

JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
STRUCTURAL ENGINEERING STREAM

Flexural Strength of fiber-reinforced alkali-activated concrete beam made from locally available cementitious materials under monotonic load

A Research Thesis Submitted to the School of Graduate Studies, Jimma University, Jimma Institute of Technology, and Faculty of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree Master of Science in Structural Engineering Stream

By

Esirael Yohannis Gulta

JULY 2023

JIMMA, ETHIOPIA

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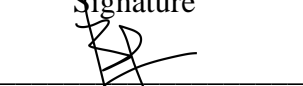
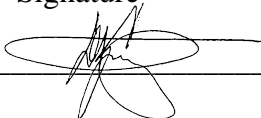
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**FLEXURAL STRENGTH OF FIBER-REINFORCED ALKALI-ACTIVATED
CONCRETE BEAM MADE FROM LOCALLY AVAILABLE
CEMENTITIOUS MATERIALS UNDER MONOTONIC LOAD**

BY:

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**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**


DECLARATION

I declare that this research Thesis entitled “Flexural Strength of Fiber-reinforced Alkali-activated Concrete Beam made from Locally Available Cementitious Material under Monotonic Load.” is my original thesis work and has not been submitted as a requirement for the award of any degree at Jimma University or elsewhere.

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FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

ABSTRACT

Concrete is a fundamental building material that was in demand for a very long time. Geopolymer concrete is considered an eco-friendly alternative to ordinary Portland cement (OPC). Because it is made using industrial waste materials such as fly ash and slag, which are by-products of other industrial processes. The addition of fibers to geopolymer concrete can enhance its mechanical properties. Research on fiber-reinforced geopolymer concrete beams has been ongoing since the early 2000s. The flexural strength of glass fiber-reinforced geopolymer concrete beams is an important area of research in the field of construction and civil engineering. The main aim of this research was to investigate the flexural strength of an alkali-activated concrete beam, which was produced using locally available white soil (Nech Afer), through the addition of fiber. The production of alkali-activated concrete involved a mixture of 50% white soil (Nech Afer) with 50% normal cement. In this study, plain normal concrete (control), plain alkali-activated (0%GF) concrete, and glass fiber-reinforced alkali-activated (0.2%GF, 0.4%GF, and 0.6%GF) concrete were cast. All specimens were tested for flexural strength on the 7th and 28th days, with different glass fiber percentages of 0.2%, 0.4%, and 0.6% by volume of concrete. Additionally, this study investigated workability, compressive, and split tensile strength tests. The strength of an alkali-activated concrete was investigated for C-25 concrete grade in this paper. According to the experimental investigation, the workability of alkali-activated concrete decreased as the percentage of glass fiber increased. The compressive strength of glass fiber-reinforced alkali-activated concrete showed an increment compared to the control concrete on the 7th and 28th tests. The split tensile strength showed an increment of 5.6% and 7% for 0%GF and 0.2%GF and it was below control for the rest mixes on 28th-day tests. In the study, it was observed that the addition of glass fibers greatly increased the flexural strength of the fiber-reinforced alkali-activated concrete beams. The increase in flexural strength was even greater than that of the control concrete beam. During the study, it was observed that the fiber-reinforced alkali-activated concrete exhibited additional load-carrying capacity after reaching peak load. Based on the study, it was concluded that the optimal percentage of glass fibers for the alkali-activated concrete was found to be 0.2.

Keywords: Nech Afer, Alkali-activated concrete, Flexural strength of Fiber-reinforced alkali-activated concrete beam

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**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

TABLE CONTENT

Content	page-no
Declaration.....	I
Abstract.....	III
Acknowledgment.....	IV
Table Content.....	V
List of Tables.....	IX
List of Figures.....	XI
Acronym.....	XIII
1. Chapter I-Introduction.....	1
1.1 Background of Study.....	1
1.2 Statement of Problem.....	2
1.3 Research Questions.....	3
1.4 Objectives of Study.....	3
1.4.1 General Objectives.....	3
1.4.2 Specific Objectives.....	3
1.5 Significance of Study.....	4
1.6 Scope and Limitation of Study.....	4
2. Chapter II-Literature Review.....	5
2.1 General Overview.....	5
2.2 Concept of Development of Green Concrete Technology.....	5
2.2.1 The Advantage of Green Cement Compared to Regular Portland Cement.....	6
2.3 Fiber-reinforced Alkali-activated Concrete.....	7
2.3.1 Flexural Performance of Fiber-reinforced Alkali-activated Concrete.....	7
2.4 Performance Evaluation of Geopolymer Concrete Beams under Monotonic Loading.....	15
2.5 Flexural Performance Parameters and Test Types for Fiber-reinforced Alkali-activated Concrete	16
2.5.1 Flexural Performance Parameters.....	16
2.5.2 Flexural Strength Test Types.....	17

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

3. Chapter III-Research Methodology	19
3.1 Study Area.....	19
3.2 Research Design.....	19
3.3 Study Variables	20
3.3.1 Dependent Variables	20
3.3.2 Independent Variables.....	20
3.4 The total number of experimental samples, method, and size of study	20
3.5 Material Collection Procedure	21
3.6 Materials Used For Experiment	21
3.7 Data Requirement	23
3.8 Sources of Data	24
3.8.1 Primary Data:	24
3.8.2 Secondary Data:	24
3.9 Laboratory Result Presentation and Analysis	24
3.10 Experimental Works Procedure	24
3.10.1 Materials Physical Property Tests.....	24
3.11 Mix Design, Mix Proportion, Mixing Procedure, and Specimen Preparations	26
3.11.1 Mix Design of Alkali-activated Concrete	26
3.11.2 Mix Proportion of Alkali-activated Concrete	34
3.11.3Mixing Procedure of Alkali-activated Concrete Preparation.....	34
3.11.4 Specimen Preparation of Alkali-activated Concrete	34
3.12 Testing of Fresh Alkali-Activated Concrete	35
3.12.1 Flow Rate Test for Workability of Alkali-activated Mortar	35
3.12.2 Slump Test for Workability of Glass Fiber-reinforced Alkali-activated Concrete.....	36
3.13 Testing of Hardened Alkali-Activated Concrete	36
3.13.1 Compressive Strength of Alkali-activated Mortar	36
3.13.2 Compressive Strength Test of Alkali-activated Concrete.....	37
3.13.3 Stress-Strain Relationship Curve of Fiber-reinforced Alkali-activated Concrete.....	38
3.13.3.1 Stress-strain relationship curves analysis under ES EN1992-2015	39
3.13.3.2 Analytical Stress-Strain Curves for Alkali-activated Concrete	40

