PPC)

Portland-pozzolana cement is formed by combining 10–30% by weight of pozzolanic material with ordinary Portland cement, either by simple mixing or through intergrading with cement clinker (Surahyo et al., 2019). The word "pozzolana" refers to naturally occurring and synthetic materials that, by themselves, have little to no value for cementation but, in the presence of moisture, chemically react with calcium hydroxide to produce compounds having cementation

capabilities. The pozzolana slowly mixes with the calcium hydroxide released during the hydration of the cement to create cementations property, which contributes to the concrete's water tightness and long-term strength growth (Fernandez et al., 2011)

2.7.4 Concrete Containing Pozzolan Materials

According to ASTM C618, Natural pozzolans and synthetic or artificial pozzolans are the two main categories of pozzolan materials.. The basic difference between the two groups is that the former do not need any treatment except grinding. Whereas the latter are either obtained by the heat treatment of materials with no or very little pozzolanicity or as industrial by-products which experienced high temperatures.

ASTM C618, Standard Specification for classification of pozzolan presented below:-

1. Class N is for raw or calcined natural pozzolans, such as some diatomaceous earths; opaline cherts and shales; tuffs and volcanic ashes or pumicites, calcined or unclaimed; and various materials requiring calcinations to induce satisfactory properties, such as clays and shales.
2. Class F is for fly ash that has pozzolan and not cementations properties.
3. Class C is fly ash that has pozzolan properties and some cementitious properties.

ASTM C618 have four chemical requirements that should be met when evaluating a proposed pozzolan such as calcined bentonite clay. To meet the class N requirements the oxides $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ must sum to a minimum of 70% of the components.

The loss of mass on ignition can be up to 10.0% maximum. The loss of mass on ignition according to ASTM C311 is that the material is heated to $750 \pm 50^\circ\text{C}$ in a porcelain crucible and follows the process of ASTM C114. The third chemical requirement of ASTM C618 is that the maximum SO_3 content is 4.0%. However, the ability of performance for fly ash or natural pozzolan to react with hydraulic cement in concrete is not predicted by the chemical requirements outlined in ASTM C618, as it only helps describe the composition and uniformity of the pozzolan material.

2.8 Bentonite

The name "bentonite" refers to any smectite-group clay substance, the most prevalent of which being montmorillonite mineral.(Kumari et al., 2021). While sharing a common elementary structure. Types of bentonite are very different with regard to their chemical composition, as

well as to the physical state of their constituents, which account for bentonite different properties and determine its various technological applications. Montmorillonite is an aggregate of lamellar platelets, packed together by electrochemical forces and containing interposition water. Each platelet consists of three sandwich-arranged layers: a central octahedral alumina (Al_2O_3) layer, and two tetrahedral silica (SiO_2) layers (Mouzon et al., 2016). The silicon ion and the aluminum ion often undergo iso-morphous substitutions by lower valence metals, such as magnesium and iron. In turn, these substitutions lead to a charge imbalance, compensated by exchangeable cations, in particular calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^+) ions together with water molecules. Bentonite, in addition to montmorillonite, contains a small portion of other mineral matter usually quartz, feldspar, volcanic glass, organic matter, gypsum, or pyrite (Kumar et al., 2017). In natural calcium bentonite, where calcium is the predominant exchangeable cation. It has much lower swelling ability and liquid limit and much higher filter or fluid loss than natural sodium bentonite (J. Ahmad, Kontoleon, et al., 2022)

2.8.1 Raw bentonite nature and occurrence

The word "bentonite" was first used in 1848 by Knight to describe a highly flexible clay substance that was found close to Fort Benton; the bentonite business has been around for more than 70 years (Ismaeel et al., 2017). Bentonite is dissolved in water, it may swell and gel. Due of its low permeability, high swelling capacity, and self-sealing qualities, bentonite is frequently used as the clay backfill or designed barrier in these systems. At the Beginning production amounted to only a few tons per year, bentonite production now exceeds a million tons per year. In 2020, the country with the largest output of bentonite was China, at approximately 5.6 million metric tons. The United States ranked second, with a production volume of some 4.2 million metric tons. That same year, the global production of bentonite reached 20.85 million metric tons worldwide. The largest single use of bentonite is in foundry molding sand (24%), followed by drilling mud (21%) and iron ore pelletizing (15%). Various absorbent uses together account for a further 23% of world production.

The origin of bentonite is attributed to the alteration of volcanic ash, but common use of the term is often extended to include material of primarily a montmorillonite composition, which may have formed in another manner (Rusanescu et al., 2018). Bentonite from ash falls and other

sources occurs worldwide in strata spanning a broad range of ages, but is most abundant in Cretaceous or younger rocks.

2.8.2 Bentonite occurrences in Ethiopia

Bentonite resources found in Ethiopia in Afar and Oromia regions. The main occurrences in afar are located at Ledi, Gewane, Hadar and Warseiso area. The bentonitic beds are part of a thick sequence of lacustrine sediments, which consists of clays, silts, sands, calcareous grits, gravels, conglomerates, basaltic flows, and ashes (Tessema, 2012). The bentonitic beds are well exposed and the overburden consists of loamy gravel and sandy clay. The total amount of bentonitic clay in the Afar region was estimated to be over 135 million tones. Swelling tests on nine samples from Mille and Gewane bentonite have been conducted and showed an average swelling capacity of 6.1%(Mengistu, 1987) . The largest bentonite deposit in Ethiopia is located at Gewane, is found about 17 km northeast of the town of Gewane. The reserves at this site have been estimated at 77,035,000 m³. The average thickness of the bentonite clay is about 110.8 m. The second largest deposit is at Warseisa, situated 1–3 km north of the Dessie-Assab highway between the Badona River and Warseisa. The bentonite deposit occupies an area of about 127 km². The reserves have been estimated the average thickness of about 5.6 m. At Ledi, the average thickness of the bentonitic bed is estimated to be 3.2 m and the calculated reserves are 1,784,000 m³. (Tadesse et al., 2003).

Table 2.4 Estimated Bentonite resources in Ethiopia

Location	X	Y	Overburden (m ³)	Surface area (m ²)	Thickness (m)
Warseisso	40.65	11.37	245,116	1,265,155	5.58
Kada & Ounda	40.61	11.12	5,000,000	647,500	1.42
Gewane	40.61	10.25	14,354,313	6,506,874	11.83
Ledi	40.68	11.16	1,200,000	557,500	3.2
Gidicho	37.94	6.4			

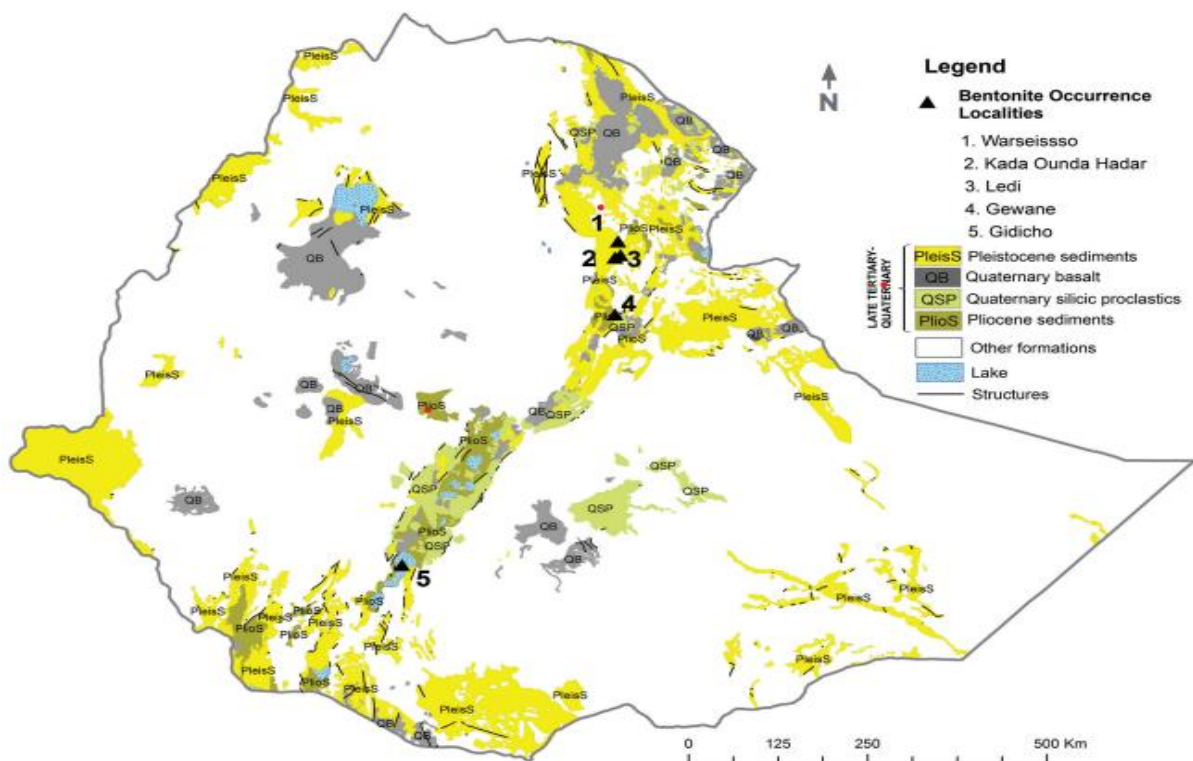


Figure 2.1 Location map of bentonite resource in Ethiopia

Table 2.5 Chemical composition of bentonites located in Ethiopia

NO	Area	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	MnO
1	Warseissso	49	13.4	8.71	1.61	3.81	2.79	1.1	1.31	0.1
2	Kada Hadar	48.78	13.42	8.78	1.5	4.12	2.8	1.32	1.4	1.1
3	Ounda Hadar	54.23	12.9	9.1	1.4	1.9	2.5	1.76	1.1	0.1
4	Gewane	61.96	11.06	6.76	1.06	1.03	2.56	1.68	1.27	0.1
5	Ledi	54.23	12.65	7.75	1.35	3.15	2.8	1.85	1.35	0.1
6	Gudicha	56.4	14.4	8.3	1.05	2	1.6	3	1.6	0.19
7	Arura	60.8	10.9	13.5	1.09	0.9	1.3	2.2	1.1	0.16
8	Biaso	59.4	16.4	8.7	1.04	0.9	1.4	2.4	1.5	0.16

According to Tessema (2012), these deposits have not been worked to provide material for use by local industries. Essentially all bentonite used within Ethiopia is imported, material coming from a range of countries.

2.8.3 Thermally Activated Bentonite as Supplementary Cementitious Material

Bentonite is a mixture of clay and non-clay minerals silica and alumina bond in the crystal structure of montmorillonite. Therefore, they cannot contribute to the pozzolanic reaction (Gilg et al., 2021). Heat treatment of bentonite leads to the destruction of the crystal structure of montmorillonite and converting silica and alumina to reactive phases. The main desirable impacts of TAB in concrete include improved segregation resistance, a slower rate of strength growth, improved concrete durability against acids, sulfates, and chlorides, as well as ecological benefit (Lima-Guerra et al., 2014).

2.8.4 Calcination of bentonite

Montmorillonite in bentonite pass through four successive stages during heating process. The first stage is Dehydration stage here loss of uncombined water release by temperature, which are adsorbed and interlayered. The temperatures require completing this stage varies according to initial moisture content, size of clay particles, type of cations fill the interlayer spaces and the presence of defects in mineral structure (Fajnor et al., 1996). The temperatures recorded for dehydration completion were is 150°C-160°C for sodium montmorillonite and 180°C for calcium montmorillonite (Z. E.-A. Laidani et al., 2022). When the temperature rise De-hydroxylation stage is continue that is responsible for loss of hydroxyl group from the mineral structure. Most of OH group binds in aluminum coordinate sheet convert to octahedral 5-fold coordinate and tetrahedral cordon. The structural transformation in octahedral sheet leads to loss the crystallinity of 1:1 clay minerals like kaolinite, but the 2:1 clay minerals like montmorillonite conserve their crystallinity. The temperatures reported for the initiation and completion of the de-hydroxylation ranged is from 400°C to 500 °C (Taher, 2003).

Partially or completely decomposition of crystalline structure and formation of new amorphous and/or cryptocrystalline reactive phases is under goes at amorphization stage. This stage represents the goal of the thermal activation process; the optimum temperature required to achieving this aim was determined precisely in each experiment but there is no specific degree. The structure of Iraqi calcium bentonite is completely collapsed at 700°C while higher degrees were reported 800°C by (Darweesh et al., 2007). It is not certain what causes the differences in temperatures required for Amorphization, but the differences may be attributed to the calcination

program like heating rate, holding period, and cooling rate (Farhan Mushtaq et al., 2022). The last stage is recrystallization stage which is responsible for formation of new crystalline inert phases due to high temperature effect; recrystallization was noticed at 920°C (Z. E.-A. Laidani et al., 2022) most of researchers stop their heating at the stage before amorphization is occur.

Table 2.6 Bentonite montmorillonite activation programs proposed by several researchers.

Author	Activation temperature (°C)	Activation period (min.)
Taher (2003),	550	240
He et al.(1996),	700	60
Penson(2019),	800	240
Darweesh et al.(2007),	800	180
Mirza et al.(2009),	250	180
Fernandez et al.(2011),	600 & 800	60
Laidani et al.(2022),	800	180

The pozzolanic reaction was also observed with Portland cement after calcination; the replacement of Portland cement by thermally activated bentonite at different percentages leads to gradual consumption of $\text{Ca}(\text{OH})_2$. As Fernandez et al. (2011), stated that TAB, at 600°C, seems to be effective in depleting $\text{Ca}(\text{OH})_2$ at 30% substitution of Portland cement in both cement paste and mortar. Other report prevail TAB enhancement in compressive strength observed due to pozzolanic reaction in the paste consists of 30% TAB at 700°C using 0.5 water to powder ratio got the best result (Khushnood et al., 2014).

2.9 Previous Studies on bentonite as a supplementary cementations material

Researchers from different locations throughout the globe carried plenty of investigations by using bentonite as substitute material to cement in concrete. They reported some facts related to bentonite utilization based on the experimental results. The most important properties of bentonite makes it suitable to be employed in concrete work which are studied by different researchers are the following

2.9.1 Physical Properties

Bentonite is generally available in various colors and forms. A Few authors reported about the color, greenish gray (Mirza et al., 2009), browning green (Akbar et al., 2013). light yellow

colored bentonite was utilized in research work by (Afzal et al., 2014). Table 2.6 shows the overview of physical properties of bentonite reported by some authors. Almost all authors reported different values.

Table 2.7 Physical properties of bentonite used in previous research works

Authors	Specific gravity	Average particle size	Blain fineness (cm ² /gm)
(Memon et al., 2012)	2.82	0.75 µm	4800
(Mirza et al., 2009)	2.63	17% retained 0.75 µm	---
(S. Ahmad et al., 2011)	2.44	13.5% retained on 45µm	2689
(Khushnood et al., 2014)	2.79	4.32 µm	4800

Ground raw bentonite (RB), without any other treatments was used as a partial substitution for Portland cement in many studies. Its use has modified some of the fresh and/or hardened properties of cement paste, mortar and concrete. This type of bentonite has been called "as is" bentonite or "as received" bentonite (Z. E.-A. Laidani et al., 2022). RB characterized by its relatively low specific gravity and relatively high surface area with compared with Portland cement. Therefore, the physical properties of the dry cementitious binder, consists of RB and cement, tend to modify as the RB content increases, for example, 30% cement replacement by RB decreases the specific gravity from 3.15 to 2.98 and increases the surface area from 2850 cm² /g to 5180 cm² /g (Al-Hammood et al., 2021).

Table 2.7 Chemical properties of bentonite used in previous research works

Authors	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	LoI
Memon et al. (2012)	54.55	20.19	8.6	4.2	7.28	1.27	3.92	5.42
Mirza et al. (2009)	49.44	19.7	6.2	1.61	7.45	8.87	0.63	13.74
S. Ahmad et al. (2011)	65	15	3	6.5	2.66	0.12	0.27	6
Akbar et al. (2013)	49.63	21.11	3.23	12.56	3.59	0.44	2.09	
Shabab et al. (2016)	52.1	13.4	7.5	2.64	12.0		2.64	8.61
Reddy et al. (2019)	51.11	16.83	7.65	7.57	6.60	0.29	1.34	6.75

2.9.2 Bentonite behavior in fresh concrete

Cement replacement by BN causes two opposite effects on the consistency of cement paste: the dispersing effect of fine bentonite particles leads to increase paste fluidity and the absorption effect leads to increase the paste stiffening (Al-Hammood et al., 2021). The interaction between two effects appears at the low level of cement replacement by Ca-BN, if the absorption is dominant.

2.9.3 Water cement ratio

Slight increment in water demand observed to obtain the standard consistency at 20%, 25 % and 30 % replacement. While decreases in water demand at 5% and 10 % and no change in water demand at 15% were reported by (Z. E.-A. Laidani et al., 2022). Due to dispersing effect of ultra-fine particles at replacement levels, more than 15% of the absorption of Ca-RB is dominant and causes significant increases in water demand. The high absorption of Na-RB overcomes the dispersing effect of fine particles at any level of substitution (Karthikeyan et al., 2015).

2.9.4 Workability

Drastic decrease in workability was observed at higher percentages minimum of 20% of bentonite substitution in concrete. Bentonite utilization was done in lower percentages 0-21 at 3% interval by (Memon et al., 2012) he recommended utilization of super plasticizer needed to enhance workability. By other research of Murray (2006), initiates 5-15 % addition of sodium bentonite improves the workability as well as segregation of concrete.

2.9.5 Setting time

Fine bentonite particles provide additional nucleation sites that lead to promoting the hydration process and then accelerate setting time, and the bentonite absorption accelerates cement paste setting also; on the other hand, Portland cement replacement by RB reduces cement components C_3A and C_3S which response the paste setting then causes retardation strength (Targan et al., 2002). Whereas Reddy et al. (2017), reported retardation effect of RB on both initial and final setting time at all replacement levels. The Na-BN incorporation in cement grout reduces bleeding and even eliminates it at 16% or more; besides, it causes reductions in fresh densities of grout proportion with RB content.

2.9.6 Bentonite behavior on hardened concrete

Plenty authors reported the effect of bentonite on mechanical properties of hardened concrete. Compressive strength was determined at different ages of concrete. Resistance of concrete was tested and reported under various climatic condition some of their finding is summarized and presented here

2.9.7 Compressive strength

Majority of authors reported that lower strengths were observed by addition of bentonite at early ages 3, 7 & 28 days of test. Better performance shown at later ages 56 & 90 day of curing comparatively with control concrete.

Sudheer et al.(2017), used 10-30% of bentonite substitution at 5% interval, tests were conducted as per standard procedure IS: 516 and reported that lower CS were observed for blended mixes among all. Karthikeyan et al. (2015), reported that 30% of bentonite replacement results higher CS than control mix. Aravindhraj et al. (2016), suggested that 15-50% bentonite-quarry dust mixture exhibits maximum CS at the age of 28 days.

Shabab et al.(2016), investigates about bentonite-fly ash mixes, reported that the concrete contains equal combination (50-50%) of bentonite and fly ash exhibits better results at the age of 90 days. According to the findings of the research by Al-Hammood et al. (2021), at each testing days, the proportion of improvement in strength was 0.9 percent, 1.5 percent, 1.8 percent, 2.7 percent, 2.5 percent, and 2.2 percent, respectively, when compared to the control group. Mesboua et al.(2018), mentioned that Na-RB reduces both water absorption and compressive strength of hardened grout at 28 days. However, the reductions values were differed, at 18% replacement the reduction in absorption was 24% from reference grout absorption while the reduction in compressive strength was only 6%. The decrease in absorption has been explained by three reasons: 1 the formation of additional C–S–H due to pozzolanic reaction, 2 filling micro pores by bentonite fine particles and 3 reduction in water to binder ratio; but these explanations are supposed to lead to an increase in compression strength, or at least not to reduce it. On other research, compressive strength of concrete decreases due to cement replacement by BN, but there is no specific rule governing the relationship between BN content and the amount of strength loss. High levels of replacement (35-50) percentage lead to adverse reductions in compressive strength of about 45-60 percentage (J. Ahmad, Kontoleon, et al., 2022; Karthikeyan

et al., 2015; Sudheer et al., 2017) Moderate levels (15-30) percentage of replacement cause reductions of about (3-40) percentage proportioned to BN content.

2.9.8 Split tensile strength

On sing bentonite clay as a binding substance, a researcher discovered that split tensile strength decreased when the bentonite clay was substituted (Karthikeyan et al., 2015)

However, according to other research, the split tensile strength improved due to the replacement of BC 30% substitution of bentonite results maximum split tensile strength to concrete. The pozzolanic reaction enhanced the binding qualities of the cement paste and thus raised the split tensile strength. Additionally, the presence of micro-filling gaps of bentonite clay also leads to increased split tensile strength. Overall, the combination of pozzolanic and micro-filling gaps in BC has a good effect on split tensile strength. Aside from that, the increased dosage of BC resulted in a drop in split tensile strength as a consequence of a lack of workability (Farhan Mushtaq et al., 2022)

2.10 Summary and gap

The literature review in the previous sections on bentonite as a cement substitute and glass fiber as a reinforcing material reveals that several researchers have carried out studies in this area independently. However; there are still some gaps to collaborate both the economic and strength problem of concrete. Incorporation of glass fiber improve the tensile strength by limiting the crack width and length. In some extent it increase the compressive strength but not much significant. The glass fiber content applied in most researches varies from 0.1 up to 1.5 percentage weight of concrete, and the aspect ratio have a great impact on its property however when the glass fiber content increase the slump value decrease (Kene et al., 2012; Kizilkanat et al., 2015; Lalinde et al., 2022; Ruben et al., 2021; SrinivasaRao et al., 2012). Recently it was found that the behavior of concrete can be improved with addition of hybrid fibers such that combination of different types of fibers. The intent is that the performance of these hybrid systems would exceed that induced by each fiber type alone. But most of the studies hybrid fibers with another fiber types like steel and Polypropylene (Afroughsabet et al., 2015), bamboo and glass fiber (Mathew et al., 2022), steel carbon and palm fibers (Hidayat et al., 2021) . But only few researcher hybrid fibers with pozzolanic materials.