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

3.13.4 Split Tensile Strength Test of Alkali-Activated Concrete	41
3.13.5 Flexural Strength Test of Alkali-Activated Concrete	42
3.13.5.1 Flexural Tensile Strength of Concrete at Various Ages per ES EN1992-2015	43
3.14 Mixing and Casting of the Specimen	44
3.14.1 Curing Temperature of Alkali-activated Concrete.....	44
4. Chapter IV-Results and Discussion	46
4.1 Test Results Conducted on Cementitious Materials	46
4.1.1 Normal Consistency test results for Binder Content.....	46
4.1.2 Setting Time of Binder Content	46
4.2 Physical Properties Test Result of Aggregates	47
4.2.1 Silt Content of Fine Aggregate	47
4.2.2 Particle Size Distribution of Fine Aggregate	48
4.2.3 Particle Size Distribution of Coarse Aggregate	49
4.2.4 Absorption Capacity, Specific Gravity, Moisture Content, and Unit Weight of Aggregates as per ASTM Standards	49
4.3 Test Results Conducted on Fresh Alkali-activated Concrete.....	51
4.3.1 Flow Test Results conducted on Alkali-activated Mortar	51
4.3.2 Slump Test Results Conducted on Fresh Fiber-reinforced Alkali-activated Concrete	52
4.4 Test Results Conducted on Hardened Alkali-activated Concrete	54
4.4.1 Mass and Density of Hardened Mortar.....	54
4.4.2 Mass and Density of hardened Alkali-activated Concrete.....	55
4.4.3 Compressive Strength Test Results Conducted on Alkali-activated Mortar	56
4.4.4 Compressive Strength Test Results Conducted on Alkali-activated Concrete	56
4.4.5 Stress-Strain Relationship for Compressive Strength as per ES EN1992-2015	57
4.4.6 Stress-Strain Relationship Curve for Geopolymer Concrete	60
4.4.7 The Elastic Modulus from Compressive Cube Test Result	61
4.4.8 Split Tensile Strength Test Results Conducted on Alkali-activated Concrete.....	61
4.4.9 Flexural Tensile Strength Test Results Conducted on Alkali-activated Concrete Beam	63
4.4.10 Failure Mode of Alkali-activated Concrete Observed During Test.....	65
5. Chapter V-Conclusion and Recommendation.....	68

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

5.1 Conclusion	68
5.2 Recommendation	70
References	71
Appendix	75
Appendix-A: Test Results Conducted Materials.....	75
Appendix-B: Tests Conducted on Alkali-Activated Concrete.....	86
Appendix-C: Stress and Strain Relationship of Cube Compression Test	91
Appendix-D: Stress-Strain Relationship Curve from Compression Test.....	116
Appendix-E: Photos Taken During Laboratory Test	119

LIST OF TABLES

Table 2-1: Mechanical characteristics of steam-cured and standard-cured alkali-activated (ARPC) and traditional CRPC[30].	13
Table 3-1: The designed sample that was expected for this study.....	20
Table 3-2: Specific gravities for cementitious materials.	24
Table 3-3: Summary of absorption capacity, specific gravity, unit weight, and total moisture content of aggregates.	25
Table 3-4: The solid and water content of 12M, 14M, and 16M of NaOH.	29
Table 3-5: The summary of amounts (kg/m ³) of NaOH for different molarities.....	30
Table 3-6: The quantities of both aggregates for specific gravities.....	32
Table 3-7: ES EN code's cubic, cylindrical, and their fcm at 7 th and 28 th days.	38
Table 3-8: ES EN code's splitting tensile strength and its mean, characteristics on the 7 th and 28 th days.....	42
Table 3-9: ES EN code's mean and characteristic flexural tensile strength on the 7 th and 28 th days.	43
Table 4-1: Normal consistency test results for binder content.	46
Table 4-2: Setting time of binder content.	46
Table 4-3: Summary of physical property test result of fine aggregate.....	50
Table 4-4: Summary of physical property test result of coarse aggregate.....	50
Table 4-5: Flow rate value of mortar workability for different molarities.	51
Table 4-6: The mass and density of 7 th -day hardened mortar.....	54
Table 4-7: The mass and density of 7 th -day hardened concrete.....	55
Table 4-8: The mass and density of 28 th -day hardened concrete.....	55
Table 4-9: The average compressive stress of hardened mortar on the 7 th -day.....	56
Table 4-10: Compressive strength of alkali-activated concrete test result on the 7 th and 28 th days.	57
Table 4-11: The mean compressive strength for standard cylinder and standard cube.	58
Table 4-12: The elastic modulus of alkali-activated concrete at 28th day compressive stress.....	61
Table 4-13: Split tensile load stress of alkali-activated concrete on the 7 th -day result.....	62

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table 4-14: Split tensile load stress of alkali-activated concrete at the 28 th -day result.....	62
Table 4-15: The average flexural stress (modulus of rupture) of the alkali-activated concrete beam at the 7 th -day test.....	63
Table 4-16: The average flexural stress (modulus of rupture) of the alkali-activated concrete beam at the 28 th -day test.....	64

LIST OF FIGURES

Figure 2-1:Green Concrete for a green sustainable environment[10].	6
Figure 2-2:Potential applications for fiber-reinforced geopolymer composites[19].	8
Figure 2-3:Variation of flexural strength and work of fracture of geopolymer matrix and short carbon fiber (Cf) geopolymer composites versus starting fiber length[32].....	15
Figure 2-4: Flexural test setup [12]: (a) main dimensions; and (b) full configuration.	17
Figure 2-5: Three-point flexural strength test.	18
Figure 2-6: Four-point flexural strength test.....	18
Figure 3-1: The flowchart in the methodology section illustrates the research design.	19
Figure 3-2: Nech Afer (white soil) used in experimental investigation.....	21
Figure 3-3: Alkali-activating chemicals used for the experiment.....	22
Figure 3-4: Superplasticizer used in the experiment.....	23
Figure 3-5: Glass fiber used in the experiment.	23
Figure 3-6: Photos taken during the test of specific gravity and normal consistency.	25
Figure 3-7: Photos taken during the test of coarse aggregate.	26
Figure 3-8: The specimen preparation for the test.	35
Figure 3-9: Flow test measurement of trial alkali-activated mortar using flow test table.	35
Figure 3-10: Slump test for the workability of alkali-activated concrete with fiber.	36
Figure 3-11: The hardened mortar cured at room temperature after 24hr.	37
Figure 3-12:Schematic representation of the stress-strain relation of structural analysis (the use of 0.4fcm for the definition of Ecm is approximate).	40
Figure 3-13: Mixing and casting of concrete for testing.....	44
Figure 3-14: Curing the alkali-activated concrete for 24hrs at 80°C.	45
Figure 4-1: Washing of sand to remove decant materials.....	47
Figure 4-2: Fine aggregate particle size distributions.....	48
Figure 4-3: Coarse aggregate particle size distributions.....	49
Figure 4-4: The workability of alkali-activated mortar with 1.5% of SP for 14M.	51
Figure 4-5: Slump test result for the workability of alkali-activated concrete for different mixes.	52

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Figure 4-6: Percentages of glass fiber vs slump test results by simple linear regression. 53

Figure 4-7: The cube compressive stress-strain curve by ES EN1992-2015 on the 7th-day result.
..... 58

Figure 4-8: The cube compressive stress-strain curve by ES EN1992-2015 on the 28th day result.
..... 59

Figure 4-9: The cube compressive stress-strain curve by Hardjito and Sarker[45], [46] prediction
model on the 28th-day result. 60

Figure 4-10: Crack pattern observed on cube under UTM for normal and glass fiber reinforced
concrete..... 65

Figure 4-11: Crack pattern observed on cylinder under UTM for normal and glass fiber reinforced
concrete..... 66

Figure 4-12: Crack pattern observed on the flexural beam under UTM for normal and glass fiber
reinforced concrete. 67

ACRONYM

AAB	Alkali activated binder
AAC	Alkali activated cement
AAGC	Alkali-activated geopolymer concrete
AAS	Alkali-activated solution
AASC	Alkali-activated slag cement
ARG	Alkali-resistant glass
ARPC	Alkali-resistant powder concrete
ASTM	American Society for Testing and Materials
BFS	Blast furnace slag
CEM	Clean Energy Ministerial
CO ₂	Carbon dioxide
CRPC	Carbon-reinforced powder concrete
FEM	Finite Element Method
FRAAC	Fiber-reinforced alkali-activated concrete
FRC	Fiber reinforced concrete
GGBS	Ground granulated blast furnace slag
GPC	Geopolymer Concrete
HRWR	High-range water reducer (HRWR)
HT	High tenacity
IEA	International energy agency
JIT	Jimma Institute of Technology
MR	Modulus of rupture

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

NaOH	Sodium hydroxide
Na ₂ SiO ₃	Sodium silicate
OPC	Ordinary Portland cement
OPCB	Ordinary Portland cement beam
PP	Polypropylene
PVA	Polyvinyl alcohol
PVC	Polyvinyl chloride
SF	Slag furnace
GFRAACB	Glass fiber-reinforced alkali-activated concrete beam
SFGPC	Steel fiber geopolymer concrete
GFRAAC	Glass fiber-reinforced alkali-activated concrete
SFRC	Steel fiber reinforced concrete
0%GF	0 percentage of glass fiber-reinforced alkali-activated concrete
0.2%GF	0.2 percent of glass fiber-reinforced alkali-activated concrete
0.4%GF	0.4 percent of glass fiber-reinforced alkali-activated concrete
0.6%GF	0.6 percent of glass fiber-reinforced alkali-activated concrete

1. Chapter I-Introduction

1.1 Background of Study

Globally, construction industries are responsible for 40 percent of global carbon emissions, according to a climate adaptation engineering investigation[1]. Global warming is significantly impacted by the usage of standard ordinary Portland cement (OPC) in the production of concrete. According to the world data atlas by Knoema digital assistant, 13,000 metric tons of carbon dioxide were emitted in 1965 as a result of Ethiopian cement manufacture. According to their preliminary forecast, Ethiopia's cement output is predicted to raise its carbon dioxide emissions from 13,000 metric tons to 734,000 metric tons in 2014, expanding at an average annual rate of 10.57 percent[2]. The search for environmentally friendly building materials for global green concrete technology is the construction industry's current vision for environmental problems.