And-also in the area of pozzolanic material bentonite is hydride with different cementitious material to minimize the cost of cement like bentonite with marble (Z. E. A. Laidani et al., 2022), bentonite with gypsum (Tilak B et al., 2015), bentonite with glass powder (Al-Soud et al., 2022), bentonite with lime (Taher, 2003) Etc. Although the overall review shows that bentonite clay have the creditability to be used as cement replacement in concrete up to some extent (Darweesh et al., 2007; Farhan Mushtaq et al., 2022; Z. E.-A. Laidani et al., 2022; Memon et al., 2012) those results show partial substitution of cement from 5-20% have some positive effect on properties of concrete. Similar study by Farhan Mushtaq et al. (2022) and Sarikaya et al. (2000), bentonite substitution more than 25 percent decrease the compressive strength but steel improve its durability like acidic and Sulphate resistance. And some researchers report a failure in compressive strength due to substitution of cement by bentonite. study by Khushnood et al. (2014), investigate the strength development, hydration and microstructure of concrete containing bentonite and wheat straw as reinforcement and cement partial substitute. However still there is a limited knowledge on behavior of concrete using hybrid bentonite and glass fibers as a hybrid reinforcing and cementitious material. This study was done to fill the gap on the experiences and knowledge on the effect of using hybrid effect of bentonite as a cement and glass fibers as a reinforcement. So from the review the researcher understand that there is a significant result variation on previous works both on bentonite and glass fiber concrete as well morphological behavior mechanical property and hydration process of concrete containing bentonite and glass fiber is not studied at all. And this taken as research gaps that enabled to set objective for this research.

The next chapter discusses the research methodology adopted to achieve the objectives of the study.

3. MATERIALS AND METHODS

3.1 Introduction

The literature review in previous chapter has present past studies and research gaps in relation to utilization of different type of fiber in concrete to enhance tensile strength and replacement of cement by different materials. Based on the identified research gaps, this chapter elucidates the methodology adopted to accomplish the study's objectives of the work. This Chapter discuss about the general experimental package in ASTU construction material laboratory, biology laboratory, material engineering laboratory and Geological Survey laboratory at Addis Ababa. In addition, the detail procedures of the material preparation, mix proportions, mixing process, workability tests, casting process and curing process, type and method of testing of various concrete mixes used in this investigation are presented.

This experimental research work have two parts the first one is preliminary test of concrete to determine the fiber content amount, which blend with the bentonite. Therefore, for the preliminary test compressive strength and flexural strength of concrete is investigated with addition of 0.3%, 0.5%, 0.7%, 1 % of concrete material weight. After getting the optimum amount of glass fiber in the next experiments it used as a constant ingredient amount and experiments done by changing the replacement level of bentonite by cement in percentage of 5%, 10%, 15%, and 20% by percentage weight of cement.

Before the commencement of the main experiment, the material that have been used in this research were collected and prepared then their concerned property also investigated to assure whether those materials are complying with the required standard and specification. The material use for this research are cement, sand, aggregate, water, calcine bentonite and glass fiber. The effect of individual and combined integration of bentonite and glass fiber as a partial replacement for cement and reinforcing material in concrete mixes were investigated by determining the mechanical properties of concrete mixes.

The laboratory investigation consists of testing of cement past and hardened concrete properties; the cement pest test include consistency test, initial and final setting time test and its workability is measured. The hardened concrete test include compressive strength split tensile strength, flexural strength test, X-RD and SEM image of samples which is done after 7, and 28

day of curing. The content of bentonite was proportion of percentage weight of cement and a content of glass fiber used is proportion of percentage weight of concrete materials. The testing procedure on hardened and fresh concrete was made according to the ASTM Standard. Surface Morphology was examined by Scanning Electron Microscopy and phase composition for both control and replaced concrete is done at 7th and 28th day to follow up its progressive change experimental results then analyzed to reach to conclusion.

3.2 Data collection

The data collection was mainly based on the tests conducted on the prepared specimens in the laboratories. experimental research design are concerned with examination of the effect of independent variable on the dependent variable, where the independent variable is manipulated through treatment or intervention and the effect of those interventions is observed on the dependent variable. The study variables of this experiment are

1. **Independent Variables** is the variable the researcher manipulate or vary in an experimental study to explore its effects. It is not influenced by any other variables in the study. Think of the experiment as a "cause and effect" exercise. The independent variable is the "cause" factor. Values of independent variable were under experimenter control. The independent variable for this research are Bentonite content and glass fiber amount.
2. **Dependent Variables** A dependent variable is the variable that changes as a result of the independent variable manipulation. It's the outcome interested in measuring depends on independent variable. The dependent variable is what is measured or observed as an effect of independent variable are:- Setting time test, Consistency test, Workability, Compressive strength test, tensile strength, water absorption and hydration products.
3. **Controlled Variable** In order to make the test to be fair, other factors that could affect the outcome of the experiment should be kept the same, or controlled. In this study, the control variables were fine aggregate and coarse aggregate, mixing casting and curing condition.

3.3 Data Analysis and Evaluation techniques

The test results of the samples were compared with the respective control concrete properties to evaluate the effect of independent variables on the concrete property and the results from compressive, tensile and flexural test were collected, analyzed and presented using relevant

formulas, tables, pictures and graphs. X-RD result was analyzed by ORIGIN Software and presented by graph. Finally recommendations were forwarded based on the findings and observations

3.4 Materials and there properties

All the necessary materials required for the preparation of the necessary specimens were transported, collected and delivered to the laboratory from their respective sources. These main ingredients were Coarse aggregate, which was got from crusher site. Fine aggregates from Local market its original source is from metehara, Cement from Amede market the cement is product of national cement OPC Grade 42.5. And the two additive the bentonite is delivered from afar bentonite mining and production company from afar mile. Moreover, the glass fiber is got from world Fiber Company located at Addis Ababa city.

3.4.1 Cement

Cement is binder, a material used for construction that sets, hardens and adheres to other materials to bind them together. This research was done using the particular brands of cement, which is national cement 42.5 R grade Ordinary Portland Cement (OPC) cements. Which give strength not less than 43 N/mm² at 28 days.

3.4.2 Fine aggregate

Fine aggregate or sand is a granular material composed of finely divided mineral particles. Sand grains are smaller than gravel and coarser than silt. Sand can also refer to a textural class of disintegrated or crushed stone containing more than 85 percent sand-sized particles by mass. The sand sources for this research was from Metehara, which give better sand quality.

3.4.3 Coarse Aggregate

Aggregates are coarse particulate rock-like material consisting of a collection of particles ranging in size from 37mm-4.75mm commonly obtained by crushing naturally occurring rock. The properties of aggregates depend on the parent rock which can be igneous, sedimentary, or metamorphic. Aggregates are evaluated through tests to determine their suitability for various applications.

3.4.4 Water

Water is the most important and least expensive ingredient of concrete. It distributes the cement evenly. It lubricates the mix to form reaction the quantity of water is the most important parameter and controlled by the w/c ratio. Portable water that is free from organic matter, silt, oil and acidic materials have been used for both mixing and curing purpose.

3.4.5 Bentonite

Bentonite is an absorbent clay consisting mostly of montmorillonite usually got from the weathering of volcanic ash or by hydrothermal circulation through alteration of volcanic glass to clay minerals. Bentonite used for this experimental investigation is got from afar region mile area. bentonite with chemical composition of 65.34% SiO_2 , 14.39 % Al_2O_3 , 8.52% Fe_2O_3 , 0.76% CaO , 1.88% Na_2O and 0.04 % MnO was used.

3.4.6 Glass fiber

Glass fiber is non-metallic material consisting of numerous extremely fine fibers of glass. The base ingredients of glass fibers are forms of silica, mainly sand, limestone, stone ash and borax. Although strength properties are favorable for concrete it is less stiff, the material is typically far less brittle and the raw materials are much less expensive. The glass fibers used for this research is product of world fiberglass plc. With diameter of 14.5 microns, and length 2cm long.

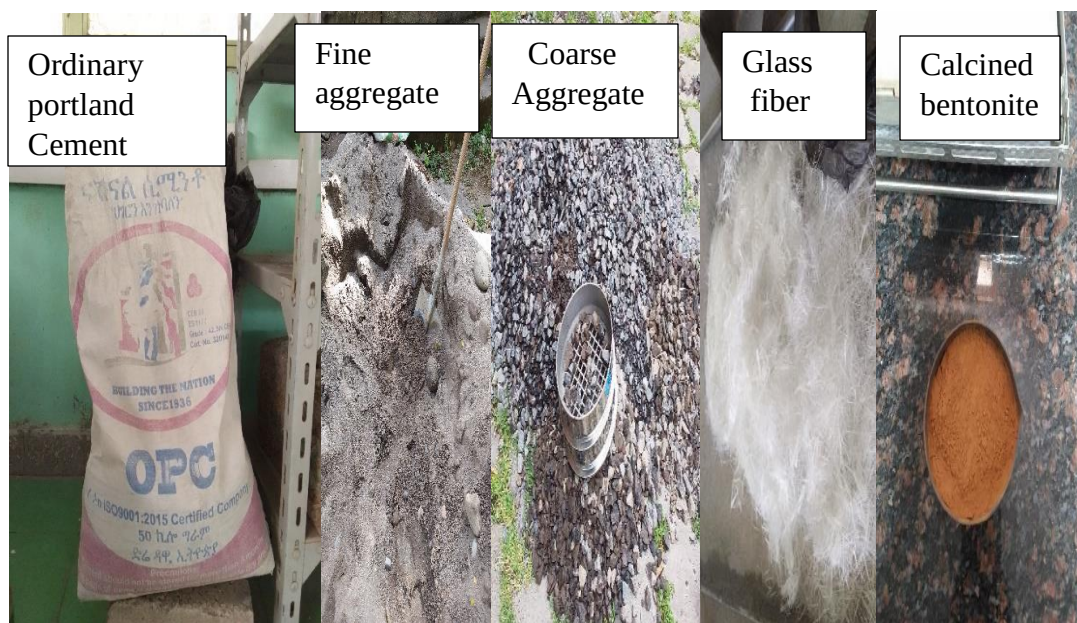


Figure 3.1 Concrete ingredients

3. 5 Methods

3.5.1 Experimental diagram

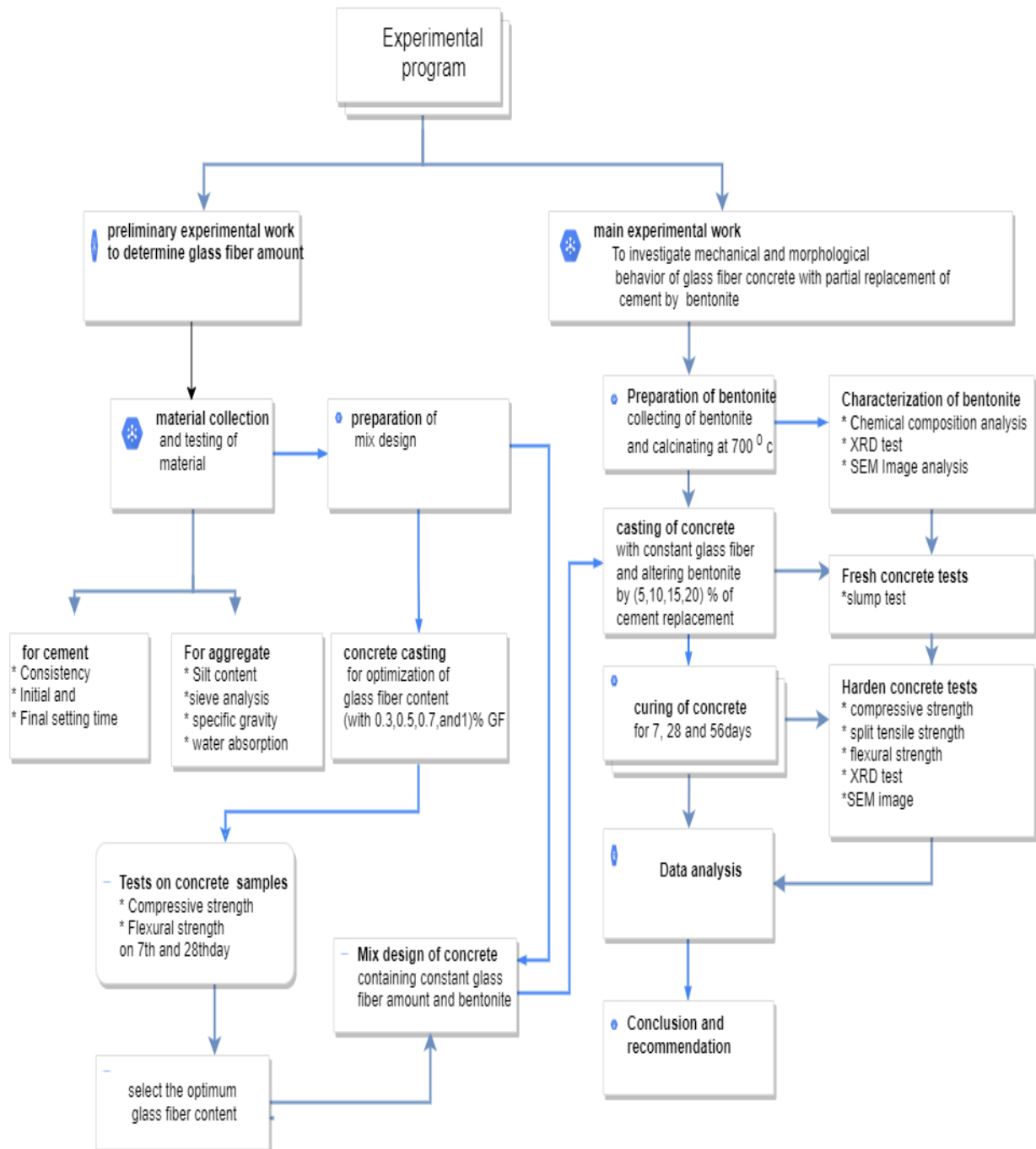


Figure 3.2 Experimental program designed for this study

3.5.2 Concrete mix design and proportions

Concrete mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. In this study, ACI method was used to design mix proportion for C-25 grade of concrete. The mix designs were done as per ACI 318 building code requirement for structural concrete, the detail procedure is provided in the Appendix-A. Five mix categories for concrete grades of C-25 were produced. A control mix with null of glass fiber and bentonite is done and replacement was casted to make a comparative analysis. The step followed to calculate the mix design is

Step One Computing required average compressive strength from the given characteristic strength of 25MPa. Calculating the required mean compressive strength based on characteristic strength of 25 MPa which gives; $f_{ck} = f'_{ck} + 8.5 = 25 + 8.5 = 33.5 \text{ MPa}$

Step Two Specifying minimum cement content. Minimum cement content = 300 kg/m^3

Step Three Choice of slump, the slump chosen ranges from 2-10 cm

Step Four Selecting maximum size of Aggregate, maximum aggregate size taken is 20 mm.

Step Five Estimate mixing water and air content with a slump of 2-10 cm and a maximum size aggregate of 20 mm, the water content becomes 185 Kg/m^3 and 2%, or 20 liters.

Step Six Computing water cement ratio (W/C) the minimum water cement ratio is 0.491.

Step Seven Determining the mix cement content, which becomes 377 kg/m^3

Step Eight Estimating the bulk volume of dry rodded as per unit volume of concrete Hence, the dry volume of aggregate per volume of concrete is 0.602

Step Nine Calculating the weight of coarse aggregate per m^3 of concrete = 1014 kg

Step Ten Determining the solid volume of the coarse aggregate = 358.3 kg/m^3

Step Eleven Calculating the solid volume of cement, water, and air where Volume of Water (VW) = 185 Kg/m^3 , Volume of Air (VA) = 20 Kg/m^3 , solid volume of cement = 120 Kg/m^3

Step Twelve Determining solid volume of sand (Solid volume of sand is then calculated by subtracting from the data volume of concrete).

Table 3.1 Solid volume and weight of concrete ingredients

Ingredient	Volume	Wt. (kg/m ³)
Air	20	-
Cement	120	377
Water	185	185
Coarse aggregate	359.49	1017.38
Fine aggregate	315.5	867.62
Total	1000	2,447 kg/m ³

Step fourteen Summary of mix design ratio after water adjustment

Table 3.2 Summary of mix design ratio

	Cement	Fine aggregate	Coarse aggregate
Quantity in m ³	377	877	1044
Ratio	1	2.32	2.77

Amount of glass fiber added by percentage weight of concrete ingredient which was 2298 kg/m³ is for 0.3% = 6.894 kg/m³, For 0.5 % = 11.49 kg/m³, For 0.7 % = 16.086 kg/m³ and For 1% = 22.89 kg/m³

Amount of bentonite replaced by percentage weight of cement which was 377 kg/m³ is used for 5% replacement = 18.85 kg/m³, for 10 % replacement = 37.77 kg/m³ for 15% replacement bentonite content was 56.55 kg/m³ and for 20 % replacement bentonite amount used is 75.4 kg/m³

3.6 Preparation of specimens

In the present experimental study before the commencement of main experiment the optimum amount dosage of fiber is determined by casting trial mix, glass fibers were used in varying dosages of 0.3%, 0.5%, 0.7% and 1.% of by weight percentage of concrete materials without bentonite. This laboratory work was therefore clarify the exact test requirements and the test sample with according to the requirements and guidelines. Data, which is going to analyze and answer the research questions, was collected from the concrete specimens after conduct

laboratory tests from each sample prepared. Percentage composition of cementing material for this research:- Replacement proportion of bentonite percentage was 0%, 5, 10%, 15%, 20 % And proportion of glass is 0.5% percentage weight of concrete which is got from optimization test. Each percentage are casted based on the standard to get the best result percentage variation and number of samples are shown bellow in the table 3.3

Table 3.3 Number of sample casted for optimization of glass fiber content in concrete

ID	% of glass fiber	No of sample for 7 day of testing	No of sample for 28 day of testing	No of sample for 7 day of testing	No of sample for 28 day of testing
For compressive strength				For flexural strength	
CM	0 %	3	3	3	3
GF 1	0.3%	3	3	3	3
GF 2	0.5 %	3	3	3	3
GF 3	0.7 %	3	3	3	3
GF 4	1 %	3	3	3	3
TOTAL					60

Table 3.4 Number of sample casted by blending glass fiber and bentonite

ID	% of Bentonite	% of GF	No of sample for 7 day of testing	No of sample for 28 th day of testing	No of sample for 56 th day of testing
For compressive strength					
CM	0 %	0.5 %	3	3	3
GF 1	5 %	0.5 %	3	3	3
GF 2	10 %	0.5 %	3	3	3
GF 3	15 %	0.5 %	3	3	3
GF 4	20 %	0.5 %	3	3	3
For split tensile strength					
CM	0 %	0.5 %	3	--	3
GF 1	5 %	0.5 %	3	--	3
GF 2	10 %	0.5 %	3	--	3
GF 3	15 %	0.5 %	3	--	3
GF 4	20 %	0.5 %	3	--	3
For flexural strength					
CM	0 %	0.5 %	3	--	3
GF 1	5 %	0.5 %	3	--	3
GF 2	10 %	0.5 %	3	--	3
GF 3	15 %	0.5 %	3	--	3
GF 4	20 %	0.5 %	3	--	3
TOTAL					105

3.6.1 Batching

Batching of concrete is the process of measuring concrete ingredients to get concrete mixtures. For this specific experiment, batching by weight was preferred over volume batching to get a proper mix of concrete ingredients since it is difficult to find the exact volume of granular materials because of their voids.

3.6.2 Mixing

The dry mix was carried out by mixing aggregate, cement and bentonite powder were mixed for one minute. After the aggregate and the cement well mixed chopped glass fiber is added gently not to create a ball of fiber. After that, water was added to the mix and punched for three minutes. then the slump is checked to assure the workability.

3.6.3 Casting

Castings of all specimens were carried out under same ambient conditions of average room temperature. The specimens were then placed on a firm and level surface of prepared cubic molds (150 x 150 x 150 mm) for compressive strength. Rectangular mold with cress section of (100 x100x500) used for flexural strength test. for tensile strength teste cylindrical molds with cross section of (300cm height and 150 mm diameter) used for casting of concrete.

Usually sufficient vibration has been applied as soon as the surface of the concrete has become relatively smooth and large air bubbles cease to break through the top surface. until full compaction achieved without segregation was achieved. After compaction of the final layer, the top surface was finished using a trowel. Placing, compaction and finishing were completed within 15 minutes. After 24 hours, the specimens were demolded from the mold and were curried in a curing tank for 7, 14 and 56 days at room temperature in the laboratory.

3.6.4 Curing

Mold with concrete samples after casting placed at room temperature. At the end of 24 hours taken out the sample and demolded, the concrete samples immersed in the water totally for 56 days and tests done on those days for 7, 28 and 56 days to check the necessary properties and strength characteristics . And the sample were taken out from the water 24 hours prior to the test and it stayed in dry condition to make it saturated surface dry.