Previous studies have explored alternative concrete materials to partially or completely replace ordinary cement. Alkali-activated geopolymer concrete (AAGC) has emerged as a "green concrete technology" option to replace ordinary Portland cement (OPC) concrete. The first investigation into alkali-activated materials was Purdon's research, which involved activating blast furnace slag with a sodium hydroxide solution. In 1959, Gluchovskij studied the production of novel binding materials by combining raw aluminosilicate minerals with alkaline chemicals. In 1976, Davidovits defined the term "geopolymer" to classify the geosynthetic that produces inorganic polymeric materials used for many industrial applications[3][4].

For all varieties of concrete, high compressive strength and low tensile strength are typical characteristics. When the compressive strength of concrete exceeds a certain limit, it loses toughness and ductility and becomes brittle. By incorporating fibers into concrete, this behavior can be minimized. For concrete to overcome its brittleness, increase its toughness, and achieve its best performance, fibers absorb the tensile strain placed on it. Structures subject to impact and earthquake loads can use concrete that is more resilient or capable of absorbing energy. Fiber can have a degree of control over each type of concrete due to the differing cement systems used in ordinary Portland cement (OPC) and alkali-activated concrete (AAC)[5][6].

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

Geopolymer concrete reinforced with glass fiber enhances structural durability, increases flexural strength, and prolongs the longevity of the concrete by restricting cracks and precisely controlling their length[7]. Fiberglass is a lightweight and durable material with exceptional strength. It is used in concrete structures in the form of glass fiber reinforced polymer (GFRP), which offers several advantages over traditional steel reinforcement. GFRP has a high strength-to-weight ratio, and its bulk strength and weight properties are more favorable than those of metals. Moreover, it can be easily molded. The addition of glass fibers to concrete enhances its desirable strengths compared to conventional concrete mixes, making it suitable for concreting purposes[8].

The alkali-activated concrete used in this investigation was produced from mixing normal cement with white soil(Nech Afer) partially as cementitious materials. Glass fiber was added to alkali-activated concrete to investigate the ultimate load-carrying capacity, tension resistance, and crack delays of the activated concrete. It examined the flexural strength of glass fiber-reinforced alkali-activated concrete beams. Laboratory experiments were conducted on activated concrete with and without glass fiber, and normal concrete specimens to determine compressive, split tensile, and flexural strength results on the 7th and 28th days. The percentages of glass fiber used were 0.2, 0.4, and 0.6 by the volume of concrete based on previously published papers[23].

This research discussed the ultimate load-carrying capacity, failure mode, and optimum percentage of fiber. The stress-strain relationship curves were compared for ES EN1992-2015 with previously developed predictions for geopolymer concrete.

1.2 Statement of Problem

In concrete production, ordinary Portland cement (OPC) is conventionally used as a primary binder to produce concrete. Global warming is significantly impacted by the usage of standard ordinary Portland cement (OPC) in the production of concrete. Currently, the construction sector is seeking environmentally friendly building materials, and alkali-activated geopolymer concrete has emerged as a "green cement concrete" alternative to replace ordinary Portland cement concrete[9][10]. This study, therefore used locally available white soil(Nech Afer) with normal cement for alkali-activated concrete production.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

The construction sector around the world has its unique structural requirements. Engineers and Architects need to design structures that can withstand the stresses and loads placed on them over time. Alkali-activated concrete beams need an investigation of flexural strength to determine the ability of beams to resist bending or cracking under monotonic load. Therefore it needs to an investigation of the flexural strength of glass fiber-reinforced beams to determine their suitability for use in construction applications.

1.3 Research Questions

The following inquiries will be addressed by this research:

1. What are the effects of varying percentages of glass fiber on the workability of alkali-activated concrete?
2. What are the effects of varying percentages of glass fiber on the flexural strength of alkali-activated concrete?
3. What is the optimal percentage of glass fiber that can be added to achieve the strength of C-25 concrete grade?

1.4 Objectives of Study

1.4.1 General Objectives

- ❖ The main objective of the study was to investigate the flexural strength of fiber-reinforced alkali-activated concrete beams made from locally available cementitious material under monotonic load.

1.4.2 Specific Objectives

The specific objectives of this study are:-

- ❖ To study the workability of alkali-activated concrete with the addition of fiber percentages.
 - ❖ To determine the flexural strength of alkali-activated concrete beam by varying percentages of glass fiber.
 - ❖ To determine optimal percentages of glass fiber that can be added to achieve the strength of C-25 concrete grade.
-

1.5 Significance of Study

Several previous researchers around the world have investigated the flexural strength of fiber-reinforced alkali-activated concrete beams under monotonic load. They used industrial by-products such as fly ash, slag furnace, ground granulated blast furnace slag, and metakaolin as a binder. However, there is a gap in the literature regarding the investigation of the flexural strength of fiber-reinforced alkali-activated concrete beams under monotonic load using locally available white soil (Nech Afer) as cement. This gap presents an opportunity for creativity in the sector.

The investigation of the flexural strength of alkali-activated concrete beams reinforced with glass fiber in this study provided the following significance.

- ❖ It helps to determine the effectiveness of using fibers as reinforcement materials in alkali-activated concrete beams. This information can be used to optimize the mix design and improve the mechanical properties of cementitious materials.
- ❖ The investigation can provide insights into the behavior of alkali-activated concrete beams under flexural loads. This can help engineers and designers to better understand the performance of the materials in real-world applications
- ❖ Furthermore, the study provided knowledge and experience around geopolymer concrete with fiber in research.
- ❖ Its findings can be used for future literature reviews and by other researchers.

1.6 Scope and Limitation of Study

The scope of the study was extended to investigate flexural strength with other related factors such as the ultimate capacity, stress-strain curve relationship, and failure modes of the fiber-reinforced alkali-activated concrete beam. In addition, the effects of glass fiber on the compressive and split tensile strength of alkali-activated concretes were also investigated. The study also investigated the effects of molarities of alkaline solution with superplasticizer on activated mortar to determine the optimum solution.

The study used glass fiber only to examine the flexural strength of alkali-activated concrete beams. The tests were conducted only on the 7th and 28th day to determine the early and ultimate strength of activated concrete.

2. Chapter II-Literature Review

2.1 General Overview

Concrete is a fundamental building material that will be in demand for a very long time. It's difficult to imagine a world without concrete, which served as its main forerunner. Concrete has been developed in a variety of forms for use in a variety of purposes, but they all share the same characteristics: familiarity, adaptability, strength, durability, wide availability, fire resistance, resistance to the elements, and relatively low cost[11].

Due to the construction industry's explosive growth over the past few decades, there has been a sharp rise in the production of regular Portland cement worldwide. About one ton of carbon dioxide (CO₂) is released into the environment during the manufacturing of one ton of Portland cement clinker. Additionally, the production of Portland cement involves extensive overexploitation of natural resources, particularly limestone quarries. The production of the world's 2.0 billion tons of Portland cement requires more than 3.0 billion tons of raw materials, 70% of which are limestone[12].

The cement industry around the world faces some difficulties, such as diminishing fossil fuel supplies, a lack of raw materials, escalating cement, and concrete demand, rising environmental concerns related to climate change, and a faltering global economy. Therefore, reducing or eliminating CO₂ emissions from the cement manufacturing process through improved production processes and formulas is a top priority. Emission reductions are also necessary to offset the effects of new regulations, green fees, and rising fuel prices on product costs[11].

2.2 Concept of Development of Green Concrete Technology

In the history of the concrete industry, green concrete is a groundbreaking concept. In 1998, Denmark was where this was first developed as green concrete. Green has nothing to do with color. It is a way of thinking about the environment when making concrete, taking into account every stage from the production of raw materials through mixture design to structural design, building, and service life. It is a type of concrete that resembles conventional concrete but requires less energy to produce or use and has less of an impact on the environment[13]. For the production of green cement, numerous processes and technologies have been patented by various production

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

companies. To reduce the carbon dioxide emissions caused by the regular cement manufacturing process, green cement may be a viable option[10].

2.2.1 The Advantage of Green Cement Compared to Regular Portland Cement

When compared to regular cement, green cement performs better and uses fewer natural resources during production. The amount of carbon dioxide released is greatly decreased during the production of green cement. It can cut carbon emissions by 40%. Additionally, it prevents land from being used as a landfill and then ruined. However, the resources required for the production of green cement call for locally accessible cementitious materials and industrial by-products. This greatly reduces the amount of energy required for production[10]. Its advantage in a clear way to understand include:

- ❖ Reducing carbon dioxide emissions from the cement industry, a greenhouse gas.
- ❖ Reduces the number of natural resources used to make traditional concrete, including limestone, clay, shale, sand from Natural Rivers, and natural rocks.
- ❖ Uses industrial waste, such as fly ash, silica fume, and a final furnace, whose disposal might take up several acres of space.
- ❖ Produces with less energy needed.
- ❖ Withstands temperature variations, which lowers the expense of heating and cooling.
- ❖ Sturdy, fire-retardant, and energy-efficient.



Figure 2-1: Green Concrete for a green sustainable environment[10].

2.3 Fiber-reinforced Alkali-activated Concrete

Fiber-reinforced concrete (FRC) is a potential material for construction because discrete fibers can give naturally brittle concrete crack-control mechanisms. Synthetic fibers are a promising option to prevent corrosion-related durability problems, while microfibers, in particular, are successful at providing post-crack ductility and toughness[14].

The addition of fibers improves geopolymer's tensile strength and shifts their fracture behavior from brittle to more ductile. Alkali-activated (potassium or sodium silicate) dehydroxylated halloysite clay reinforced with single-wall carbon nanotubes or graphite was the subject of a 2009 study by Mackenzie and Bolton. Although sodium-based geopolymers outperformed both composites' tensile strengths, there was no discernible difference between carbon nanotubes and graphite-containing composites with tensile strengths of about 2 MPa. The maximum tensile strength (8 MPa) was attained at 0.25 weight percent carbon nanotube concentration[15][16].

The use of fiber in geopolymer concrete is quickly becoming the greatest option for improving structural performance. Previous studies have shown that the flexural performance of fiber-reinforced geopolymer concrete beams is superior to that of specimens with no fiber content, particularly in terms of the ductility properties of geopolymer concrete members. For illustration, in the 2022 study by Dheyaaldin, Mosaberpanah, and Alzeebaree, polypropylene fiber considerably improved the flexural strength of alkali-activated mortar, and samples with 0.5% polypropylene fiber outperformed those with 1%[17].

2.3.1 Flexural Performance of Fiber-reinforced Alkali-activated Concrete

Ranjbar *et al.*, (2015) [19] reviewed that the growing number of applications, particularly environmentally sustainable construction, and high-temperature resistant manufacturing, have sparked interest in the creation, characterization, and use of geopolymers in recent years. Geopolymers, however, typically exhibit tension weakness and brittle failure. Numerous studies have concentrated on the integration of various fiber reinforcements into geopolymers to achieve ideal mechanical and thermal properties for each particular application to address such deficiencies.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

Uddin, Shaikh, and Hosan, (2016) [20] reported that the main goal of adding fibers to concrete was to enhance its tensile and flexural strengths as well as its post-cracking ductility. Concrete is strengthened using a variety of fiber types. In their findings, the tensile and flexural strengths, hardness, and ductility of concrete are all greatly increased by steel fibers, among other fibers.