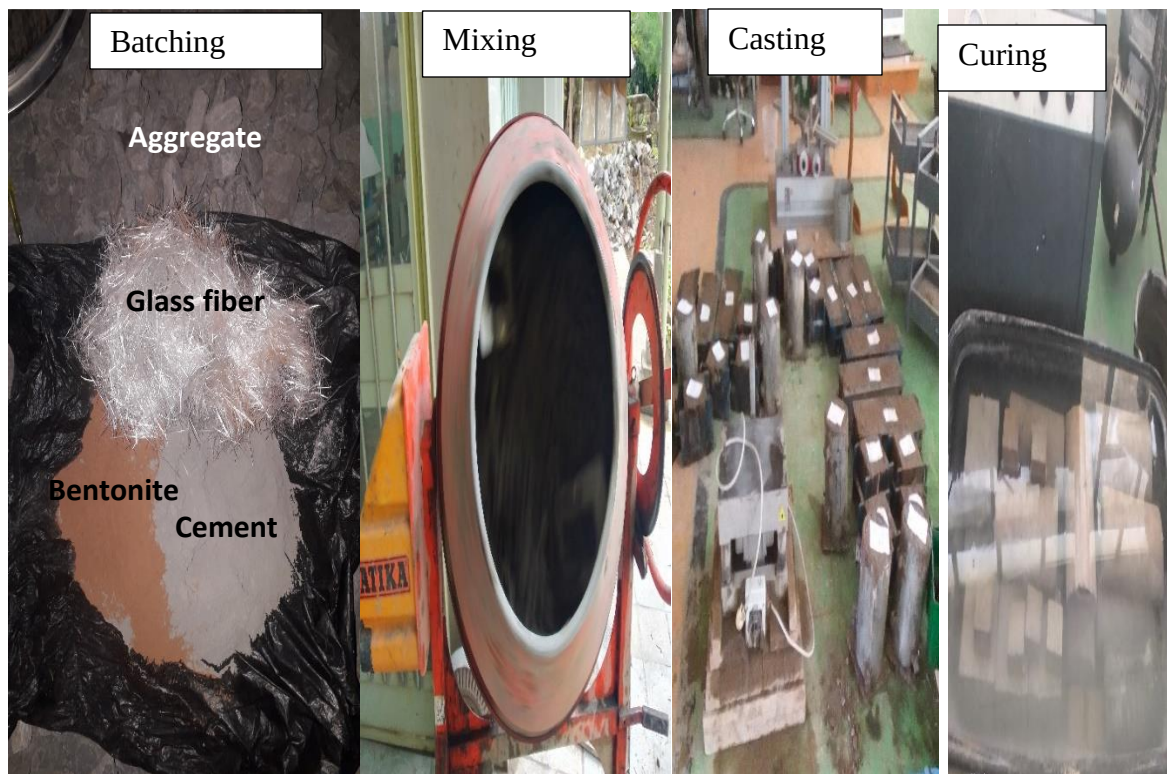


Figure 3.3 Concrete specimen preparation process

3.7 Test on concrete ingredients

3.7.1 Tests for fine aggregate

3.7.1.1 Silt content of fine aggregate

There are two types of harmful substances preset in fine aggregates i.e. organic matter produced by decay of vegetable matter and/or clay and silt, which form coating thus preventing a good bond between cement and the aggregates. If present in large quantities, result in the increase water-cement ratio and finally affecting the strength of concrete the apparatus and materials used for this study are sample sand, clean water, graduated jar, spoon, dish for taking a sand sample, and funnel. Then the next procedure was done based on ASTM C117. According to Ethiopian standards, the silt content should not exceeds a value of 6%. The impurity level of the sand have assured by the following procedure was followed.

Test Procedure for Silt Content test

The researcher took 1000 ml capacity of graduated cylinder next 300 ml of sand was poured into

the cylinder 3/4 of the jar was filled with water. And the jar was shaken vigorously for a minute then the jar was left for an hour to allow the silt to settle on the layer of sand at the end the amount of fine forming a separate layer on the top was measured. The silt content was calculated based on equation specified on 3.1.

$$\text{silt content} = \frac{\text{silt deposit above the sand}}{\text{amount of clean sand}} \times 100\% \dots \text{Equation 3.1}$$



Figure 3.4 Silt content test

3.7.1.2 Sieve analysis of fine aggregates

The sieve analysis commonly known as the gradation test determines the distribution of aggregate particles by size within a given sample in order to determine compliance with design production control requirements and verification specifications. The reason of the researcher to do this test is to determine the fineness modulus of fine aggregate. With the help of the apparatus like a Sieve having (4.75 mm, 2.36 mm, 1.18 mm, 0.6mm, 0.3mm, 0.15, and pan) size from top to bottom respectively, balance, 1000g of fine aggregate, shovel, sieve shaker, and sieve brush. All the test procedure was performed based on the standards of ASTM C136/c136M.

Test Procedure for Sieve analysis test followed was

1000g of sample mass taken, which gave representative gradation of whole sample. Using the sieve sizes required by the specification, the set of sieves arranged in descending order with the largest size on top. Then sample pour the on the top sieve. After that stack of sieves and pan covered and shake the sample for at least 5 min. Next, any aggregate particles brush for clinging to each sieve and the aggregate passing the sieve into the next smaller sieve. Lastly the mass of the aggregate retained on each sieve is measured and computed by the following equation 3.2.

$$\% \text{ retained} = \frac{\text{Weight of retained sample on sieves or pan}}{\text{Total weight of original sample}} \times 100 \dots\dots\dots \text{Equation 3.2}$$

$$\text{Fineness modules} = \sum \left(\frac{\text{cummulative percent of retained}}{100} \right) \dots\dots\dots \text{Equation 3.3}$$

3.7.1.3 Unit weight of fine aggregate

Unit weight is the ratio of the weight of a material to its volume. The unit weight of fine aggregate is the weight of the sand that is required to fill a container of a specified unit volume.

Test Procedure for measuring unit weight of fine aggregate followed is

An empty cylinder was weighed and recorded to conduct a test the cylinder was then filled with fine aggregate in three layers, each of which was tamped with 25 strokes by a tamping rod. When roding the first layer, it doesn't allow the rod to strike the bottom of the measure forcibly. In roding, the second and third layers use only enough force to cause the taping rod to penetrate the previous layers of aggregate. Then the surface of aggregate leveled in such a way that any slight projections of the large pieces of the aggregate removed after proper leveling the fine aggregate was weighed and the data were recorded to analyze by the next formula on equation specified on 3.4

$$\text{unit weight} = \frac{\text{weight cylinder and fine aggregate} - \text{weight of empty cylinder}}{\text{volume of cylinder} = \left(v = \frac{\pi d^2 h}{4} \right)} \dots\dots\dots \text{Equation 3.4}$$



Figure 3.5 Unit weight measurement of fine aggregate

3.7.1.4 Specific Gravity of fine aggregate

Specific gravity is the ratio of the mass of a given volume of material to the mass of an equal volume of water, which could tell us how much the material is heavier than water.

Test Procedure for measuring Unit Weight of Fine Aggregate

500g of S.S.D sample was taken from its natural state. Then pycnometer was half-filled with water and instantly filled with 500 g of S.S.D fine aggregate. After that, the pycnometer filled with additional water to 90% capacity. Moreover, rolled to eliminate all air bubbles. Following the removal of air bubbles, the water level was transmitted to the pycnometer-calibrated capacity. Total weight of the pycnometer, specimen, and water was measured. Secondly, Weight of pycnometer and water without the sample measured Then fine aggregate was removed from the pycnometer, dried to 110°C for 24 h, cooled for one hour in the air at room temperature. The oven dry sample of fine aggregate was weighed. Finally, Bulk specific gravity, apparent specific gravity and absorption capacity of fine aggregate were computed through the following formulas on equation 3.5 and 3.6

$$\text{Bulk specific gravity} = \frac{C}{B+(D-C)} \dots\dots\dots \text{Equation 3.5}$$

$$\text{Apparent specific gravity} = \frac{A}{A+(B-C)} \dots\dots\dots \text{Equation 3.6}$$

3.7.1.5 Water absorption of fine aggregate test

The absorption and surface moisture of aggregate is need to be determined in order to control the net water content of a concrete mix and to make adjustments in batch weights of the materials. The water absorption of aggregate is calculated as the ratio of the difference between the weight of the aggregate in the surface-dried saturated state (SSD) and the weight of the oven-dried aggregate (at specific temperature). Water absorption capacity of fine aggregate was calculated and all experimental procedure is done and the procedure is the some as procedure of measuring Unit Weight of Fine Aggregate based on ASTM C128/c1128M standard. And water absorption capacity of fine aggregate calculated by the following formula of equation 3.7:-

$$\text{Absorption capacity} = \frac{D-A}{A} \times 100 \dots\dots\dots \text{Equation 3.7}$$

Where A: - Weight of oven dry specimen in oven

B: - Weight of pycnometer filled with water

C: - Weight of pycnometer with specimen and water

D: - Weight of saturated surface dry specimen



Figure 3.6 Specific gravity and water absorption of fine aggregate

3.7.2 Test for coarse aggregate

3.7.2.1 Sieve analysis of coarse aggregates

Aggregates may be dense, gap-graded, uniform, well graded, or open-graded. The use of well graded mixture of aggregates results in improved workability of the concrete and economy of the cement since such aggregate has a decreased amount of voids between the particles and consequently requires less cement paste. For a given consistence & cement content, a well-grades aggregate produces a stronger concrete than a poorly graded one because less water required to give suitable workability.

The main aim of coarse aggregate grading is to determine the fineness of the aggregate and to identify the category of aggregate use for the test. Gradation is determined by passing the material through a series of sieves stacked with progressively smaller openings from top to bottom and weighing the material retained on each sieve sizes of (20 mm, 19 mm, 12.5 mm, 9.5 mm, 4.75 mm, and pan) from top to bottom. The range of fineness modulus of coarse aggregate measured according to ASTM C33.

Test Procedure for measuring gradation of coarse aggregate

2 kg of coarse aggregates taken which is representative sample. Then sample Placed on the top sieves to Smashed the sample for about 10 minutes in a sieve shaker. Weight of aggregate

retained on each sieve is measured and their percentage calculated .Finally Fineness modules of coarse aggregate computed by using equation 3.8.

$$\text{Fineness modules} = \frac{\text{cummulative percent of retained}}{100} \dots\dots\dots \text{Equation 3.8}$$



Figure 3.7 Sieve analysis of coarse aggregate

3.7.2.2 Unit Weight of Coarse Aggregate

The unit weight of coarse aggregate is the weight of the coarse aggregate required to fill a container of a specified unit volume. Test procedure of rodded unit weight of coarse aggregates followed is Calibrate the metal bucket to determine its volume by determining the net weight of water required to fill it and dividing it by the density of water. Rodding the aggregates: Fill the bucket one third full and rod the aggregate layer with 25 strokes of the tamping rod. Add another layer of aggregates so that the bucket is approximately two thirds full and repeat the rodding procedure. The third layer of aggregates should fill the pail to overflowing. Manually try to balance the depressions below the top of the bucket with slight projections above the top. The rodded unit weight is computed in kg/m³ from the net weight of the rodded aggregates in the bucket divided by its volume.

$$\text{unit weight of coarse aggregates} = \frac{(G-T)(1+A/100)}{V} \dots\dots\dots \text{Equation 3.9}$$

Where G = Combined mass of the oven-dry aggregate and the bucket, kg

T = Mass of the bucket alone, kg

V = Volume of the bucket, m³ A = Percent absorption, determined by ASTM C 127

3.7.2.3 Specific gravity and water absorption capacity of coarse aggregate

Specific gravity is the ratio of a given volume of aggregate to the weight of an equal volume of water. The water absorption test determines the water holding capacity of the coarse aggregates. It gives an idea of the internal structure of the aggregate and the strength of the aggregate. Apparatus used for specific gravity analysis are balance, sample splitter, wire basket (20 cm diameter and 20 cm in height), absorbent cloth, and oven. Density, specific gravity and water absorption tests were done according to ASTM C127(2007) standard.

Test Procedures for Specific Gravity and Water Absorption of Coarse Aggregate was

First the researcher took the sample of coarse aggregate. The taken sample sieved and the sample passing through the 4.75 mm sieve was ignored. The sample was washed to remove dust and dried in oven at 105°C for 24 hours and left to cool, and then the weight was measured. After that sample was submerged in water for 24 hours. Then researcher removed the sample from the water and rolled it in large absorbent cloth until all visible films of water were removed. The required weight of the sample in its saturated surface dry condition was taken. S.S.D sample put in the sample container and immersed in water to determined the weight in water at 23 °C, and recorded the data. Overall calculations were done using the following equations

$$\text{Bulk specific gravity of coarse aggregates} = \frac{A}{A+S-C} \dots\dots\dots \text{Equation 3.10}$$

$$\text{Apparent specific gravity of coarse aggregates} = \frac{A}{B+A-C} \dots\dots\dots \text{Equation 3.11}$$

$$\text{Water Absorption capacity of coarse aggregates} = \frac{S-A}{A} \times 100 \dots\dots\dots \text{Equation 3.12}$$

Where, A: Weight of oven dry specimen in oven, (g)

B: Weight of wire basket with water, (g).

C: Weight of wire basket with specimen in the water, (g).

S: Weight of saturated surface dry specimen, (g).



Figure 3.8 Specific gravity and water absorption capacity of coarse aggregate

3.7.3 Tests on cement

3.7.3.1 Normal consistency test for cement

When cement mixed with water cement set and harden in to a solid mass up on hydration. The normal consistency refer the amount of water require to make a neat paste of satisfactory workability. The normal consistency test of cement is measured based on the ASTM C 187 standard method. As a result, a vicat apparatus was used to determine the typical consistency.

Test Procedures for normal consistency test of cement

500 grams of cement were measured and taken water added to cement and mixed thoroughly for 3 min. Water amounting to a percentage of cement was 26% for the first trial. cement paste in approximate shaped like a ball with gloved hand by tossing 6 times from one hand to another hand. Then Vicat mold filled with the paste in appropriately, and removed any surplus paste. Then, set the Vicat mold on the glass plate, making sure the plunger lightly touches the surface of the Vicat mold. Allow the plunger to sink into the test mold after it has been released. Thirty second after releasing the plunger record its penetration. The paste said to be of normal consistency when the rod settle 10 ± 1 mm below the original surface with in 30 seconds. Repeat the experiment with varied percentages of water until the Vicat apparatus scale reading is between 10 ± 1 mm. and water amount is calculated by the formula specified on equation 3.13

$$\text{percent of water} = \frac{\text{weight of water in g}}{\text{weight of cement in g}} \times 100 \dots\dots\dots \text{Equation 3.13}$$



Figure 3.9 Normal consistency test for cement

3.8 Fresh Concrete Test

3.8.1 Slump cone test

The concrete slump test measures the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete. The slump cone test can be used as an indicator of an improperly mixed batch. If the concrete cannot flow because the consistency or slump is too low, there are potential problems with proper consolidation. If the concrete will not stop flowing because the slump is too high, there are potential problems with mortar loss through the formwork, excessive formwork pressure, finishing delays, and segregation. The test was done with accordance of ASTM C143 (2010) standard. To undertake this test slump cone which have the shape of a frustum of a cone having dimensions, base diameter 200 mm, top diameter 10 mm, and height 300 mm used, tamper rod 16 mm in diameter and 600 mm in length, Ruler, flat pan and tools were used.

Procedure for Slump test followed was

First, the slump cone was placed on a smooth metal plate and filled with freshly mixed concrete in three different layers each layer of the concrete mix was tapped 25 times with a 600 mm long metal rod that was 16 mm in diameter. Extra concrete was removed after filling the last layer from the top of the cone. The slump cone was then quickly lifted upward with two hands. The concrete is then free to fall. After free fall, the remaining height is known as a

slump (the difference between the height of the mold and the height of the vertical axis) and was measured.

3.9 Hardened Concrete Test

3.9.1 Compressive Strength test

Compressive strength is the ability of hardened concrete to withstand axial loads without any cracks or deflection on its surface. Compressive strength formula for calculating concrete strength is got by dividing the applied load at the point of failure to the cross-section area of the face on which load was applied and expressed in equation 3.14.

$$\text{Compressive Strength} = \frac{\text{Load}}{\text{Cross-sectional Area}} \dots \dots \dots \text{Equation 3.14}$$

For this experimental research concrete cube with cross section of 150*150* *150 used by replacing cement with a different percentage of bentonite and addition off glass fiber for 7, and 28 and 56th date compressive strength checked for bentonite after the curing period. The test was carried out through an automatic compressive machine that has capacity of 3000KN at Adama Science and Technology University in accordance with ASTM C192 standard.

The procedure followed to measure compressive strength of concrete cube

The specimen was removed from the water before 24 hr. of performing the test after specified curing time and the sample was air-dried. Next the dimension and weight of the specimen taken and the specimen placed in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast. And align the specimen centrally on the base plate of the machine. The movable portion rotate gently until it touches the top surface of the specimen. Then load applied gradually without shock and continuously at the rate of 140 kg /cm² /minute till, the specimen fails. Then maximum load Record and note.

3.9.2 Flexural test of concrete

It tests and assure ability of concrete beam or slab to withstand failure in bending. The results of flexural test on concrete expressed as a modulus of rupture that denotes in MPa or psi. The flexural test on concrete for this experimental research conducted using three-point load test by following the ASTM C0947-03R16 (standard test method for flexural properties of thin-section

glass-fiber-reinforced concrete using simple beam with third-point loading) standard test procedure. A 100*100*500mm molds were used. Three samples for 7 three samples for 28-day and an other three samples for 56th date of cured sample tested from each mix. After 24 hours of casting, the molds are removed and the specimens are cured in curing tank using potable water up to the date of test. A two-point loaded flexural strength-testing machine having 2000KN was used. The beam sample was marked at 5 cm from each end and at the mid span. The loads are applied at one-third from the support in both sides.

The strength was determined from the general formula of flexural stress

$$\text{Flexural stress}(\sigma) = \frac{PL}{bd^2} \dots \dots \dots \text{Equation 3.15}$$

Where σ -Flexural stress in MPa

P -rupture load in N

L -length of the beam between the two supports (300mm)

B -width of the beam cross-section (100mm)

d -depth of the beam (100mm)

3.9.3 Split tensile strength test

One of the common methods used to measure the tensile strength of concrete is split tensile strength test. The test was conducted as per ASTM C-496 specification for split tensile strength. The samples were casted by using a steel cylinder molds having 150mm diameter and 300mm length. After 24 hours, the samples were removed from the molds and placed in curing tank for 7,28 days and 56 days of curing period. The cylinders were tested using compression-testing machine having 2000 KN capacity. The test was conducted by placing the cylinder sample in opposite direction to its longitudinal axis and the load is gradually applied and peak load versus stress was recorded.

The procedure followed to measure split tensile strength of concrete was

The sample Surface dried by air by removing it from curing tank before 24 hrs. to start the test a steel strip placed along the length of each contact area by ensuring that each end of steel strip is aligned with the respective diametric line as long as or slightly longer than the sample length. Then the sample placed in the compression-testing machine between the strips. First, center the sample along and verified that the top bearing block is parallel with the top surface of the sample and make adjustments as necessary. Make zero the force readout of the compression-

testing machine and ensure that the peak recording function is enabled. Apply load continuously at a rate of movement corresponding to a splitting tensile stress rate on the sample of 150 ± 50 psi per minute. Continuously apply load until the force indicator shows that the load is decreasing steadily and the sample displays a well-defined fracture pattern. Then the maximum load recorded carried by the sample during the test and note the observed fracture pattern. The fracture pattern also documented with a camera.

The stress was determined by using the following formula;

$$\text{Split tensile stress} = \frac{2P}{\pi dl} \dots\dots\dots \text{Equation 3.16}$$

Where P:-Peak load (N) ,

d:-diameter of cylinder (mm) ,

l:- length of cylinder(mm)

3.10 Morphological investigations

3.10.1 Scanning electron microscope image

The morphology of concrete assesses the types, amounts and distribution of its constituent phases, is the fundamental link between the processes that form the material and its properties. However, the complexity, heterogeneity and large range of relevant length scales in cementitious materials make it difficult to evaluate, as yet, fully realized their potential in helping to understand the process microstructure property relationships for these materials. A major obstacle is the lack of rapid, reliable, and accurate techniques to quantify the amounts of the different phases present. whereas the overall pattern of microstructural development during the hydration of cement paste is established methods are not generally available that are capable of quantifying differences between broadly similar materials, due to use of admixtures, cement substitution, or thermal history. Concrete structure consists of three components namely cement paste, pore structure, and interfacial transition zone between the cement paste and aggregates. Which means it has a heterogeneous microstructure. Improving these three components leads to enhance mechanical strength and durability of concrete. The sample taken to SEM machine to identify what internal structure of concrete looks like when bentonite and glass fiber is added into concrete.

3.10.2 X-ray diffraction (XRD) test

XRD is best technique for the study of crystalline phase of materials. The technique of refinement now enables the amounts of different phases in an hydrated cementitious materials to be determined to a good degree of precision. For this experimental research, this technique used pilot study of the hydration of a typical Portland cement alone. And percentage replacement of cement by bentonite to compare each other. In addition, the internal consistency of the measurements was studied by comparing the XRD estimates of the amounts of hydrates formed with the amounts expected to form from the XRD estimates of reacted. Moreover, it is done twice to check how the hydration product of the ordinary portland cement plus bentonite and cement alone is altered from early strength on 7th day to late strength of 28th day. The scanning parameters used in the analysis included. The drive axis utilized for scanning was 2Theta. The scan range spanned from 10.000 to 80.000 degrees. The scan mode was Continuous Scan, implying a continuous movement during data acquisition. The scan speed was set to 3.0000 degrees per minute (deg/min), indicating the rate at which the scan was performed. The sampling pitch, or the angular step size between data points, was set to 0.0200 degrees. Finally, the preset time, which determines the duration of data acquisition at each point, was specified as 0.40 seconds.

3.11 Environmental and economic implication exploration

The environmental and economic implications of using glass fiber as reinforcing agent and bentonite as partial cement replacement in concrete were explored in terms of raw materials usage, energy usage, CO₂ emissions, and economic implications. To investigate raw material usage, raw material consumption for the production of one cubic meter of concrete without and with glass fiber and bentonite was calculated and compared. The difference in incineration temperatures of cement clinker and CBS was employed as a parameter to investigate the energy usage and coal consumption of concrete without and with bentonite. To determine CO₂ emissions during the manufacturing of 1 kg of CBSA and compare them to cement CO₂ emissions, coal consumption and the difference in incineration temperature were used as a parameter due to the CO₂ emission of cement highly depends on coal consumption. Lastly, the cost of one cubic meter of concrete without and with 10% of bentonite was computed to explore cost implications.

4 RESULTS AND DISCUSSION

4.1 Introduction

In this section analysis and discussion of laboratory test results of glass fibered concrete with conjugation of bentonite clay for its suitability as cement, replacing material and glass fiber as a reinforcement additive are analyzed and presented. The type of test performed and analyzed to determine amount of fiber are workability, compressive and flexural strength are investigated. And by blending both materials the following test results are collected and discussed here under. Those are characterization of ingredients, consistency of the blended pastes at different replacement contents, the workability, strength tests (compressive, tensile and flexural) and to study morphology of bentonite and concrete SEM and X-RD results are analyzed and their implication is presented.

4.2 Fine aggregate

Results obtained from the physical tests of fine aggregate were discussed those include Silt content, sieve analysis, unit weight, specific gravity, and water absorption of fine aggregate were determined and discussed.

4.2.1 Silt Content

The sand sources for this research was from Metehara, however, do not provide pure sand. It contain dust and clay which are finer than sand. There may two types of harmful substances preset in fine aggregates. Organic matter produced by decay of vegetable matter and/or clay and silt, which form coating thus preventing a good bond between cement and the aggregates. In order to prevent this problem silt content determination of sand done based on ASTM C33 and presented in table 4.1 bellow.