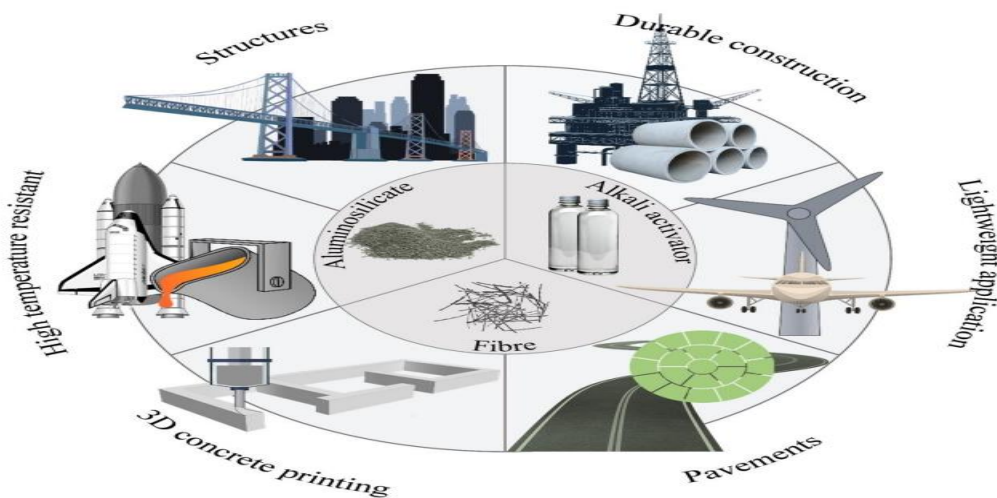


Figure 2-2: Potential applications for fiber-reinforced geopolymer composites[19].

2.3.1.1 Flexural Performance of Macro-synthetic Fiber-Reinforced Alkali-activated Concrete

Dopko et al. (2018) [14] investigated the effect of macro-synthetic fibers on class-F fly ash with 30% type I or II Portland cement replacement. Three different types of macro-synthetic fibers include polypropylene (PP), polyvinyl alcohol (PVA), and alkali-resistant glass (ARG) macro-fibers mixed at volume fractions of 0.5%, 1.0%, and 1.5%. The three studied fibers' post-crack performance characteristics of residual strength, toughness, and equivalent flexural strength ratio all improved with fiber volume increases of 0.5% to 1.5%.

The ARG fibers consistently produced the highest residual strength and toughness values of the three tested fibers, with the 1.0% volume ARG fiber mixture having a more obvious advantage. For each of the three-volume percentages examined, PVA fibers consistently generated the lowest toughness values. Its volumes tended to re-aggregate and form clumps with the sand and paste when they were increased to 1.0% or more, resulting in a non-homogeneous mixture that had noticeable effects on the composite's pre-crack flexural performance but less of an impact on the

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

composite's post-crack flexural performance. PP fibers showed the most consistent increases in post-crack flexural properties when fiber volumes were increased.

2.3.1.2 Flexural Performance of Steel Fiber-reinforced Alkali-activated Concrete

Steel fiber reinforced concrete (SFRC) has gained popularity in recent years and is frequently used in place of traditional reinforcing bars in a variety of applications, including flat slabs, sewer pipes, industrial floors, and tunnel constructions (shotcrete, precast tunnel lining segments). The geometrical and mechanical characteristics of steel fibers, which are frequently utilized in the building sector, vary widely. The main result of adding steel fibers to concrete is to increase the quasi-brittle material's ductility or toughness, which increases the load-bearing capacity of the concrete beyond the peak load. This is primarily caused by the fact that fibers used to span cracks pass pressures across them, slowing the growth and spread of the fissures. SFRC was initially widely applied to crack control (non-structural application).

Song, (2017), [21] reported that new fiber types and contemporary concrete technology had led to an increase in the use of SFRC (often with excellent performance) as a full replacement for traditional reinforcement in concrete structures (structural application).

According to **Uddin, Shaikh, and Hosan, (2016)** [20], demonstration concrete is reinforced using a variety of fiber types. Among all fiber types, steel fibers help concrete's tensile and flexural strength, hardness, and ductility in a big way. Steel fiber reinforced concrete (SFRC) is consequently extensively utilized in a variety of construction applications, such as tunnel lining, airport paving, impact and blast resistance of significant structures, etc. However, a fire occurs during the service life of the aforementioned structures as well as other reinforced concrete structures. Significantly high temperatures that develop around the structures during a fire cause the Uddin concrete to deteriorate through spalling and cracking.

Ganesan et al. (2013), [16] studied how steel fiber reinforcing affected the engineering parameters of Class F fly ash-based geopolymer concrete, including its compressive strength, splitting tensile strength, rupture modulus, elasticity modulus, and Poisson's ratio. A superplasticizer with a naphthalene basis was used to make concrete more workable, and it was then cured for 24 hours

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

at 60°C. Steel fibers enhanced the compressive strength (49.23 MPa, an increase of 8.51%), splitting tensile strength (4.17 MPa, an increase of 61.63%), modulus of rupture (6.2 MPa, a reduction of 24%), modulus of elasticity (35.5 GPa, a reduction of 64.92%), and Poisson's ratio (0.21, a reduction of 50%).

Bernal *et al.*, (2010) [22] reported that crack-delaying, fiber addition is an effective way to increase the mechanical performance and shrinkage control of brittle matrices like mortars and concretes made of alkaline cement. For illustration, the post-cracking behavior of these alternative concretes is significantly improved by the inclusion of steel fibers in alkaline concrete. The addition of steel fibers significantly improved the parameters linked to durability performance, such as water absorption and the number of permeable pores, with the effect becoming more obvious with increasing fiber volume.

2.3.1.3 Flexural Performance of Glass Fiber-reinforced Alkali-activated Concrete

Mermerdaş, (2019) [23] performed an experimental program to ascertain the characteristics of glass fiber-reinforced geopolymer mortar, a blend of fly ash, alkaline liquids, fine aggregates, and glass fibers. In hardened geopolymer composite (GPC), the effects of glass fiber inclusion on density, compressive strength, splitting tensile strength, absorption, and sorptivity were investigated. The ratio of alkaline liquid to fly ash was set at 0.33. Fly ash was activated using alkaline liquids such as solutions of NaOH and Na₂SiO₃. For Na₂SiO₃: NaOH, an alkaline liquid combination ratio of 2.5:1 was employed. Glass fiber was incorporated into the mortar mixtures in amounts of 0.2%, 0.4%, 0.6%, 0.8%, 1.0%, and 1.2% by volume of concrete. The results showed that the presence of the glass fiber reduces the workability over a 48-hour curing regimen at a temperature of 60°C. However, by increasing the fiber content, fly ash-based GPC's compressive strength and splitting tensile strength were both improved. However, the sorptivity and water absorption of GPCs have not changed noticeably.

The mechanical characteristics of geopolymer concrete composites (GPCC), which incorporate fly ash (FA), alkaline liquids, and glass fibers, were investigated by **Kumar et al. (2012)** [23]. The ratio of alkaline liquid to fly ash was set at 0.4 with 100% OPC replacement. Concrete mixtures containing 0.01%, 0.02%, and 0.03% volume fraction of glass fibers. Based on the test findings, it

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

was found that compared to Geopolymer concrete and regular Portland cement concrete, Geopolymer concrete composites had considerably better strength in a short curing period (one day). Their investigation revealed that, in addition to curing time results, concrete containing 0.02% E-glass fiber per volume performed well in all tests.

Mehta and Bhandari (2021) [24] looked at the effects of alkali-resistant glass fibers with a length of 36 mm and contents varying from 0.3, 1, 2, 3, and 3.5% based on the weight of the concrete. For various scenarios, the flexural strength and compressive strength were compared at 7 days and 28 days. According to the findings, glass fibers at 1%, 1.5%, 2%, and 2.5% have a 20% greater flexural strength than geopolymer concrete.

2.3.1.4 Flexural Performance of Different Fiber-reinforced Alkali-activated Concrete

Construction applications place a premium on AAB's elastic characteristics under an applied force. By adding fiber reinforcement to the AAB matrix, such as short fibers or unidirectional long fibers, these properties can be enhanced. The mechanical properties of alkali-activated BFS, fly ash, or a BFS/fly ash (50/50) mixture were slightly improved when 0.5% polypropylene fibers were added (by volume of mortar), but all the investigated binders' modulus of elasticity was decreased when 1.0% polypropylene fibers were added, according to the study of Puertas et al., 2003. The counterpart made of cement saw an increase in elasticity at the same time[24].

In AAS prisms, alkali-resistant glass fibers were incorporated at a dosage of up to 0.22%, which, like in the OPC specimens, increased flexural strength and 20% less drying shrinkage, but compressive strength was unaffected[16][25]. The mechanical characteristics of AAS were adversely affected by the addition of carbon fibers[26][27]. AAS and the reference cement mortar both experienced a decline in compressive and flexural strength as the carbon fiber percentage rose. However, the addition of carbon fibers has some favorable effects on the characteristics of AAS, such as a 50% reduction in drying shrinkage.

According to **Bernal et al., (2010)** [22] studies of strain-hardening and high tensile ductility in polyvinyl alcohol (PVA) fiber-reinforced AAS mortar was accomplished despite the high brittleness of the AAS mortar itself. In their study, they examined the mechanical characteristics of AASC reinforced with steel fibers. With more fiber composition, splitting tensile and flexural

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

strength was dramatically increased. However, the compressive strength decreased with higher fiber content, both in concrete that is based on type I of the OPC and AASC.

The qualities of a novel kind of ultra-high-strength composite material based on alkali-activated slag/silica fume (AAS/SF) were investigated by Aydn and Baradan (2013a, 2013b) [25][28]. This brand-new class of high-performance composite material was created as a substitute for reactive powder concrete (CRPC), which has a compressive strength of over 200 MPa. In contrast to systems based on Portland cement, alkali-activated systems benefited from the inclusion of silica fume by using less water and shrinking less. Sodium silicate ($M_s = 1.2, 4\%$ Na_2O by weight of binder) was used to activate a BFS/SF-quartz sand mixture (four distinct size fractions, 3 mm maximum size). All combinations had a 0.17 water-to-binder ratio[16].

The effects of high-strength brass-coated steel fiber reinforcing on the characteristics of AAS/SF mortars were discussed in Aydn and Baradan's initial publication (2013a)[28]. With an increase in fiber volume fraction (0-2.0%) and length, the initial AAS/SF mortars' extremely high strength significantly increased (6–13 mm). With 1.5% fiber reinforcement, the compressive strength rose from 132 MPa without fibers to 192 MPa (6 mm fibers) and 223 MPa (13 mm fibers). Compressive strength was not significantly affected by further increases in fiber volume fraction (up to 2.0%). Additionally, mortars' flexural strength rose from 12 MPa without fibers to 25.2 MPa (6 mm fibers) and 48.4 MPa (13 mm fibers) with 2.0% fiber reinforcement. AAS/SF mortars were more durable as a result of longer fibers. Regardless of the fiber length, the increase in fiber content decreased the drying shrinkage of AAS/SF mortars[29].

In the second study of Aydn and Baradan, 2013b, the outstanding engineering properties of this new composite material (ARPC), reinforced with 1.5% high-strength brass-coated steel fibers (13 mm) [30] [16], were described and compared with a typical CRPC shown in Table 2.1.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table 2-1: Mechanical characteristics of steam-cured and standard-cured alkali-activated (ARPC) and traditional CRPC[30].