Table 4.1 Silt content of fine aggregate

Trial	Silt Content	Pure Sand	% Silt Content $\frac{\text{silt}}{\text{puresand}} \times 100$
1	8	290	2.75
2	6	295	2.03
3	9	295	3.05
Average			2.61%

ASTM specifies maximum allowable silt content in fine aggregate for concrete is 3% by weight of total fine aggregate our result yields 2.61 it is acceptable. It is important to note that the specific requirement of fine aggregate used in concrete can vary depending on application and local standards and regulations so according to Ethiopian standards, silt content should not be greater than 6%. As shown in Table 4.1 the average of the three-trail test of silt content of fine aggregate used for this study was 2.61 %. The result implies that using this fine aggregate for construction purposes is permissible.

4.2.2 Sieve analysis of fine aggregate

The gradation test is done to determine the distribution of aggregate particles, by size, within a given sample in order to determine compliance with design, production control requirements, and verification specifications. Hence, the aim to perform this test is was to determine the fineness modulus of fine aggregate.

Table 4.2 Sieve analysis results and ASTM standard for fine aggregate

Sieve size (mm)	Weight retained (g)	Percentage retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C33 requirements
4.75	0	0	0	100	95-100
2.36	110	11	11	88	80-100
1.18	130	13	24	65	50-85
0.63	310	31	55	34	25-60
0.3	360	36	91	8	5-30
0.15	70	7	98	2	0-10
Pan	20	2	100	0	0
Total	1000g	Total	279		

$$\% \text{ retained} = \frac{\text{Weight of retained sample on individual sieve or pan}}{\text{Total weight of original sample}} \times 100$$

$$\text{Fineness modules} = \sum \left(\frac{\text{cumulative percent of retained}}{100} \right) = \frac{296}{100} = 2.79$$



Figure 4.1 Sieve analysis test of fine aggregate

FM of the fine aggregate fraction is also an important predictor of other characteristics of both plastic and hardened concrete like workability, finish ability, shrinkage, porosity, permeability, strength, and the tendency to crack. A higher FM index indicates coarser aggregate that produce a “harsh” mix, prone to segregation and difficult to place and finish properly. A low FM indicates finer aggregate that require additional cement and increase water demand. This mix is easier to place and finish, but costlier, with increased potential for early-age cracking. According to ASTM C33 (2003) Fineness modules value in range from 2.3 to 3.1. So this sand is acceptable in terms of gradation distribution since its FM is 2.79. To assure the existence of fine aggregate gradation lied in between ASTM standard lower and upper limit the following gradation curve is plotted and as shown in Figure 4.2 the fine aggregate used in this experimental research meet ASTM standard.

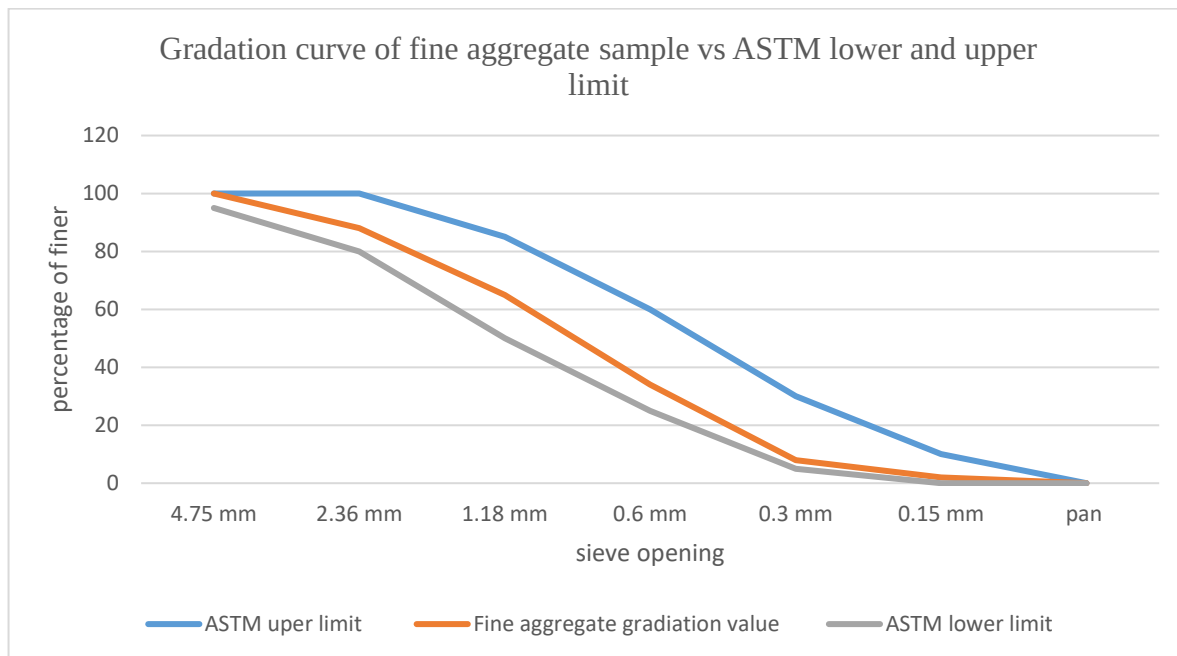


Figure 4.2 Gradation curve of fine aggregate sample vs ASTM lower and upper limit

4.2.3 Unit weight

The unit weight of fine aggregate is the weight of the sand that is required to fill a container of a specified unit volume.

$$\text{Unit weight} = \frac{\text{weight cylinder and fine aggregate} - \text{weight of empty cylinder}}{\text{volume of cylinder}}$$

Weight of the fine aggregate plus the cylinder was 6.817 kg

Weight of empty cylinder was 4.734 kg

Volume of the cylinder was $= \left(v = \frac{\pi d^2 h}{4} \right) = 0.001375 \text{ m}^3$

Unit weight $= \frac{6.817 - 4.734}{0.001375 \text{ m}^3} = 1515 \text{ kg/m}^3$

Unit weight of fine aggregate was within the range 1200 to 1750 kg/m³ that specified by ASTM C29. Therefore, the computed result, which is 1515 kg /m³, is acceptable.

4.2.4 Specific gravity

Specific gravity is the ratio of the mass of a given volume of a material to the mass of an equal volume of water, which could tell us how much the material is heavier than water. Where:- A :-

Weight of oven dry specimen in oven, = 495.

B: - Weight of pycnometer filled with water, 1500.

C: - Weight of pycnometer with specimen and water =1820

D: - Weight of saturated surface dry specimen,=500

Bulk specific gravity $= \frac{C}{B+(D-C)} = \frac{500}{1500+500-1820} = 2.75$

Apparent specific gravity $= \frac{A}{A + (B - C)} = \frac{495}{495 + 1500 - 1820} = 2.8$

Water absorption capacity $= \frac{D-A}{A} \times 100 = \frac{500-495}{495} \times 100 = 1.01 \%$

Table 4.3 Summary of physical properties of fine aggregate

No	Property	Test Result
1	Silt content	2.61
2	Fineness Modulus	2.79
2	Bulk Specific Gravity	2.75
3	Unit weight	1515
4	Apparent specific gravity	2.8
5	Water Absorption	1.01

4.3 Tests for coarse aggregate

The laboratory test was carried out to identify the physical properties of the coarse aggregate those was gradation, bulk specific gravity, apparent specific gravity and water absorption capacity and moisture content .

4.3.1 Sieve analysis of coarse aggregates

The grain size distribution of the coarse aggregate and the grading requirement for coarse aggregate performed according to ASTM C136 (2006) as show in Table 4.4 below

Table 4.4 Sieve analysis results and standard for coarse aggregate

Sieve size (mm)	Weight retained (gm)	Percentage retained (%)	Cumulative retained (%)	Cumulative passing (%)	ASTM C 331
20	0	0	0	100	100
19	500	10	10	90	90-100
12.5	1530	30.6	40.6	59.4	40-80
9.5	1270	25.4	66	34	20-55
4.75	1690	33.8	99.8	0.2	0-10
Pan	10	0.2	100	0	0
Total	5000		216.8		

$$\text{Finesse modules} = \frac{\text{cumulative \% retained} + 500}{100} = \frac{216.8 + 500}{100} = 7.1$$

Fineness Modulus limits for coarse aggregate ranges from 5.5 to 8.0. The FM of coarse aggregate which is used for this research is become 7.16 so it is acceptable.

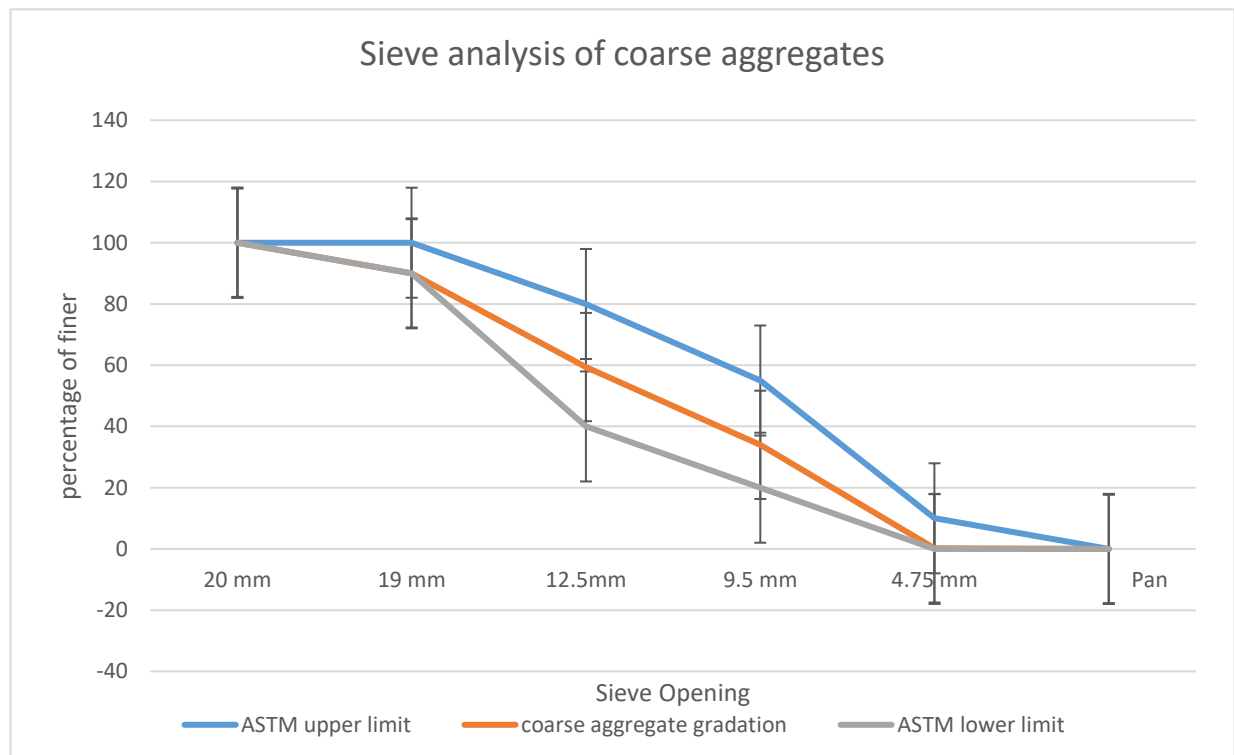


Figure 4.3 Gradation curve of fine aggregate sample vs ASTM lower and upper limit

It is not necessary that 100% of the particles of an aggregate be within the specified size range for construction purposes. A small amount, unusually 5% or 10% is allowed to be either larger or smaller than the specified size. Therefore, if 19mm is the maximum size of aggregate desired for concrete mix, specifications indicate that the nominal maximum size is 19mm. In this case, 90% of the sample must be smaller than 19mm and 100% smaller than the next higher standard size.

4.3.2 Unit Weight of Coarse Aggregate

The unit weight of coarse aggregate is the weight of the coarse aggregate required to fill a container of a specified unit volume. The unit weight is computed in kg/m³ from the net weight of the rodded aggregates in the bucket divided by its volume.

Where G = Combined mass of the oven-dry aggregate and the bucket, = 7.0577 kg

T = Mass of the bucket alone, kg = 4.734

V = Volume of the bucket, m³ = 0.001375 m³

$$\text{Unit Weight of Coarse Aggregate} = \frac{(G-T)}{V} = \frac{(7.057-4.734)}{0.001375\text{m}^3} = 1690 \text{ kg/m}^3$$

According to ASTM C 29/C29M-20a unit weight of coarse aggregate for concrete ranges from 1400 Kg/m³ – 1700 kg/m³ there for the aggregate unit weight got above which is 1690 kg/m³ satisfied the ASTM standard.

4.3.3 Specific Gravity and Water Absorption

Specific gravity and water absorption of coarse aggregate were computed to study the physical property of coarse aggregate and their compliance to the standard is checked. To get an idea of the internal structure of the aggregate and the strength of the aggregate.

Weight of oven dry specimen (A) was 4960 gram.

Weight of saturated surface dry specimen (B) was 5094 gram.

Weight of specimen in the water without wire basket (C) was 3300 gram.

Weight of basket in water was 522 gram

$$\text{Bulk specific gravity} = \frac{B}{B-C} = \frac{5094}{5094-3300} = 2.83$$

$$\text{Apparent specific gravity} = \frac{A}{A-C} = \frac{4960}{4960-3300} = 2.98$$

$$\text{Water Absorption capacity} = \frac{B-A}{A} \times 100 = \frac{5094-4960}{4960} = 2.7$$

Table 4.5 Summary of Physical properties of aggregate

No	Property	Test result
1	Fineness Modulus	7.1
2	Bulk Specific Gravity	2.83
3	Water absorption capacity	2.7%
4	Unit weight	1690 kg/m ³

4.4 Water

Portable water is used in the study for both mixing and curing. Clean water that is free from organic matter, silt, oil and acidic materials was be used. The quantity of water is the most important parameter and is controlled by the w/c ratio. As the quantity of water in a mix goes up the strength decreases, durability decreases, and workability increases.

4.5 Bentonite preparation and characterization

Afar calcium bentonite stone were dried then grinded to passed through a 75 μ m sieve and then calcined in electrical furnace at 700 °C for 2h. it is observed that the pozzolanic reactivity of calcium bentonite is improved at an optimum calcination temperature of 700 °C by destruction of the crystalline structure and the formation of non-crystalline compound enhanced pozzolanic activity by facilitating chemical reaction. Additionally, the physical and mechanical characteristics of the clay are altered. As shown in Fig.4.4, it is observed that the color of the bentonite changes from grey to reddish-brown upon heating this color change comes from the modification in iron oxide content. This could be verified with phase analysis of the raw and calcined clay by the X-ray diffraction method.



Figure 4.4 Bentonite preparation process

4.5.1 Chemical composition of bentonite

As shown in appendix D, Chemical composition of calcined bentonite is have percentage composition of ; SiO_2 (65.34%) + Al_2O_3 (14.39%) + Fe_2O_3 (8.52%) = 88.25% which satisfies the pozzolanic requirement of material as per ASTM C- 618 specifications which recommend minimum 70%.

The loss on ignition (LOI) value for the bentonite was found to be 3.77 %, falls in the range that specified by the same standard which is 10%, and bentonite is ultra-fine material which 86% powder pass through 45 micrometer sieve, which satisfy the ASTM requirement of fineness. So from chemical analysis result it conclude that bentonite can be used as a cement replacement in concrete. The comparison of bentonite test result and ASTM standard is tabulated below in Table 4.6

Table 4.6 Pozzolanic property of bentonite

Characteristics	ASTM Standard (%)	Bentonite characteristics (%)	Remark
Fineness (max % retained on 45 sieve)	34	16	Satisfied
Minimum $\text{SO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	70	88.25	Satisfied
Max LOI	10	3.77	Satisfied

4.5.2 Unit Weight of bentonite

Unit weight is physics terms that relate volume, amountof concentration or density and weight along with specific gravity. Unit weight of bentonite was calculated as follow

Weight of empty cylinder was 4.740 kg

Volume of the cylinder was 0.001375 m³

Weight of the cylinder filled with bentonite was 5.285 kg

$$\text{Unit weight} = \frac{\text{weight cylinder filled with bentonite} - \text{weight of empty cylinder}}{\text{volume of cylinder}}$$

$$\text{Unit weight of bentonite} = \frac{5.285 - 4.740}{0.001375} = 593 \text{ kg/m}^3$$

As the result, unit weight of bentonite is much lower than unit weight of cement, which is 1440 kg/m³ that indicates concrete with partial replacement of cement by bentonite have less weight than concrete with pure cement.

4.5.3 Finesse of bentonite

Sieve analysis of bentonite powder and cement is done to determine the percentage of fine particles of that pass through a sieve opening of 75 µm.as a result 91% of bentonite powder was passed through sieve opening of 75 µm, whereas 75 % cement passed on the same sieve.

Table 4.7 Fineness of bentonite

Sieve size (µm)	Cement		Bentonite	
	Weight retained	% of retained	Weight retained	%retained
150	0	0	0	0
75	12.5	25	4.5	9
Pan	37.5	75	45.5	91
Total	50 g	100%	50 g	100 %

Therefore, it conclude that bentonite is finer than cement. It implies that bentonite has a larger specific surface area than cement since particle size decreases, the surface area of substances increases. Which improve particle packing by filling the micro gaps with in the cement paste that reduce pores and contribute for durability of concrete.

4.5.4 SEM result of raw bentonite and calcined bentonite

The scanning electron microscopy image taken out to find the shape and size of bentonite powder particles at 105⁰c heating and at 700⁰c calcination temperature. The calcination changes the topology of bentonite. The images that illustrate this are presented below on figure 4.5

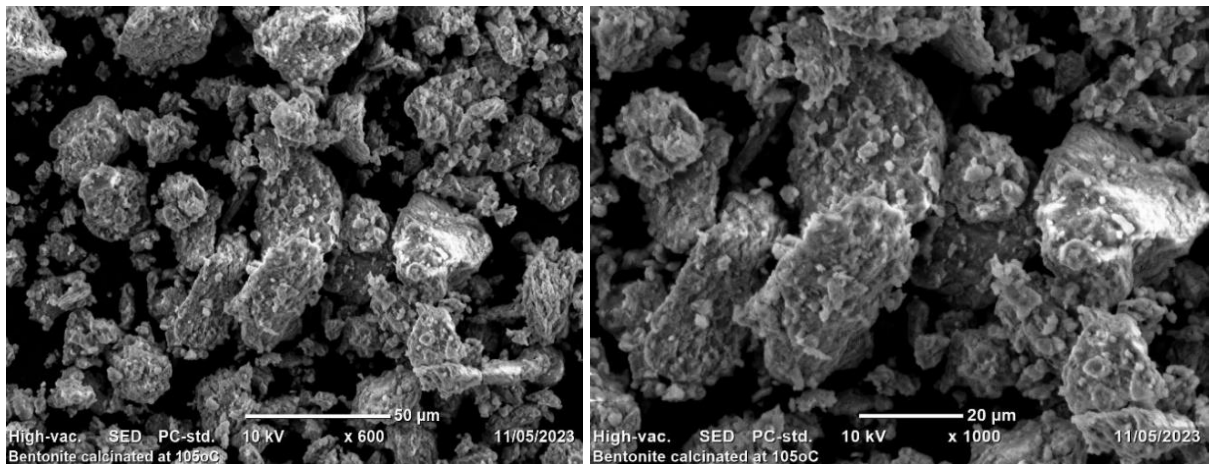


Figure 4.5 SEM image of bentonite at heated at a temperature of 105°C

At heating temperature of 105⁰c most of the bentonite morphology is distributed in very compacted layers, the surface is rough and the layers are closely arranged. Which formed by the strong interaction of octahedral bond of montmorillonite packed together by electrochemical forces, which make the clay material water absorbent and less reactive (González-Santamaría et al., 2021).

Another aspect of texture is shown by those images are the first micrograph or un calcined bentonite shows the typical surface appearance of a clay largely composed of smectite. This crinkly, ridged, honeycomb-like texture is characteristic of the smectite group and probably develops from shrinkage of the expandable clay minerals as they dry. This texture resembles desiccation mud cracks and other dewatering features. Individual crystal platelets are almost invisible in the smectites because they are small and dispersed, leaving an impression of cohesive thin films composing the basic textural units of these clays (Ural, 2021).

Afterwards, the morphology of the sample changes considerably when the calcination temperature is at 700⁰C. It can be observed that the surface of the material has become smooth, and the distribution is relatively independent and scattered and porous, which proves that the heat break the hydroxyl group from the mineral structure and decomposition of crystalline structure leads to formation of new amorphous phase which also proved by phase identification of x-ray diffraction test. and the SEM image show in the figure below on figure 4.6

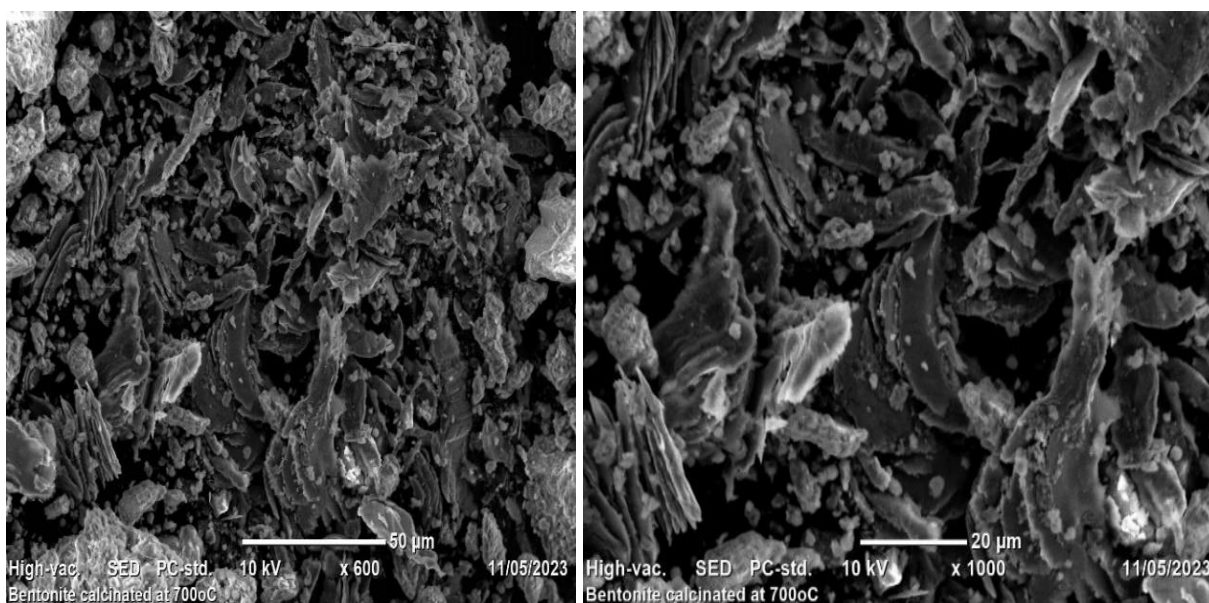


Figure 4.6 SEM image of bentonite at calcination temperature of 700°C

The flaky and oval type irregular morphology of bentonite in the SEM of bentonite images indicates that the surfaces are more loosely bound which make them highly amorphous and reactive. The SEM images also show that many residual pores are distributed within the calcined samples, indicating that the silica is an active and highly porous material (Mouzon et al., 2016).

4.5.5 XRD result of raw bentonite and calcined bentonite

Clay crystal structures and amorphous content is analyzed here. The diffraction patterns of uncalcined and calcined bentonite showed the reflections corresponding to the diffraction of the basal planes of each mineral and impurities, with the internal standard, crystalline oxides, in all x-ray patterns.

At heating temperature of 105 °C, the height of the diffraction peaks are high, but the width are narrower. it can be speculated that the appearance of ions which decrease the diffraction peak due the heat treatment at 105°C is insufficient to convert montmorillonite to the de-hydroxylated state (Ferone et al., 2015) . Unlike the results of low-temperature calcination, the diffraction peaks of montmorillonite decreased significantly for bentonite calcined at 700°C. It indicates that the de-hydroxylation reaction of montmorillonite occurred and the amorphous alumino silicate phase was formed (W. Li et al., 2022). The active Si-O-H bonds break and recombine to form the stronger Si-O-Si bonds is takes place. Furthermore, increases in the amorphous alumino silicate content reduced the cohesiveness, which can reflect the pozzolanic activity of the calcined bentonite (Taylor-Lange et al., 2015)

The results, shown in Figure 4.7, the first strongest peak found at 2 theta degree of 21.7780 represents montmorillonite. The second strongest peak found at 2 theta of 20.0028 the third strongest peak observed at 2 theta of 27.7265 These findings are consistent with previous studies by (Yang et al., 2021). According to the crystal data sheet JCPDS00-046-0744, they correspond to Miller Indices (hkl) (111), (022), (114)

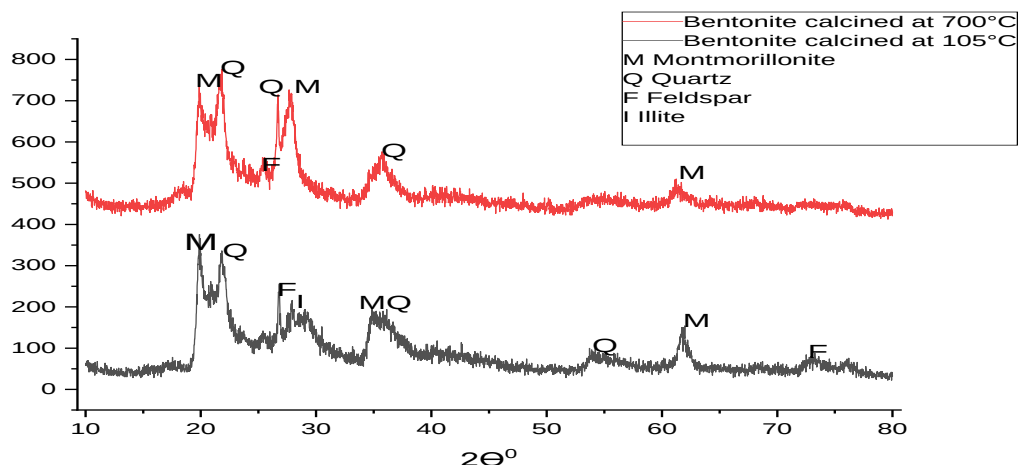


Figure 4.7 XRD graph of calcined and un-calcined bentonite

Some of the changes that observed on the XRD graph of bentonite after calcination at 700 degrees Celsius include:-Decrease in intensity of the peak: The montmorillonite peak is the most prominent peak in the XRD pattern of bentonite, and it is associated with the basal spacing of the montmorillonite layers. After calcination, the intensity of this peak decreases due to the loss of hydroxyl bond and the collapse of the clay structure. Calcination at high temperatures can cause the formation of new phases, such as mullite or cristobalite, which can be identified by the appearance of new peaks in the XRD pattern. The peak positions in the XRD pattern of bentonite can shift due to changes in the lattice parameters caused by the mineral transformations that occur during calcination.

The interpretation of an XRD pattern of calcined bentonite with peaks on (022), (-111), (-114), (202), and (131) according to the crystal data sheet JCPDS00-046-0744, which corresponds to Miller Indices peak of (hkl) (111), (022), and (114), is as follows: The (022) that appear on 2 theta degree of 21.7780° corresponds to quartz clay mineral in the bentonite structure. The position and intensity of this peak can provide information about the interlayer spacing and the degree of crystallinity of the material. The (-111) peak corresponds to the presence of the clay mineral montmorillonite in the bentonite structure in our graph it is observed on $2\theta^\circ$ of 18.2424° . The (-114) peak corresponds to the presence of the clay mineral illite in the bentonite structure it presented at $2\theta^\circ$ of 26.7680° . The (202) peak corresponds to the presence of the mineral quartz in the bentonite structure quartz observed as a second strongest peak appear on $2\theta^\circ$ of 21.7780° . The (131) peak corresponds to the presence of the mineral mullite in the

bentonite structure from the xrd data it is presented at 2 theta of 35.7572 with low intensity. Overall, the XRD pattern of calcined bentonite with peaks on (022), (-111), (-114), (202), and (131) suggests the presence of montmorillonite, illite, quartz, and feldspar in the sample. The position and intensity of these peaks can provide information about the degree of crystallinity of each mineral phase and the abundance of each in the sample.

Feldspar is not typically found in bentonite after calcination. The appearance of feldspar in the XRD pattern of calcined bentonite at 700 degrees Celsius would depend on the concentration and particle size of the feldspar in the sample. It is important to note that the presence of feldspar in the XRD pattern of calcined bentonite at 700 degrees Celsius would likely indicate incomplete calcination of the sample, as feldspar has a much higher melting point than the clay minerals present in bentonite. Complete calcination of bentonite at 700 degrees Celsius should result in the complete transformation of the clay minerals to their respective oxide phases, such as silica, alumina, and magnesia, without the presence of any residual minerals. In this XRD graph feldspar is disappeared after calcination.

4.6 Preliminary testes results to determine glass fiber content

Preliminary tests to determine the appropriate glass fiber content for use in concrete typically involve a series of trial mixes, in which different amounts of fiber (0.3%, 0.5%, 0.7%, 1%) by percentage weight of concrete materials and the resulting properties of the concrete are evaluated. These tests include slump test, compressive strength test and flexural strength tests.

4.6.1 Workability of glass fiber concrete

The slump values of fresh concrete with addition of glass fiber depict that, addition of glass fiber decrease the workability of the concrete and it is onerous to cast the concrete in high percent addition of glass fiber because it creates a ball of fiber. To create smooth surface and to remove all airs during casting it is mandatory to have long vibration time for compaction when it compare with control. 0.3%, 0.5%, 0.7% and 1% addition of glass fiber show and a dropped slump by 6.6 %, 13.33%, 23.33%, and 30 % respectively, when compared to the control slump value. Detail slump value for each mix is presented in Table 4.8 below.

Table 4.8 Slump value of glass fiber concrete

Percentage of fiber added	Water cement ratio	Slump value (mm)	Percentage of loss of slump with respect to control
Control	0.5	30	0
0.3 %	0.5	28	6.6
0.5 %	0.5	26	13.33
0.7 %	0.5	23	23.33
1 %	0.5	21	30

The slump value of fresh concrete decrease from 30mm to 20mm when it goes from 0% to 1% addition of glass fiber but the water cement ratio is not changed and the maximum slump loss is 10 mm. It emphasis that if the percentage of addition is increase above this level additional water is required since the slump selected in mix design is minimum of 20mm. However, this effect can be mitigated by using the appropriate type and amount of glass fiber, as well as by adjusting the mix design and placement techniques to accommodate the fiber. Like using smaller diameter fibers or shorter lengths may be used to minimize their impact on workability.

4.6.2 Compressive Strength of glass fiber concrete

Compressive strength of concrete is a measure of how well it can withstand being compressed or subjected to pressure without any cracks or deflection on its surface. For this research the effect of adding glass fiber in compression resistance of concrete evaluated after 7 and 28 day of curing was tasted. The detail results of compressive strength test are tabulated in Appendix B1, and average compressive strength results are presented in the Figure 4.8.

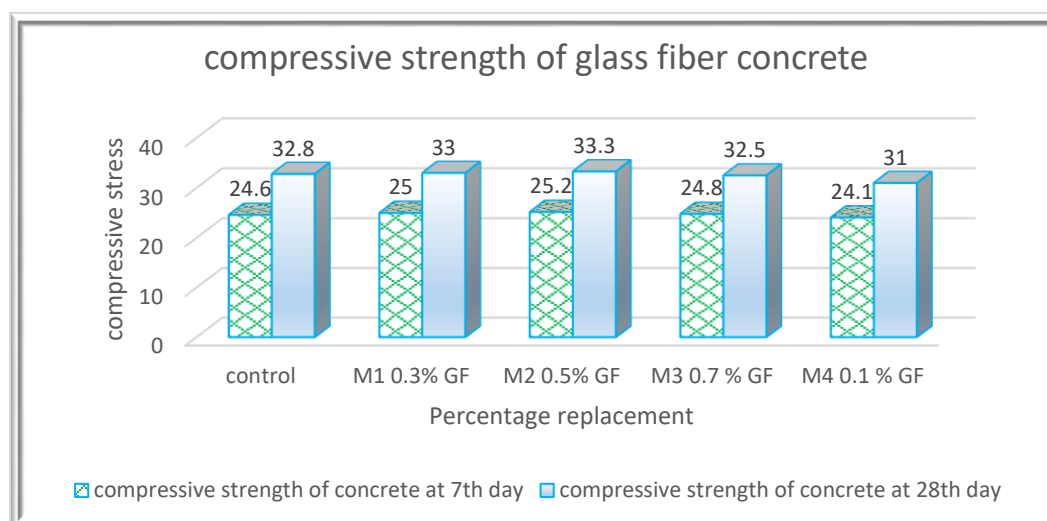


Figure 4.8 Compressive strength of glass fiber concrete

Based on compressive strength result show in figure 4.8 above, it was clearly observed that, As the date of curing increases the compressive strength of concrete increases. The maximum result of compressive strength was found at 0.5 % GF addition. After 0.5% GF compressive strength starts to decline but still greater than the plain concrete. This due to the fact that fibers limit cracks which are responsible for failure and in this research glass fiber used as part from sand so this compressive strength increment come from the glass fiber resistance to compression than sand. This shows that there is synergetic response of glass fiber to resist the applied compressive load. Nevertheless, when the percentage excide the limit it starts to decline. The compressive strength increment for the optimal glass fiber content that means for 0.5% is 1.5%. There are some research prevail that the compressive strength of concrete is enhanced by addition of glass fiber up to 10% (Deshmukh et al., 2012; Hilles et al., 2019).

4.6.3 Flexural strength of glass fiber concrete

Since the objective of adding glass fiber in concrete is to enhance the tensile strength and bending ability of concrete the selection of glass fiber content is depend on flexural strength rather than enhancement in compressive strength. Addition of glass fiber yield positive result in all level of addition but the maximum strength is got at 0.5 % addition of glass fiber. The overall test result are summarized and presented in figure 4.9 below and detail result is tabulate under appendix B2.

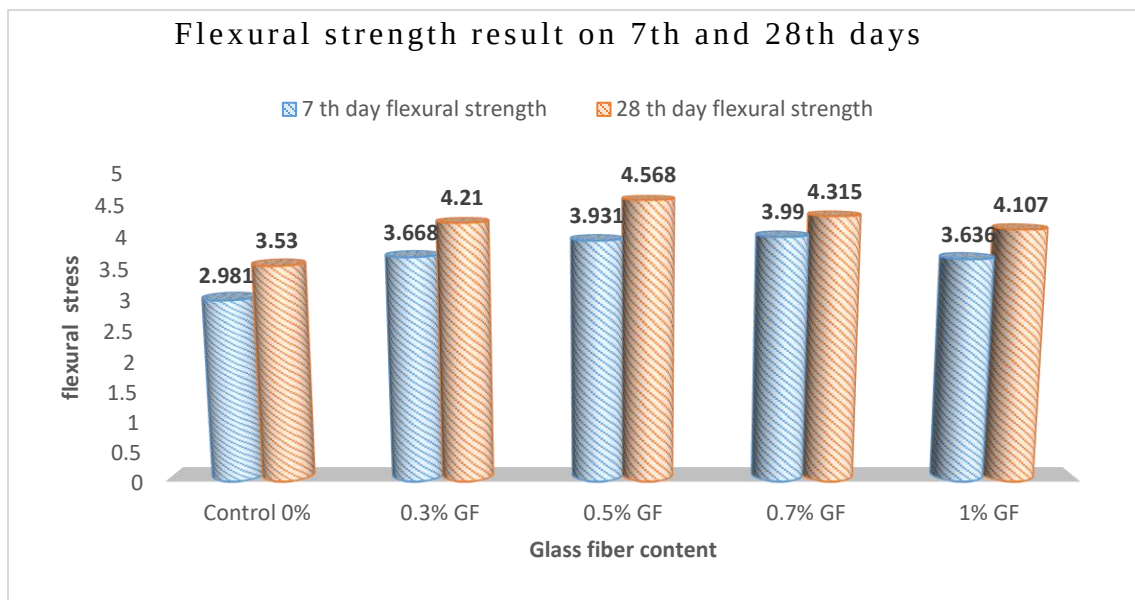


Figure 4 9 Flexural strength of glass fiber concrete

From the above chart, it is observed that the flexural strength of concrete increased from the control specimen in both 7th and 28th testing dates. The increment from control at 28 day for 0.3 percent addition of glass fiber was increased by 19.29 %, for addition of 0.5 glass fiber flexural strength increase by 29.40 %. But after this point the flexural strength doesn't show increment it yield 22.26 % increment which decrease by 7.14 % for 0.7% glass fiber addition and 16.34 % for 1% fiber addition compared from plain concrete. So 0.5 % glass fiber content taken as the optimum glass fiber content that yield maximum flexural strength. Further test is performed by taking 0.5% glass fiber as reinforcement additive and trial tests are conducted to determine bentonite replacement percentage of cement. By altering bentonite percentage by 5%, 10%, 15 % and 20% by weight of cement.

4.7 Main experimental work by blending of glass fiber with bentonite

4.7.1 Cement and fresh concrete test results

4.7.2 Normal consistency test of cement paste

This test method is intended to determine the amount of water required to prepare hydraulic cement pastes for mixing. The test was done according to (ASTM C 187– 98, 2004) standard by using Vicat apparatus. Table 4.9 shows summarized result of the pastes with varying percentages of water until the normal consistency was obtained. The control paste and blended mix of cement and bentonite at different percentage of replacement level had studied, normal consistency of 28% control mix is got, and all of the pastes containing bentonite showed normal consistency equal and higher than the control paste. Amount of water required in order to give the normal consistency was 28%, 28%, 30%, 33% and 35 % respectively for 0%, 5%, 10%, 15% and 20% replacement of cement by bentonite.

This finding on the consistency of the blended pastes conformed that when replacement percentage of bentonite increases by 5 % interval the water demand increase. However no change is observed in water demand for 5% replacement but the penetration decreased however still stay in the limit, when replacement increase additional 7%,17.2%, 25% water needed respectively for 10%, 15 % and 20% bentonite substitution to get normal consistency.

The increment on water requirement due to the higher fineness of bentonite and its chemical arrangement as compared to cement.

Table 4.9 Normal consistency of ordinary portland cement and bentonite

No	Designation	Percentage of Water	Amount of water	Penetration Depth at 30 second (mm)
1	Control	28	140	10.5
2	5% BN	28	140	10
3	10% BN	30	150	11
4	15% BN	33	165	10.5
5	20% BN	35	175	10

Usual range of water to cement ratio for normal consistency is between 26% and 33%. The pastes with replacement up to 15% showed a consistency within this range, however, on bentonite replacement of 20% results showed slightly higher values than this range.

4.7.3 Workability of glass fiber concrete with bentonite

The slump test of fresh concrete inferred that replacement of bentonite by cement with addition of glass fiber decrease the workability of the concrete since the loss of workability is significant additional water is used to make concrete expedience for work at high percentage replacement of cement by 10%, 15% and 20% replacement values. The full results are tabulated under Table 4.10 below.

Table 4.10 Slump value of glass fiber added and bentonite replaced fresh concrete

Percentage of fiber added and bentonite replaced	slump by 0.5 w/c (mm)	Corrected Water cement ratio	Slump value (mm)
Control	30	0.5	30
0.5 % GF with 5% BN	25	0.5	25
0.5 % GF with 10% BN	19	0.53	25
0.5 % GF with 15% BN	17	0.55	20
0.5 % GF with 20% BN	15	0.58	20

For replacement of cement by bentonite with 5% no additional water is required to maintain the workability even the slump value is decreased from the control since it was workable no additional water is used. For replacement level of 10% additional 6% water is used for 15% and 20% replacement additional 10 % and 16 % water is used to make the mix workable. The slump

test carried out for all mixes were done using the apparatus inverted slump cone shown in Figure 4.10



Figure 4.10 Workability test of concrete by slump cone

4.8 Hardened Concrete

Testing of hardened concrete is important because the test can investigate the fundamental physical behavior of concrete such as elastic properties and strength characteristics and durability of concrete work; when physical laws are not fully understood, testing can simulate expected conditions to evaluate performance.

4.8.1. Unit weight of glass fibered concrete with replacement of cement by bentonite

Average unit weight of cube on 7th and 28th days for control and glass fiber blend with bentonite are calculated and shown in Table 4.11 below. Cross section of cube used was (150*150*150) mm the volume become 0.003375 m³

Table 4.11 Unit weight of glass fibered concrete with replacement of cement by bentonite

Concrete type	Day of testing					
	7 th day			28 th day		
	Mean mass (kg)	Unit wt. (kg/m ³)	Reduction (%)	Mean mass (kg)	Unit wt. (kg/m ³)	Reduction (%)

Control	8.25	2444.44	0	8.3	2459.26	0
5%	8.13	2408.88	1.4	8.19	2426.66	1.3
10%	8.10	2400	1.8	8.15	2414.81	1.8
15%	8.06	2388.14	2.3	8.11	2402.96	2.29
20%	7.9	2340.74	4	8.05	2385.18	3.01

As discussed in 4.5.2 the unit weight of bentonite is 593 kg/m³ and unit weight of cement is 1440 kg/m³ which implies that bentonite is 41.18% less in density than cement so when the when amount of bentonite substitution increase, the density of the concrete decrease. The biggest reduction in a unit weight of 4 % was obtained when 20 % of the cement replacement by bentonite during the 7 day curing period. The graphical presentation of unit change with respect to replacement level is presented below in figure 4.11

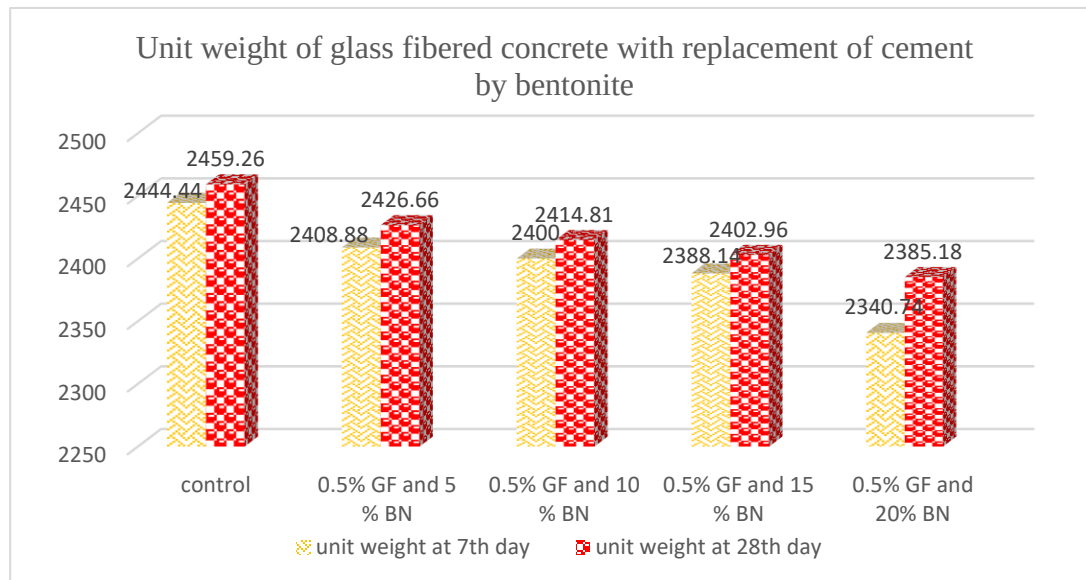


Figure 4.11 Unit weight of glass fibered concrete with bentonite

The biggest reduction in a unit weight of 3.01 % was obtained when 20 % of the cement replacement by bentonite during the 28 day curing period.

4.8.2 Compressive strength of bentonite and glass fiber blend

For observing, the changes in performance of concrete due to the substitution of part of cement by bentonite and addition of glass fiber five types of mixes have prepared with addition of bentonite by five percent interval up to twenty percent and the observed results are summarized

and presented below in Table 4.12. The detailed results of the compressive strength tests are given in the appendix C1

Table 4.12 Compressive strength test results of glass fibered concrete with bentonite

Mix type	7 th day		28 th day		56 th day	
	Average peak load	Average compressive stress	Average peak load	Average compressive stress	Average peak load	Average compressive stress
Control 0%GF 0% BN	577.66	25.67	752	33.41	753.33	33.47
Mix1 0.5%GF &5%BN	516	22.93	580.66	25.80	777.3	34.55
Mix2 0.5%GF &10%BN	351.66	15.62	527.66	23.44	783	34.79
Mix3 0.5%GF &15%BN	330	14.66	458.33	20.36	579.33	25.74
Mix4 0.5%GF &20%BN	266	11.81	392.33	17.43	505.66	22.47

According to data presented in Table 4.12, at 7 days, the compressive strength of the control mix was recorded as the highest value 25.67 N/mm² but the replaced concrete yield maximum result of 22.92 N/mm² at 5 % replacement of bentonite which decrease by 10.71% and the early strength decrease with an increasing the replacement level. Because of concrete with pozzolanic materials does not achieve early strength when compared to normal concrete due to slow hydration and slower setting.

While the compressive strength of the bentonite and cement mix was plummy than control mix when the curing date is at 56th day. At this time the control compressive strength was 33.47 N/mm² and 5 % and 10% replacement have compressive strength of 34.55 N/mm² and 34.79 N/mm² respectively, they were the highest values for their respective curing days than the control mix. concrete with 5 % bentonite replacement maintains maximal compressive strength during seven day and 28 day of curing from the replacement mixes. However, at 56 day of curing the compressive resistance of 10 % replacement were better than 5 % replacement it is due to the fact 10% replacement contain high amount of silica that make capable to consume high amount of calcium hydro oxide that liberate during the hydration of cement. Based on the result the researcher took 10 % replacement of bentonite as an optimal replacement level to achieve the desire strength at 56thday of curing. The enhancement of strength for 10% replacement of cement by bentonite is 3.97 %. This result also can improve by taking long curing time since replacement by pozzolan require additional curing time to fully attain their

strength. Graphical outlying of compressive strength vs replacement level is presented below in Figure 4.12.

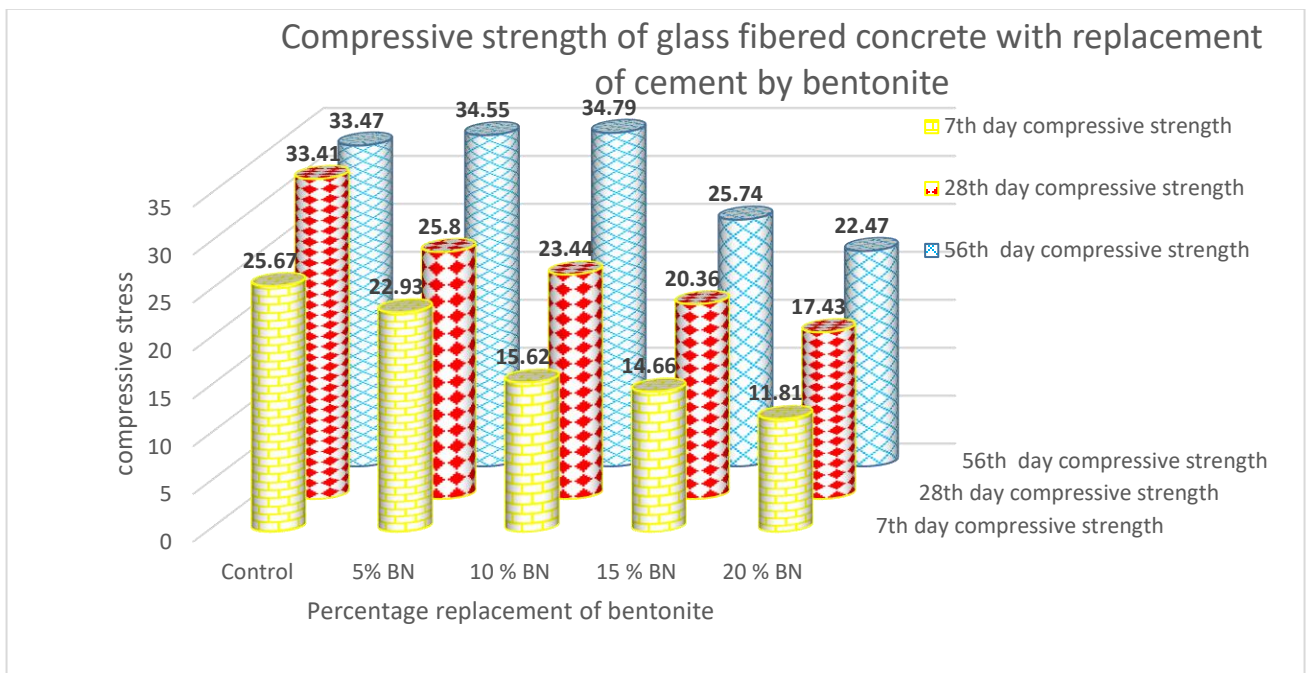


Figure 4.12 Compressive strength of GFC with replacement of cement by bentonite.

The Compressive strength of concrete samples decreased with the addition of bentonite at 7th days of curing ages as shown in Figure 4.12. This is owing to the reduction of $3\text{CaO}\cdot\text{SiO}_2$ (C_3S) alite phase amount in the mix with bentonite replacement. Which is responsible for early age strength this might also decrease the formation of Calcium Silicate Hydrated (C-S-H) gel and in bentonite replaced concrete additional Calcium Iron Aluminum Silicate Hydroxide (C-I-A-S-H) bond is created as shown on XRD of concrete. At 56th day of testing higher compressive strength of concrete was obtained at 10 % bentonite replacement of OPC which is 34.79 and exceed by 3.94% from the control mix. Moreover, the formation of additional Calcium Silicate Hydrated (C-S-H) gel is a result of the reaction of the active silica of bentonite and the $\text{Ca}(\text{OH})_2$ from cement hydration. However, the compressive strength of bentonite blended cement concrete samples decreased with high percentage replacement of 15% and 20% bentonite. The other cause for reduction of compressive strength is that the demand of additional water for cement and bentonite blend to make it workable as discussed 4.5.3 for high percentage replacement of bentonite above 10% significant additional water is used. As a result increasing water cement ratio have a negative impact on compressive strength of concrete.

4.8.3 Flexural strength of GRFC with replacement of cement by bentonite

Flexural test evaluates the tensile strength of concrete indirectly. It tests the ability of unreinforced concrete beam to withstand failure in bending. The average flexural stresses were calculated from average rupture loads recorded from the testing machine and flexural stresses are determined for each sample. The average flexural strength test results for 7 and 56 days are shown in figure 4.13 detail flexural test results are tabulated under appendix C, Table C2.

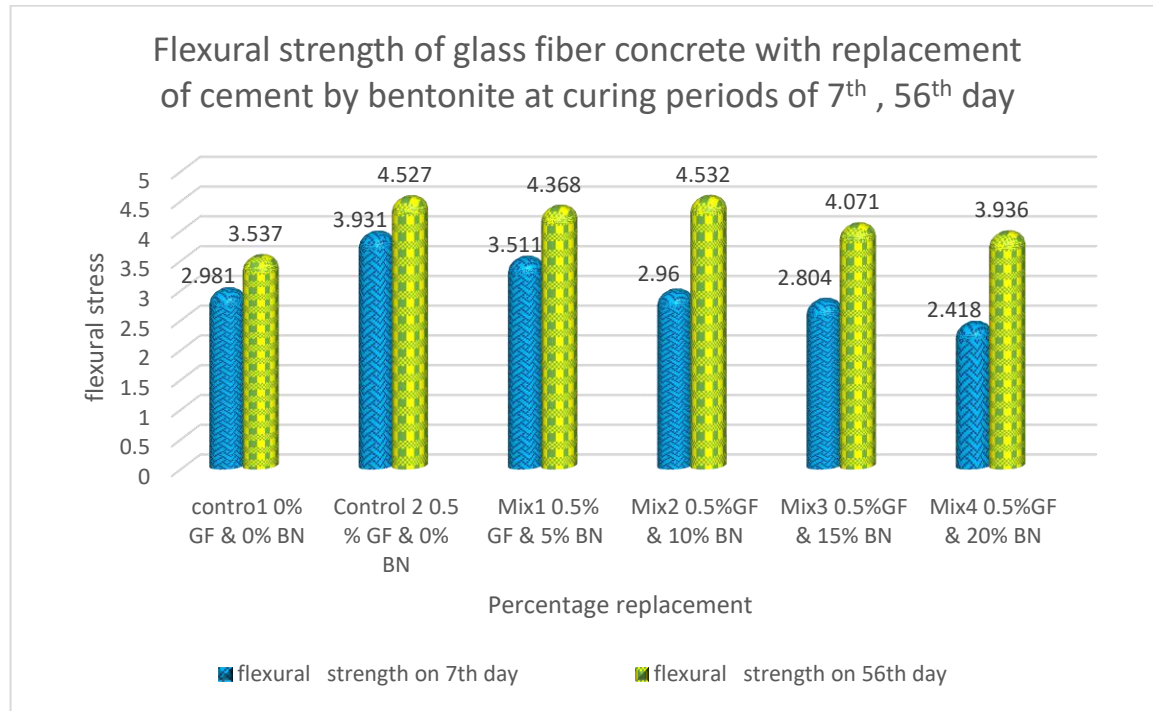


Figure 4.13 Flexural strength of GRFC with replacement of cement by bentonite

The maximum flexural resistance of concrete obtain at 0.5% glass fiber with 10% BN replacement of cement by bentonite at 56th day of testing it yields 4.532 MPa it increase by 28.13 % from plain concrete and increased by 0.88 % from glass fiber concrete without replacement of bentonite which specified as control 2. The other mix provide lesser value than this mix. When replacement percentage of cement by bentonite increase the flexural resistance of concrete decreases And 0.5% GF with 15% BN increase flexural strength by 15.12 % than the plain concrete and for the last mix flexural strength is observed to be enhanced by 11.28% from plain concrete. But This value decrease from control 2 that mean concrete with glass fiber only, by 13.07 % this tell as when the replacement of cement percentage increase the flexural resistance of concrete decrease but still greater than the plain concrete.

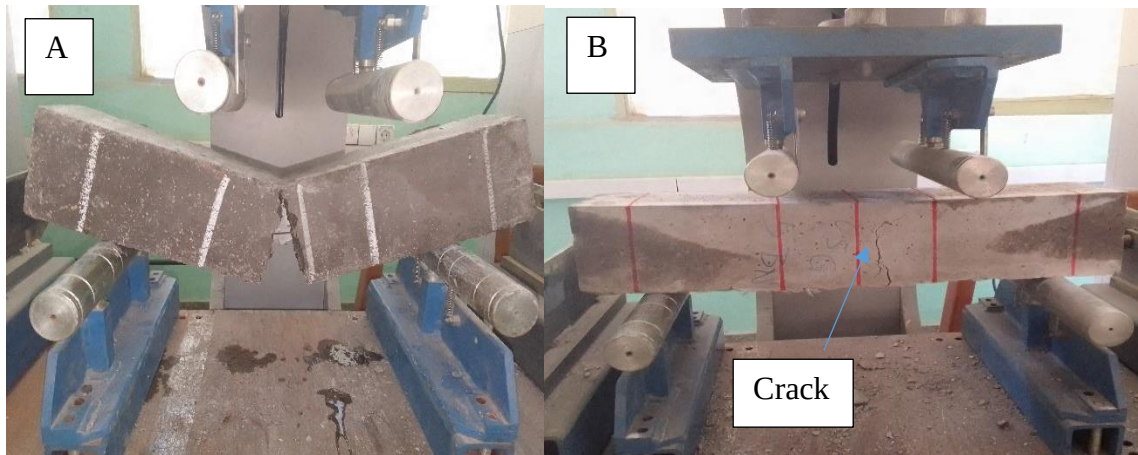


Figure 4.14 Failure crack pattern of concrete in flexural stress

As it is observed in the figure 4.14 A the concrete without fiber experience a complete failure with small flexural resistance of 3.537 MPa in the next figure 4.14 B concrete with glass fiber and 5 % bentonite resist 4.368 MPa with a small crack in its surface it emphasis that the concrete resist a flexural load even after crack.

4.8.4 Split tensile strength of GFRC with replacement of cement by bentonite

The ability of concrete material to resist a force that tends to pull it apart is lower but by adding the glass fiber, its resistance is improved. The split tensile strength test results on 7 and 56 days of testing are shown in the Table 4.13. The detail split test results are tabulated under appendix C3

Table 4.13 Split tensile strength GFRC with replacement of cement by bentonite

Mix type	7 th day		56 th day	
	Maximum load	split tensile stress	maximum load	split tensile stress
Control1 0% GF & 0% BN	140	1.98	178.33	2.51
Control2 0.5% GF & 0% BN	187.66	2.65	226.33	3.2
Mix1 0.5%GF & 10% BN	165.33	2.33	209.66	2.96
Mix2 0.5%GF & 10% BN	139	1.96	214.66	3.03
Mix3 0.5%GF & 15% BN	131.33	1.84	190.66	2.69
Mix4 0.5%GF & 20% BN	115	1.62	184.33	2.60

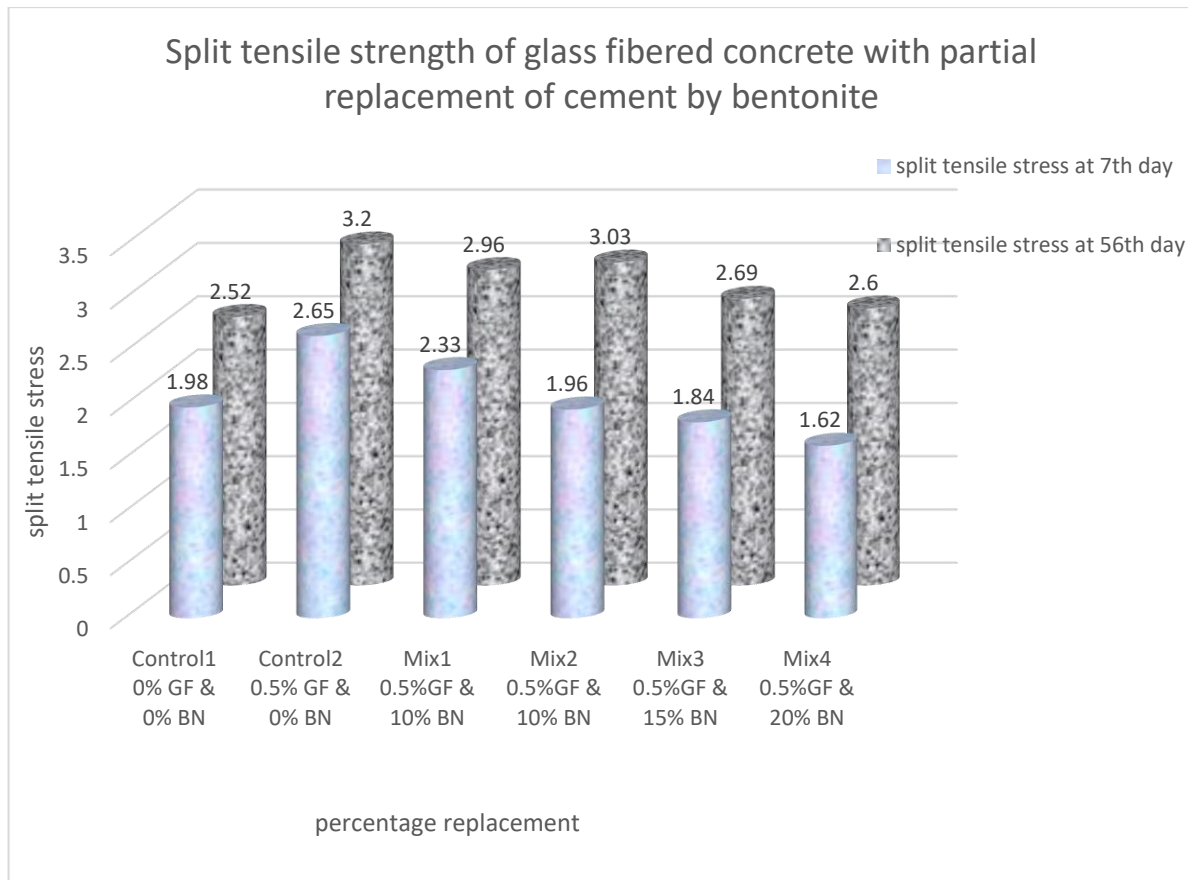


Figure 4.15 Split tensile strength of GFRC partial replacement of cement by bentonite

The minimum tensile strength observed at the control mix1 of OPC concrete without glass fiber and bentonite for both 7th and 56th day of curing. The maximum split tensile resistance is got on the second control mix, which collaborated glass fiber with ordinary portland cement with out bentonite. When bentonite replacement increase with constant glass fiber content the split tensile strength of material decrease. As a percentage implication 5% BN replacement increase split tensile strength by 17.46 % and. For 10% replacement of bentonite the increment in split stress from plain concrete is 20.23 %, which is the maximum split tensile strength resistance but it, decreased by 5.31% from control2.

For 15 and 20% replacement yield 6.7 % and 3.17 percent increment in tensile strength resistance respectively. Maximum split tensile strength attained at 10% BN replacement with 0.5 GF by 20.23% improvement of split tensile strength.

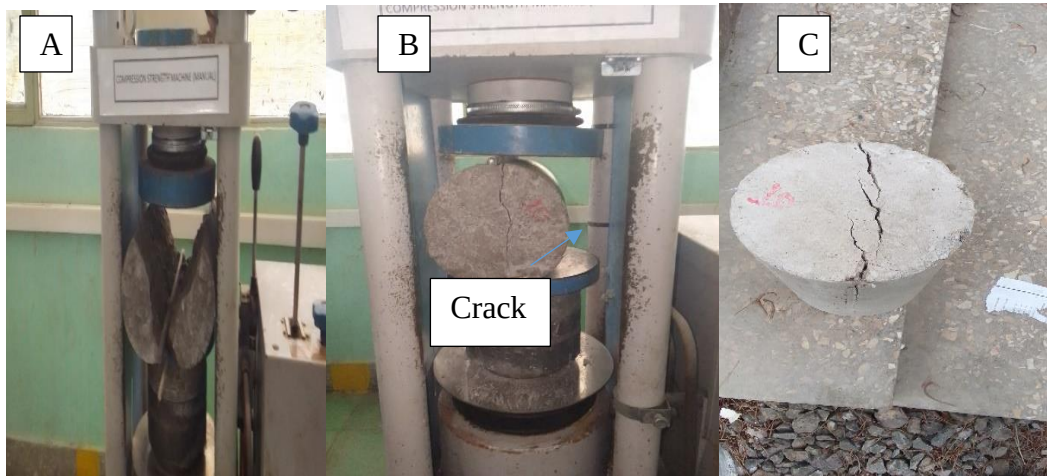


Figure 4.16 Failure crack pattern of concrete in split tensile stress A) Concrete without glass fiber B) with glass fiber C) crack pattern of Gf concrete

It is visible in the figure 4.16 A the concrete with out fiber experience a complete failure as like it observed in flexural strength test concrete with glass fiber and bentonite resist the tensile force better than plain concrete and the concrete doesn't exposed to complete failure.

4.9 Micro structural property of concrete

4.9.1 XRD test result of concrete after 7th day of curing

The major diffraction peaks that are commonly observed in XRD patterns of 7-day old cement concrete are typically associated with the mineral phases that are formed during the early stages of cement hydration. These phases include calcium silicate hydrate (C-S-H), calcium hydroxide (CH), dicalcium silicate (C_2S), tricalcium silicate (C_3S) and calcite ($CaCO_3$). The formation of C-S occurs early in the hydration process, typically within the first few hours of mixing. As the hydration process continues, C-S-H and C-A-S-H begin to form, typically after the first day of curing.

On seventh day old concrete, the most prominent peak is usually associated with the C-S-H phase, which is a poorly crystalline mineral that is responsible for the strength and durability of concrete. The peak position for C-S-H can vary, but it is typically observed at around as a broad hump between $2\theta = 29-32$ degrees correspond to various Miller indices, such as (001), (020), (110), and (002) (Esteves, 2011). Another prominent peak is usually associated with the CH phase, which is a crystalline mineral that is formed during the hydration of cement. The peak

position for CH is observed at around $2\theta = 18-19$ degrees and correspond to the Miller indices (100) and (002) (Borštnar et al., 2021).

Other diffraction peaks that observed in the XRD pattern of 7-day old cement concrete include peaks associated with un hydrated cement phases, such as tricalcium silicate (C_3S) and dicalcium silicate (C_2S). These peaks present due to cement has not fully hydrated by the 7th day of curing, or if there is an excess of un hydrated cement in the mixture. The peak positions for C_3S are observed at around $2\theta = 29-31$ degrees, while the peak positions for C_2S are observed at around $2\theta = 25-27$ degrees which correspond to the Miller indices (001), (020), (110), and (002). The other one is calcite Calcite ($CaCO_3$): This mineral phase can show diffraction peaks at Miller Indices (101) at 2 theta of 18 degrees, as well as at Miller Indices belongs ot (104), (006). Calcite can form in concrete through various mechanisms, such as the reaction between atmospheric CO_2 and calcium hydroxide (Esteves, 2011). The three strongest peaks for control and 10% replacement concrete are presented in Table 4.14

Table 4.14 XRD peak for 7th day control concrete and concrete with 10% of bentonite replacement

No	Strongest peak no	2 theta degree	D (Å)	FWHM	intensity	Integrated intensity
For 7 th day concrete without replacement of bentonite						
1	21	48.5948	1.87205	0.11090	1478	8688
2	8	27.8018	3.20633	0.12540	537	2989
3	11	29.5485	3.02065	0.20270	350	4281
For 7 th day concrete with 10% replacement of bentonite						
1	17	27.9832	3.18596	0.12200	450	3100
2	6	18.1723	4.87781	0.16970	340	31480
3	21	29.5233	3.02317	0.22690	253	2901

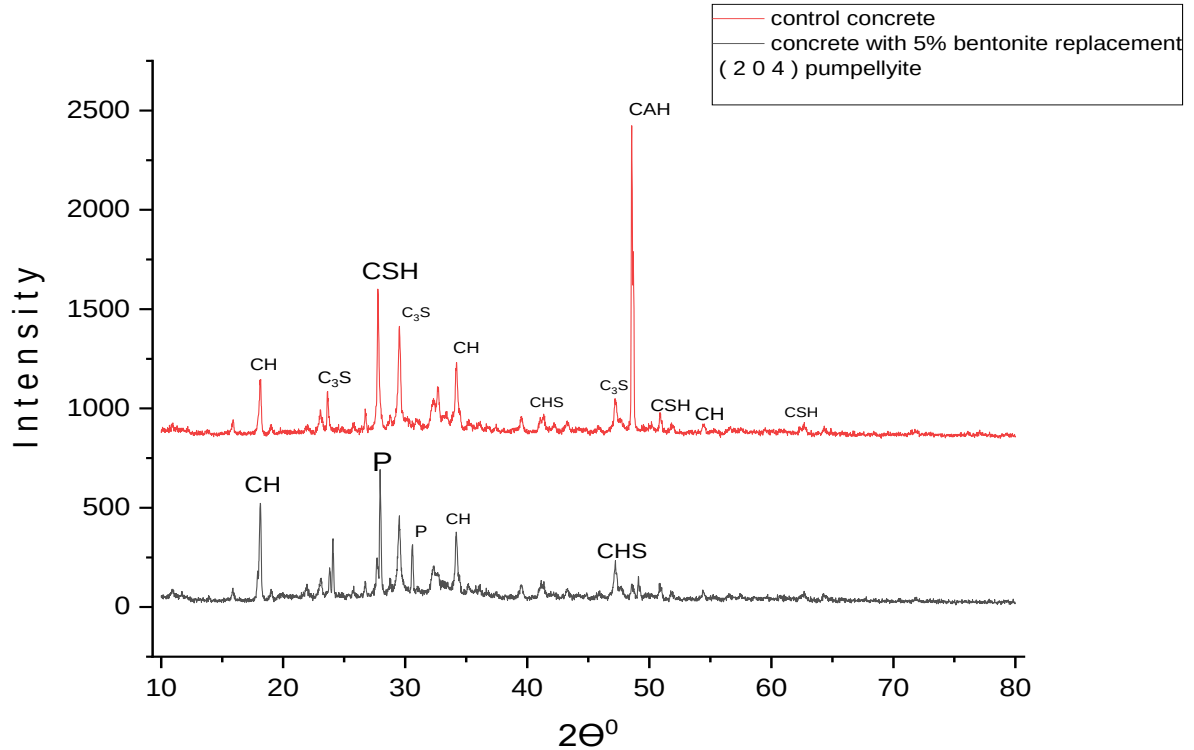


Figure 4.17 XRD graph of 7th day control concrete and concrete with 10% of bentonite replacement

Interpretation of control concrete at 7th day

The first peak observed in 2 theta degree of 18.1739 with miller indices (001) according to the crystal data sheet JCPDS 00-004-0733, indicates the presence of calcium hydroxide in the concrete sample. However, it is important to note that the presence of calcium hydroxide in the XRD pattern of concrete is a normal component of hydrated cement paste and is not necessarily a cause for concern.

The next observed phase is C_3S (Ca_3SiO_5): This mineral phase is one of the main components of Portland cement the presence in concrete XRD implies in complete hydration of cement and can show diffraction peaks Miller Indices, including (011), (200), and (220), in this graph correspond to a 2 theta of 23.6774. The presence and distribution of C_3S in concrete affect its strength, setting time, and other properties.

The mineral phase on the XRD graph of concrete with peaks at Miller Indices (hkl) (111), a 2 theta of 48.59480, according to the crystal data sheet JCPDS 00-004-0733, is likely to be

calcium aluminate hydrates (C-A-H). Tri calcium aluminate hydrates with water to form a hydrated tri calcium aluminate $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$. (C-A-H) this peak C-A-H is the result of hydration of C_3S .

Interpretation of 10 % bentonite replaced concrete

In the X-RD pattern of 10% BN replaced concrete additional compound we observe is Pumpellyite at maximum pick with miller indices of (212) Peaks found at $2\theta^0 = 27.9832$ by the reference code JCPDS of 00-036-04-37 it was the second strongest peak next to portlandite. Pumpellyite is a mineral that can occur in some types of concrete, particularly those containing volcanic ash or other types of pozzolanic materials. It is a hydrous calcium iron aluminum silicate mineral forms in low-temperature hydrothermal environments. So the formation of this material indicate that the heat of hydration of cement with partial replacement of cement by bentonite is small which prevent our concrete from thermal crack

In concrete, pumpellyite can form through the reaction of calcium hydroxide ($\text{Ca}(\text{OH})_2$) with silica-rich pozzolanic materials.

formation of pumpellyite in concrete is a complex process that depends on several factors, including the specific mineralogy of the pozzolanic material. pumpellyite got in XRD of bentonite concrete has chemical formula $(\text{Ca}_2\text{FeAl}_2(\text{SiO}_4)(\text{Si}_2\text{O}_7)(\text{OH})_2 \cdot \text{H}_2\text{O})$ named as Calcium Iron Aluminum Silicate Hydroxide C-I-A-S-H.

Existence of pumpellyite in concrete can provide valuable information about the composition and formation of the concrete, as well as its durability in long-term performance. Some possible transformations that may occur in pumpellyite at later ages of concrete hydration in like alternative recrystallization, Pumpellyite may undergo recrystallization, which involves the rearrangement of its crystal lattice structure. Recrystallization can result in changes in the chemical composition and stability of the mineral, and may result in the formation of other secondary cementitious materials.

Overall, the transformations that pumpellyite may undergo at later ages of concrete hydration depend on several factors in positive ways, and it is important implications for the properties and performance of the concrete over time.

Interpretation of Xrd peak for 28th day control concrete

The X-ray diffraction (XRD) pattern of 28-day old cement concrete shows several diffraction peaks due to the presence of various minerals and phases in the concrete. However, the major diffraction peaks that are commonly observed in XRD patterns of 28-day old cement concrete was

Calcium silicate hydrate (C-S-H): C-S-H is the primary binding agent in cementitious materials such as concrete, and typically exist in this experiment at diffraction peaks of $2\theta = 29.5195^\circ$ and 29.9634° corresponding to the (006) and (010) crystal planes, respectively. The second compound is calcium hydroxide (Ca(OH)_2) or portlandite. Ca(OH)_2 is a byproduct of cement hydration, and typically exhibits diffraction peaks at around $2\theta = 18.3^\circ$, 34.5° , and 50.3° , corresponding to the (001), (100), and (101) crystal planes, respectively. Another phase observed is calcium carbonate (CaCO_3). CaCO_3 can form in concrete due to carbonation, and typically exhibits diffraction peaks at around $2\theta = 29.4^\circ$, 47.4° , and 56.6° , corresponding to the (104), (110), and (113) crystal planes, respectively.

Ettringite ($\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \cdot 26\text{H}_2\text{O}$) is also another phase analyzed by XRD, it forms in concrete due to the reaction of gypsum with tricalcium aluminate (C_3A) in cement, and typically exhibits diffraction peaks at around $2\theta = 29.9^\circ$, 33.1° , and 37.7° , corresponding to the (020), (200), and (002) crystal planes, respectively.

Table 4.15 Results of 2 theta degree and intensity of maximum peaks of control and bentonite replaced concrete at 28th day

No	Strongest peak no	2 theta degree	D (Å)	FWHM	INTENSITY	Integrated intensity
Peak of control concrete at 28 th day						
1	29	29.5195	3.02355	0.19130	305	3267
2	25	27.9276	3.19218	0.34690	241	3799
3	39	34.1630	2.62246	0.16990	235	2242
peaks of 10% bentonite replaced concrete at 28 th day						
1	22	28.0776	3.17546	0.11790	527	3265
2	26	29.5318	3.02232	0.18320	386	3556
3	21	27.9062	3.19457	0.11760	153	1219

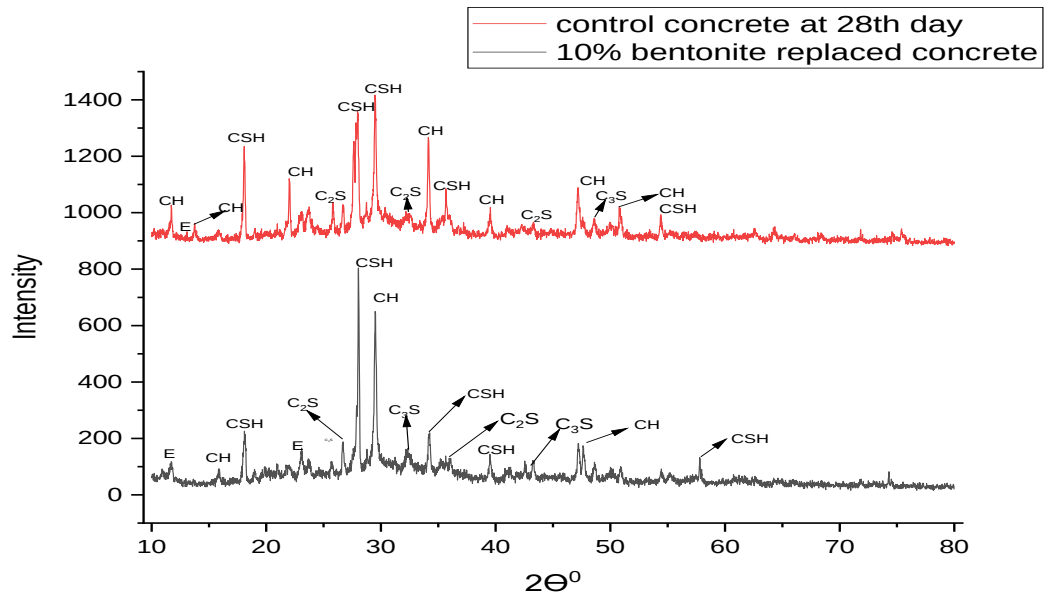


Figure 4.18 XRD graph of 28th day control concrete vs 10% BN replaced concrete

4.9.2 SEM image of concrete

Microstructural observation of concrete without bentonite and concrete with 0.5% glass fiber and 10% bentonite is observed through scanning electron microscopy machine and can be seen in the Figure 4.19. SEM images are taken after curing period of 7 and 28 days. Calcium hydroxide is identified by its relative brightness and hexagonal habits in the concrete (González-Santamaría et al., 2021). In the control mix, a narrow and bright structure with crystalline formation was observed that could be CH, as shown in the Figure 4.19(A).

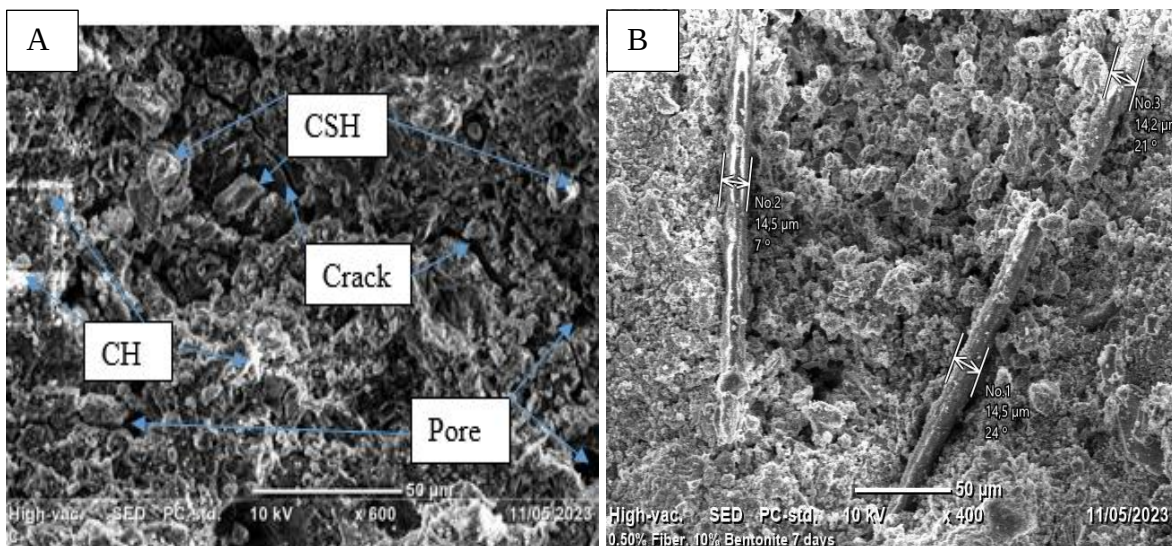


Figure 4.19 SEM images of concrete A) Plain concrete and B) Glass fiber with 10% BN

On figure 4.19 A cracks and pores are easily detected by 600x magnification but those cracks are not visible in glass fibered concrete with 10 % bentonite replacement and the size of pores also minimized this occurs due to crack limitation capacity of glass fiber and sealing ability of bentonite. As observed in this figure 4.13 B the diameter of the fibers is 14.5 micro meter which is strongly bonded with the cement paste and there is no visible cracks there, due to the crack limitation potential of the fiber but small pores are seen it, occurred due to the trouble in compaction of glass fiber concrete. It is more severe in high dosage of concrete when the glass fiber addition is more than 0.5% during preliminary test the compaction and attaining of slump value and also smoothening the surface of concrete was onerous and it is observed in SEM image. Those fibers create a ball of fiber that make concrete porous and decreases its mechanical properties. The tight fibers in concrete as seen in the fig 4.20 below

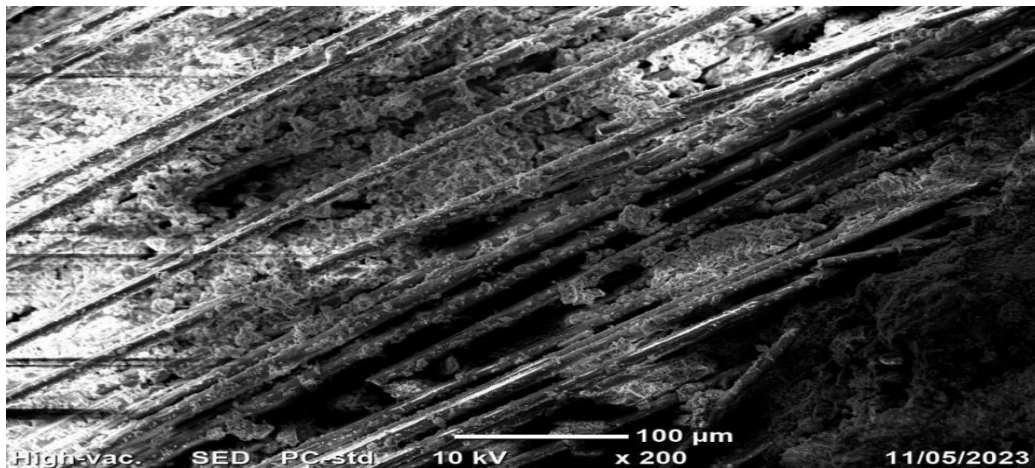


Figure 4.20 Balling effect in high dosage of fiber addition

4.10 Economical and Environmental Evaluation of Concrete

4.10.1 Economical Evaluation of glass fiber Concrete with replacement of cement

The use of glass fiber reinforced concrete (GFRC) with cement replacement by bentonite can have both economical and environmental benefit. Here are some potential economical and environmental benefits.

4.10.2 Cost analysis of concrete

The cost analysis is done for 1m³ concrete with out addition of glass fiber and replacement of cement. To compare with glass fiber concrete with partially replaced cement by bentonite.

1) Material saving

The addition of bentonite to the concrete mixture can allow for a partial replacement of cement, resulting in material savings and decreased costs. For this experimental research glass fiber is taken as part of fine aggregate to reduce the effect on volume change in concrete quantity due to addition of glass fiber. It uses 0.5 % by weight of concreting material that means consume 11.49 kg/m³ glass fiber for 1m³ concrete. 377 kg/m³ of cement is used so replacing 10 percent of it reduce 37.7 kg of cement for 1m³ of concrete.

Table 4.16 Amount of raw materials saved

Raw material type	Control	5% BN Replacement	10%BN Replacement	15%BN Replacement	20%BN Replacement
Ordinary portland cement	377	358.15	339.3	320.45	301.6
Fine aggregate	877	865.51	865.51	865.51	865.51
Coarse aggregate	1044	1044	1044	1014	1014
BN amount from part of cement	0	18.85	37.7	56.55	75.4
GF amount from part of sand	0	11.49	11.49	11.49	11.49
Total weight of material	2298	2298	2298	2298	2298

As stated on statement of problem For production of one ton of ordinary portland cement 1.52 tons of raw materials are required that mean to produce 377 kg of cement 573.04 kg of raw material needed. Saving of raw material for 5% replacement from 377 kg of cement is 28.652 kg, for 10 % replacement 57.304 kg of raw material is saved. 85.956 kg and 114.608 kg of raw material are preserved for 15 and 20% replacement.

2) Energy saving

It is estimated that the production of one tonne of cement requires between 3.2 and 6.2 gigajoules (Z. Li et al.) of energy, with an average of around 4.5 GJ. The main sources of energy consumption in cement manufacturing include the Fuel combustion: The fuel used for heating the kiln is the largest source of energy consumption in cement manufacturing, accounting for around 30-40% of the total energy consumption. The fuel used for heating the kiln may include coal, petroleum coke, natural gas, or other fossil fuels.

To determine the amount of energy required to calcine one ton (1000 kg) of bentonite at 700 degrees Celsius for two hours, calculated by the following formula:

Energy = Mass x Specific Heat x Temperature Difference

The specific heat capacity of dry bentonite is typically around 0.84 J/g°C. The specific heat capacity of dry bentonite can vary depending on several factors, such as its composition, mineralogy, and other physical and chemical properties. However, the typical specific heat capacity of dry bentonite is around 0.84 J/g°C. This value can be determined experimentally by measuring the amount of heat required to raise the temperature of a known mass of dry bentonite by a certain number of degrees Celsius. The specific heat capacity is then calculated using the formula: Specific Heat Capacity = Heat Energy / (Mass x Temperature Change). By measuring the heat energy, mass, and temperature change, the specific heat capacity of the dry bentonite can be calculated. The value of 0.84 J/g°C is an average value that has been reported in various sources for typical dry bentonite samples.

Calculate the energy required: Energy = Mass x Specific Heat x Temperature Difference

= 1000 kg x 0.84 J/g°C x 675°C Energy = 567,000 Joules

Therefore, approximately 567,000 Joules (or 0.567 GJ) of energy would be required to calcine one tonne (1000 kg) of bentonite at 700 degrees Celsius, assuming a specific heat capacity of 0.84 J/g°C for the bentonite for two hours it need 1.134 GJ/tonne .

3) Coal amount required

The amount of coal required can also depend on the calorific value of the coal and the efficiency of the cement production process. However, as a rough estimate, the amount of coal required to produce one tonne of cement is typically around 100-150 kg. This estimate includes the coal required for both fueling the kiln and producing the electricity needed to power the cement manufacturing process.

The amount of coal required to heat bentonite to 700 degrees Celsius for two hours can vary depending on several factors, such as the mass of the material being heated, the specific heat capacity of the material, and the efficiency of the heating process. To estimate the amount of coal required, we can use the formula for calculating the heat energy required: Heat Energy = Mass x Specific Heat Capacity x Temperature Change

Heat Energy = 1000 kg x 1 J/g°C x 675°C = 675,000 J

To convert this to energy in terms of coal, we need to know the calorific value of the coal, which is the amount of energy released when the coal is burned. The calorific value of coal can vary depending on the type of coal and its quality, but a typical value for bituminous coal is around 24 MJ/kg. Using this value, we can calculate the amount of coal required as follows: Energy from coal = Heat Energy / Calorific Value of Coal Energy from coal = 675,000 J / (24 MJ/kg x 1000 kg/tonne) = 0.0281 tonnes of coal

Therefore, to heat 1 tonne of material to 700 degrees Celsius for two hours, approximately 0.0281 tonnes of coal would be required, assuming a specific heat capacity of 1 J/g°C and a calorific value of 24 MJ/kg for the coal. 0.0281 ton is equivalent with 28.1 kg of coal for two hours it consume 56.2 kg of coal.

Table 4.17 Energy requirement for production of cement and bentonite per ton.

Material	Energy Consumption(GJ/tonne)	Coal required (kg)
Cement	4.5	125
Bentonite (calcined)	1.134	56.2

So from the above table it understood that to calcine 1 tonne of bentonite it require only 25.2 percent amount of coal when compared with the energy consumption to produce one tone of cement.

4) Embodied energy

The embodied energy of concrete includes the energy required to extract, process, and transport the raw materials, such as cement, aggregates (such as sand, gravel, or crushed stone), and water. It also includes the energy required for manufacturing and transporting the concrete mix, as well as the energy required for construction and maintenance over the life of the structure. It's important to note that the embodied energy of concrete can have significant environmental impacts, as it is a major contributor to greenhouse gas emissions and other pollutants so carbon dioxide emission and embodied energy calculated here together. The embodied production energy of concrete can be calculated by summing the embodied energy of its ingredients (cement, sand, and aggregate). The embodied energy (EE) is computed by summing the product of the quantity of each material (QM) with its embodied energy coefficient (EEC). Besides, the carbon dioxide emission (ECO₂) can be calculated based on the formula presented in the study . It can be computed by summing the product of the quantity of each material (QM) by its carbon

dioxide emission coefficient (CO_2EC). The embodied energy coefficient of concrete taken from the research (Goggins et al., 2010)

Table 4.18 Embodied Energy and Carbon dioxide Emissions for control concrete

No	Material	Qm (Kg)	EEc (MJ/Kg)	EE (MJ)	Qm (Kg)	$\text{CO}_2\text{ EC}$ (Kg/Kg)	ECO_2 (Kg)
Embodied Energy					Embodied carbon dioxide emission		
1	Cement	377	3.32	1251.64	377	0.73	275.21
2	Sand	877	0.06	52.62	877	0.04	35.08
3	Aggregate	1044	0.16	167.04	1044	0.010	10.44
Total				1471.3	Total		320.73

Table 4.19 Embodied Energy and Carbon dioxide Emissions for glass fibered concrete with bentonite replacement

No	Material	Qm (Kg)	EEc (MJ/Kg)	EE (MJ)	Qm (Kg)	$\text{CO}_2\text{ EC}$ (Kg/Kg)	ECO_2 (Kg)
Embodied production Energy					Embodied carbon dioxide emission		
1	Cement	339.3	3.32	1,126.47	339.3	0.73	247.689
2	Sand	865.51	0.06	51.93	865.51	0.04	34.62
3	Aggregate	1044	0.16	167.04	1044	0.010	10.44
4	Bentonite	37.7	0.83	31.29	37.7	0.06	2.262
5	Glass fiber	11.49	0.2	2.388	11.49	0.02	0.229
Total				1379.119	Total		295.24

From the above tables it conclude that the addition of glass fiber and replacement of cement by bentonite have no negative effect on both embodied production energy and embodied carbon dioxide emission, the embodied production energy decrease by 6.39% by replacement of bentonite. And the carbon dioxide emission embodied energy decreased by 7.93%.

5) Economic Implication

The exploration of the economic implications of using glass fiber and bentonite as a partial replacement of cement in concrete was evaluated in terms of estimated materials costs for the production of glass fibered with bentonite and without bentonite. The calculation of costs is based on the current market price of materials surveyed on June 4, 2023.

According to current market prices of materials, one quantal of OPC National cement costs 2,100 ETB. Fine aggregate costs 1,066 ETB per cubic meter, whereas coarse aggregate costs 1,266 ETB. Furthermore, the cost of water per cubic meter is 20 ETB.

The cost of preparing bentonite for use in concrete can vary depending on a number of factors, including the cost of labor, transportation distance, mill type to grind, and calcination temperature. The calculation below is an estimate and should be used as a rough guide only for this experimental research to use in 1 m³ concrete so for C-25 concrete it consume 377 kg of cement that mean for 10% replacement it require 37.7 kg of bentonite. The cost of preparing bentonite may be broken down as follows:

Table 4.20 Bentonite preparation cost break down

Item	Unit	Quantity	Rate	Amount
Material	Kg	37.7	5	188.5
Labor	Hr	2	31.25	62.5
Transportation	Km	90	1.1	99
Milling	Kg	37.7	0.5	18.85
Calcination	Hr	2	23	46
Total				414.85

Total cost incurred to produce 37.7 kg of bentonite is 414.85 birr from this to produce 1 kg of bentonite it requires 11 Birr/ Kg

Table 4.21 Estimated total cost of materials for production of one cubic meter glass fiber concrete

Material	Unit	Quantity	Rate	Amount
Cement	Kg	377	21	7,917
Fine aggregate	M ³	0.31	1066	330.46
Coarse aggregate	M ³	0.37	1266	468.42
Water	M ³	0.185	20	3.64
Glass fiber	Kg	11.9	120	1,428
Total				10,147.52

Table 4. 22 Estimated total cost of materials for production of concrete glass fibered concrete with 10% .

Material	Unit	Quantity	Rate	Amount
Cement	Kg	339.3	21	7125.3
Fine aggregate	M ³	0.31	1066	330.46
Coarse aggregate	M ³	0.37	1266	468.42
Bentonite	Kg	37.77	11	414.7
Glass fiber	Kg	11.9	120	1428
Water	M ³	0.185	20	3.64
Total				9770.52

The cost required to produce cubic meter of concrete is 10,147.52 birr as stated on Table 4.21 above and according to Table 4.22 the cost incurred to produce 1 M³ of glass fibered concrete with 10% of bentonite replaced cement is 9770.52. This implies that replacing cement by bentonite reduce the cost of concrete by 3.72%. by addition of glass fiber and by replacing cement by bentonite the mechanical and morphological behavior of concrete is enhanced and also the cost of production of concrete is decreased so replacing cement by bentonite in glass fiber concrete is environmentally friendly and cost effective.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The research on using glass fibered concrete with bentonite as cement substitutes in concrete has yielded promising results. The usage of 0.5% glass fiber and 10% cement replacement by bentonite has been found to be an effective combination in terms of improving the mechanical and morphological properties of concrete. The addition of glass fiber increase the tensile strength and toughness of the concrete, while the addition of bentonite has been help to improve the compressive strength even in reduced cement content. Which could have significant benefits in terms of reducing construction cost. The test results demonstrated that a fresh concrete mix containing glass fiber and bentonite needs additional water to maintain workability and consistency for 10%, 15 and 20 % bentonite replacement, glass fiber alone without bentonite replacement enhance compressive strength by 1.5% and flexural strength by 29.4%. When both glass fiber and bentonite, hybrid maximum results obtained at cement replacing percentage of 10 % by bentonite, which yields high compressive strength than the control after 56th day of curing. Furthermore flexural and split tensile strength upswing by 28.13 and 20.23% respectively from plain concrete. In addition, 10% replacement cement by bentonite increase the flexural strength by 0.88% from glass fibered concrete. Maximum split tensile strength obtain also at 10% replacement level from the replacement mix but this value is decreased from glass fiber concrete without replacement by 5.31%. So replacement of cement by bentonite in a concrete have negative effect on split tensile strength of concrete. However, all other mix yield split tensile strength better than the plain concrete at all percentage of replacement. From the morphological analysis, it is observed that bentonite is effectively reactive with cement hydration product additional cementitious material other than C-H and C-S-H is investigated which called pumpellyite which have a bond of C-I-A-S-H this subsist in some concrete which contain high reactive pozzolans. It is a good indication that concrete with bentonite is durable and resistance to chemicals. SEM image also prevailed that concrete with glass fiber and bentonite have dense internal structure with less crack and pores. As a general incorporation of glass fiber and replacement of cement by bentonite ameliorate mechanical and morphological property of concrete. More over the cost of glass fiber concrete decrease by 3.72% by replacing 10% cement by bentonite with minimized embodied energy.

5.2 Recommendations

Based on the research conducted on using glass fiber and bentonite as a reinforcement and cement substitutes in concrete it yields delight full results. But further researches needed in this area like:- Research on long-term durability and performance of concrete structures made with glass fiber and bentonite under different environmental conditions, such as

- Exposure to extreme temperatures,
- Chloride attack
- Freeze-thaw cycles.

This information could help to determine the suitability of these materials for use in a range of construction applications.

- Further research could be conducted to develop guidelines and recommendations for the use of glass fibered concrete with bentonite as cement substitutes in concrete, including guidance on optimal mix design, placement, and curing practices.

This information could help to ensure that these materials are used effectively and safely in construction projects. Overall, the use of glass fiber and bentonite as cement substitutes in concrete has shown great potential for improving the performance and sustainability of concrete structures.

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APPENDIX

Appendix A ACI concrete mix design

Step 1: Computing required average compressive strength from the given characteristic strength of 25 MPa. According to ACI-318

While designing the mix, it should be targeted for higher strength called ‘Target mean strength’ (f'_{ck}) so that not more than 5% test results fall below a desired strength ‘ f_{ck} ’

Appendix A1: Factor based on the grade of concrete

Specified characteristic compressive strength (f'_c , MPa)	Required average compressive strength in (f'_{cr} , MPa)
<21	$f'_c + 7$
21-35	$f'_c + 8.5$
>35	$1.1 * f'_c + 5$

Calculating the required mean compressive strength based on characteristic strength of 25 Mpa which gives; $f_{ck} = f'_c + 8.5 = 25 + 8.5 = 33.5$ Mpa

Step 2. Specifying minimum cement content: - From durability considerations, cement content should not be reduced below 300Kg/m³ for RCC. Minimum cement content taken as = 300 kg/m³

STEP 3 Choice of slump

Appendix A2: Recommended slumps for various types of constructions

Types of construction	Slump (cm)	
	*Max.	Min.
Reinforced foundations, walls and footings	8	2
Plain footings, cassoins and substructure walls	8	2
Beams and reinforced walls	10	2
Building columns	10	2
Pavements and slabs	8	2
Heavy mass concrete	8	2

For C-25, a concrete of Beams, reinforced walls and Building columns slump of 2-10 cm is recommended.

Step 4. Selecting the maximum size of Aggregate

Maximum aggregate size affect such PCC parameters as amount of cement paste, workability and strength. In general, ACI recommends that maximum aggregate size be limited to 1/3 of the slab depth and 3/4 of the minimum clear space between reinforcing bars.

Appendix A3: Maximum size of aggregate recommended for various types of constructions

Type of element	Dimensions of sections (cm)			
	10-15	15-20	20-35	35-75
Un reinforced or slightly reinforced foundations or slabs	Maximum size of aggregate (mm)			
	25-40	40	40-50	50
Reinforced foundations or slabs, un reinforced or lightly reinforced walls or columns	20-25	25	25-40	40
Reinforced beams, columns, walls, hollow block slabs	15-20	20-25	25-30	30

N.B. Maximum size should not be greater than 1/5 of minimum dimensions of sections or larger than $\frac{3}{4}$ of minimum clear spacing between reinforcing bars. Lets take 20 mm

Step 5. Estimate mixing water, and air content

Slump is dependent upon nominal maximum aggregate size, particle shape, aggregate gradation, temperature, the amount of entrained air and certain chemical admixtures. It is not generally affected by the amount of cementitious material. Therefore, ACI provides a table relating nominal maximum aggregate size, air entrainment and desired slump to the desired mixing water quantity.

Appendix A4:- approximate mixing water requirements for slump and maximum size of aggregate

Slump (cm)	Water kg/ m ³ of concrete for indicated mac. Size of 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	185	180	170	-

In table above, with a slump of 3-10 cm and a maximum size aggregate of 20 mm, the water content becomes 185 Kg/m³ and 2%, or 20 liters and entrapped air.

Step 6. Computing water cement ratio (W/C ratio)

The water-cement ratio is well correlated with concrete strength and durability. In general, lower water-cement ratios produce stronger, more durable concrete. If natural pozzolans are used in the mix then the ratio becomes a water-cementitious material ratio (cementitious material = Portland cement + pozzolanic material). The ACI method bases the water-cement ratio selection on desired compressive strength and then calculates the required cement content based on the selected water-cement ratio.

Appendix A5:- Average Compressive Strength with water Cement Ratio

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

The ACI table above can't provide the exact value of the water-cement ratio for a 33.5 MPa mean strength. This can be calculated via interpolating the above and below values as follows: 33.5 MPa.

35	0.47	by interpolation, $\frac{33.5-35}{30-35} = \frac{x-0.47}{0.54-0.47}$
33.5	x	by solving the above equation, x=0.491
30	0.54	Hence, the minimum water cement ratio is 0.491

Step 7. Determining the mix cement content

Once the water content and the w/c ratio is determined, the amount of cement per unit volume of concrete is found by dividing the estimated water content by the w/c ratio.

$$\text{Cement content} = \frac{\text{Cement content}}{\text{water cement ratio}} = \frac{185\text{kg}/\text{m}^3}{0.491}$$

$$= 376.8 \text{ kg}/\text{m}^3 \sim 377 \text{ kg}/\text{m}^3$$

Step 8. Estimating the bulk volume of dry rodded as per unit volume of concrete

Volumes are based on aggregate in dry rodded condition as described in ASTM C29 for unit weight of aggregate. These volumes are selected empirical relationship to produce concrete with a degree of workability suitable for usual reinforced construction. For more workable concrete, required when placement is to be by pumping, they may be reduced up to 10%.

Appendix A5 Volume of coarse Aggregate per unit Volume of concrete

Maximum size of aggregate	Volume of dry rodded coarse aggregate per unit volume of concrete for different fineness modulus		
	2.6	2.8	3.0
10	0.50	0.46	0.44
12.5	0.59	0.55	0.53
20	0.66	0.62	0.60
25	0.71	0.67	0.65

The bulk volume of dry rodded aggregate was not found in the above table directly. It can be calculated by interpolation since the fineness modulus of 2.98 is found between 2.8 and 3 for a 20 mm maximum size aggregate.

2.8	0.62	By interpolation, $\frac{2.84-2.8}{3-2.8} = \frac{x-0.62}{0.6-0.62}$
2.84	x	By solving the above equation, x=0.602
3.0	0.6	Hence, the dry volume of aggregate per volume of concrete is 0.602

Step 9. Calculating the weight of coarse aggregate (WCA) per m³ of concrete

$$WCA = \text{Dry volume of rodded agg} \times \text{bulk density C.A} = 0.602 \text{ m}^3 \times 1690 \text{ Kg/m}^3 = 1017.38 \text{ kg}$$

Where Bulk density C.A = 1690 kg/m³

Step 10. Determining the solid volume of the coarse aggregate.

$$\text{Solid volume of C. A} = \frac{WCA}{\text{spec.gravity}} = \frac{1017.38 \text{ kg}}{2.83} = 359.4$$

where; Specific gravity of C.A.: 2.83

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

$$\text{Volume of cement (VC)} = \frac{\text{Weight of cement}}{\text{unit weight of cement}} = \frac{377}{3.15} = 119.68 \sim 120 \text{ Kg/m}^3$$

Step 12. Determining solid volume of sand (Solid volume of sand is then calculated by subtracting from the data volume of concrete).

$$\text{Solid volume of sand} = \text{Solid volume of Sand} = 1000 - (VCA + VC + VW + VA)$$

$$= 1000 - (359.49 + 120 + 185 + 20) = 1000 - 684.49$$

$$\text{Solid volume of sand} = 315.50$$

$$\text{Solid Weight of sand} = \text{dry volume} \times \text{specific gravity of sand}$$

$$= 315.5 \text{ Kg/m}^3 \times 2.75 = 867.62 \text{ Kg/m}^3$$

	Volume (Gao et al.)	Wt. (kg/m ³)
Air	20	-
Cement	120	377
Water	185	185
Coarse aggregate	359.49	1017.38
Fine aggregate	315.5	867.62
Total	1000	2,447 kg/m ³

Step 13. Adjustment for moisture in the aggregate.

$$\text{Fine aggregate water absorption} = 1.1\%$$

The amount of water absorbed by fine aggregate = $867.62 \text{ kg/m}^3 * 0.011 = 9.54 \text{ kg/m}^3$

Coarse aggregate water absorption = 2.7%

The amount of water absorbed by coarse aggregate = $1017.38 \text{ kg/m}^3 \times 0.027 = 27.47$

Cement	377	377
Fine aggregate	$867.62 + 9.54$	877
Coarse aggregate	$1017.38 + 27.47$	1044

The final mix design ratio becomes

	Cement	Fine aggregate	Coarse aggregate
Quantity in m ³	377	877	1044
Ratio	1	2.32	2.77

Glass fiber content calculation

Amount of glass fiber added by percentage weight of concrete ingredient which was 2298 kg/m³ is for 0.3% = 6.894 kg/m³, For 0.5 % = 11.49 kg/m³, For 0.7 % = 16.086 kg/m³ and For 1% = 22.89 kg/m³

Bentonite replacement amount

Amount of bentonite replaced by percentage weight of cement which was 377 kg/m³ is used for 5% replacement = 18.85 kg/m³, for 10 % replacement = 37.77 kg/m³ for 15% replacement bentonite content was 56.55 kg/m³ and for 20 % replacement bentonite amount used is 75.4 kg/m³

Appendix B Test result of glass fiber concrete

Appendix B1: Detail result of compressive strength of glass fiber concrete with out replacement of cement at curing periods of 7th and 28th day.

Mix type	7 th day			28 th day	
	sample	peak load	compressive stress	peak load	compressive stress
Control 0%	1	570	25.33	743	33.02
	2	569	25.28	738	32.80
	3	522	23.2	733	32.57
	Average	553.6	24.6	738	32.8
Mix1 0.3%	1	553	24.57	752	33.42
	2	559	24.84	756	33.60
	3	576	25.60	720	32.00
	Average	562.66	25.00	742.66	33.00
Mix 2 0.5%	1	565	25.11	743	33.02
	2	595	26.44	756	33.60
	3	541	24.04	749	33.28
	Average	567	25.2	749.33	33.3
Mix3 0.7%	1	584	25.95	738	32.80
	2	552	24.53	734	32.62
	3	538	23.91	722	32.08
	Average	558	24.8	731.33	32.5
Mix 4 1%	1	563	25.02	680	30.22
	2	473	21.02	710	31.55
	3	591	26.26	703	31.24
	Average	542.33	24.1	697.66	31.00

Appendix B2: Detail result of flexural strength of glass fiber concrete with out replacement of cement at curing periods of 7th and 28th day.

Mix type	7 th day			28 th day	
	Sample	maximum load	flexural stress	maximum load	flexural stress
Control 0% GF	1	9.82	2.946	11.73	3.519
	2	10.05	3.015	11.76	3.528
	3	9.94	2.982	11.81	3.544
	Average	9.92	2.981	11.76	3.530
Mix1 0.3%GF	1	12.26	3.678	13.82	4.146
	2	12.48	3.744	14.17	4.251
	3	11.94	3.582	14.11	4.234
	Average	12.22	3.668	14.03	4.210
Mix2 0.5%GF	1	13.34	4.002	15.24	4.572
	2	13.02	3.906	15.21	4.563
	3	12.95	3.885	15.23	4.569
	Average	13.10	3.931	15.22	4.568
Mix3 0.7%GF	1	13.44	4.032	13.69	4.107
	2	13.59	4.077	14.53	4.359
	3	12.87	3.861	14.93	4.479
	Average	13.3	3.99	14.38	4.315
Mix4 1%GF	1	12.17	3.651	13.16	3.948
	2	12.04	3.612	14.15	4.246
	3	12.15	3.645	13.76	4.128
	Average	12.12	3.636	13.69	4.107

Appendix C Test result of GFRC with partial replacement of cement by bentonite

Appendix C1: Detail result of compressive strength of glass fiber concrete with replacement of cement by bentonite at curing periods of 7th, 28th day and 56th day.

Mix type	7 th day			28 th day		56 th day	
	sample	peak load	compressive stress	peak load	compressive stress	peak load	compressive stress
Control 0%	1	571	25.37	741	32.93	755	33.55
	2	594	26.40	760	33.77	749	33.28
	3	568	25.24	755	33.55	756	33.60
	Average	577.66	25.67	752	33.41	753.33	33.47
Mix1 0.5%GF & 5% BN	1	516	22.93	577	25.64	779	34.64
	2	523	23.24	586	26.04	776	34.48
	3	509	22.62	579	25.73	777	34.53
	Average	516	22.93	580.66	25.80	777.33	34.55
Mix2 0.5%GF & 10%BN	1	355	15.77	526	23.37	796	35.37
	2	335	14.88	530	23.55	781	34.71
	3	365	16.22	527	23.42	772	34.31
	Average	351.66	15.62	527.66	23.44	783	34.79
Mix3 0.5%GF & 15%BN	1	321	14.26	456	20.26	575	25.55
	2	325	14.44	451	20.04	583	25.91
	3	344	15.28	468	20.80	580	25.77
	Average	330	14.66	458.33	20.36	579.33	25.74
Mix4 0.5%GF & 20%BN	1	265	11.77	385	17.11	514	22.84
	2	259	11.51	383	17.02	516	22.93
	3	274	12.17	409	18.17	487	21.64
	Average	266	11.81	392.33	17.43	505.66	22.47

Appendix C2: Detail result of flexural strength of concrete with addition of glass fiber and partial replacement of cement by bentonite

Mix type	7 th day			56 th day	
	Sample	maximum load	flexural stress	maximum load	flexural stress
Control1 0% GF & 0% BN	1	9.82	2.946	11.82	3.546
	2	10.05	3.015	11.80	3.540
	3	9.94	2.982	11.75	3.525
	Average	9.93	2.981	11.79	3.537
Control2 0.5%GF & 0% BN	1	13.34	4.002	15.08	4.524
	2	13.02	3.906	14.97	4.491
	3	12.95	3.885	15.22	4.566
	Average	13.10	3.931	15.09	4.527
Mix1 0.5%GF & 5% BN	1	11.75	3.525	14.57	4.371
	2	11.64	3.493	14.55	4.365
	3	11.72	3.516	14.56	4.367
	Average	11.70	3.511	14.56	4.368
Mix2 0.5%GF & 10 % BN	1	9.87	2.961	15.12	4.536
	2	10.01	3.003	15.11	4.533
	3	9.71	2.913	15.09	4.527
	Average	9.86	2.960	15.106	4.532
Mix3 0.5%GF & 15% BN	1	9.32	2.796	13.37	4.011
	2	9.34	2.802	13.76	4.128
	3	9.38	2.814	13.58	4.074
	Average	9.34	2.804	13.57	4.071
Mix4 0.5%GF & 20% BN	1	8.06	2.418	12.87	3.861
	2	8.07	2.421	13.81	4.143
	3	8.05	2.415	13.12	3.936
	Average	8.06	2.418	13.12	3.936

C3: Detail result of split tensile strength of concrete with addition of glass fiber and partial replacement of cement by bentonite

Mix type	7 th day			56 th day	
	Sample	maximum load	split tensile stress	maximum load	split tensile stress
Control1 0% GF 0% BN	1	138	1.95	182	2.57
	2	145	2.05	173	2.44
	3	137	1.94	180	2.54
	Average	140	1.98	178.33	2.51
Control2 0.5%GF 0% BN	1	190	2.69	229	3.24
	2	185	2.61	224	3.17
	3	188	2.66	226	3.19
	Average	187.66	2.65	226.33	3.2
Mix1 0.5%GF & 5% BN	1	169	2.39	211	2.98
	2	162	2.29	215	3.04
	3	165	2.33	203	2.87
	Average	165.33	2.33	209.66	2.96
Mix2 0.5%GF & 10% BN	1	142	2.01	210	2.97
	2	136	1.92	215	3.04
	3	139	1.96	219	3.09
	Average	139	1.96	214.66	3.03
Mix3 0.5%GF & 15% BN	1	127	1.79	182	2.57
	2	136	1.9	199	2.81
	3	131	1.85	191	2.70
	Average	131.33	1.84	190.66	2.69
Mix4 0.5%GF & 20% BN	1	119	1.68	177	2.50
	2	109	1.54	190	2.68
	3	117	1.65	186	2.63
	Average	115	1.62	184.33	2.60

Appendix D Chemical composition result of bentonite

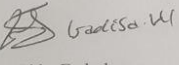
	GEOLOGICAL INSTITUTE OF ETHIOPIA		Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk			Page 1 of 1
Document Title:-	Complete Silicate Analysis Report		Effective date:	Nov. 2022

Customer Name:- Ethiopian Yirgawossen
 Sample type :-Powder(Bentonite)
 Sample Preparation: -200 Mesh
 Date Submitted:- 15/05/2023
 Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.
 Analytical Method: LiBO₂ FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC and AAS

Issue Date:-13/06/2023
 Request No:- GLD/RQ/1290/23
 Report No:- GLD/RN/1899/23
 Number of Sample:-One (01)

Collector's code	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	H ₂ O	LOI	Weight of Sample
Bentonite	65.34	14.39	8.52	0.76	2.84	1.88	0.48	0.04	0.21	0.39	1.65	3.77	1.40Kg

Note:- This result represent only for the sample submitted to the laboratory.

<u>Analysts</u>	<u>Checked By</u>	<u>Approved By</u>	<u>Quality Control</u>
Haimanot Bayeh			
Gadisa Wakuma			
Nigist Fikadu	Lidet Endeshaw	Yohannes Getachew	Nigash Worku



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Appendix D: Major and minor oxide composition of bentonite powder

Appendix E Pictures taken during experimental works.



Appendix E1: Pictures taken during testing property of material



Appendix E2: Picture taken during normal consistency and setting time test.



Appendix E3: Pictures taken during preparation of bentonite and glass fiber



Appendix E4: Pictures captured during casting of concrete.



Appendix E5: Pictures captured during curing, surface drying and testing of concrete.



Appendix E6: Picture captured during testing preparation of sample for XRD and SEM