	Steam-cured (12 h at 100°C)		Standard-cured (28 days in water at 20°C)	
	ARPC	CRPC	ARPC	CRPC
Compressive strength (MPa)	215.9	214.6	147.5	176.1
Splitting tensile strength (MPa)	19.5	19.2	15.6	15.8
Modulus of elasticity (GPa)	84.1	114.0	46.0	69.2
Poisson's ratio	0.22	0.21	0.21	0.21
Fracture energy (N/m)	16,016	14,200	12,777	15,799
Flexural strength (MPa)	41.5	34.7	25.0	29.6

Alzeer and Mackenzie, (2013)[30]described using natural fibers made of protein as long-fiber reinforcement for a geopolymer matrix. Sodium silicate was used to activate dehydroxylated kaolin-type halloysite clay, and carpet (crossbred) or Merino wool fibers were used as reinforcement. The flexural strength of the geopolymer composites was about 40% higher than that of the initial matrix, and in contrast to the former, which exhibited failure in a manner resembling ceramic brittleness, the latter exhibited graceful failure. The reinforcement of natural cellulose-based fibers also led to the graceful failure of geopolymer composites. Increased fiber content resulted in an improvement in the mechanical properties of fiber-reinforced composites, resulting in maximum flexural strengths of 70 MPa and an elastic modulus of 10 GPa with a 10% fiber content[16].

The ductility of Class-C and Class-F fly ash composites was greatly enhanced by the addition of short PVA fibers according to a study by **Sun and Wu, 2008**[31]. However, compared to Class-C fly ash produced under identical conditions, Class-F fly ash composites had lower first fracture strength and ultimate tensile strength.

Li et al. (2005) investigated the mechanical characteristics of extruded metakaolin-fly ash composites reinforced with short PVA fibers. Higher geopolymer flexural strengths and smaller deflections were achieved with the replacement of metakaolin with trace amounts of fly ash. The addition of PVA fibers significantly improved the geopolymers' ductility and shifted the failure modes from brittle to ductile[16].

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

Geopolymer ultimate strength was also significantly improved by the inclusion of PVA fibers, and impact stiffness and impact toughness were both further enhanced by the addition of fly ash in minute amounts according to a study by **Zhang et al., 2006**. Significantly less impact strength, toughness, and stiffness were present when more fly ash was added[16].

Natali et al. (2011) studied the effects of different types of dispersed short fibers (1 weight percent): HT-carbon fibers, commercial E-glass fibers, PVA fibers, and PVC fibers. All types of fiber examined resulted in a significant (30–70%) increase in the flexural strength of geopolymer composites. For the sample reinforced with carbon fiber, maximum values were discovered. Additionally, the examined geopolymer composites' toughness was improved, showing a change from a brittle failure mode to a more ductile mode[16].

Lin et al. (2008, 2009) [32][33] demonstrated the significant strengthening and toughening effects of short carbon fibers. They investigated how short carbon fiber reinforced geopolymer matrix composites' mechanical characteristics and fracture behavior was affected by the fiber content. Based on metakaolin that has been activated by potassium silicate and reinforced with various volume fractions of short carbon fibers, geopolymer matrix composites were produced. A stack was made by layering 20–50 sheets of sheet-like, short carbon fiber preform that had been coated with geopolymer. Composites were dried for an additional 24 hours at 120°C after being cured in a vacuum bag for 24 hours at 80°C. For preform laminates, a pressure of 0, 0.2, 1.2, or 2.0 MPa was loaded at the beginning of the curing process to achieve the desired final thickness of 5 mm. At 4.5% of carbon fiber volume percent, a remarkable flexural strength of >90 MPa and Young's modulus of 12 GPa were obtained shown in Figure 2.4. Young's modulus increased by 65%, up to a maximum of 20 GPa, whereas flexural strength decreased by 10% with an increase in a fiber volume percentage of up to 6%. The evaluated properties declined when the fiber volume percentage was raised further. The primary mechanisms for strengthening and toughening were attributed to the apparent fiber bridging and pulling-out action. The property improvements were mostly based on the network structure of short carbon fiber preform[16].

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

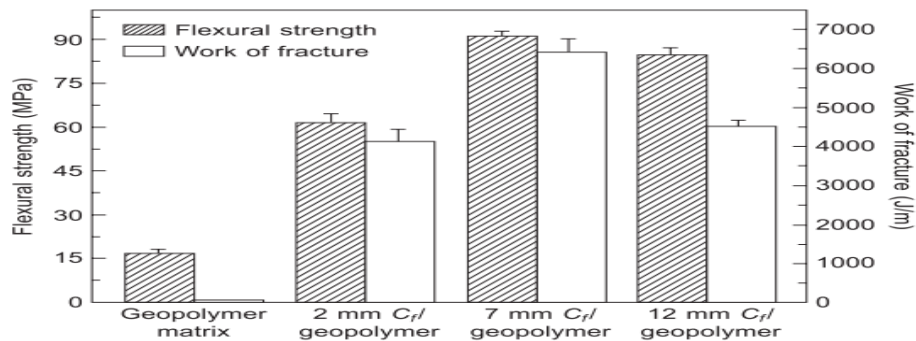


Figure 2-3: Variation of flexural strength and work of fracture of geopolymer matrix and short carbon fiber (Cf) geopolymer composites versus starting fiber length[32].

Lin and Jia's (2009) [33] research focused on electroless Ni-plated short carbon fiber reinforced geopolymer matrix composites with different carbon fiber/matrix interface coating thicknesses. The examined geopolymer composites' flexural strength and Young's modulus showed maximums of 55 MPa and 5.4 GPa at 0.15 mm coating thickness after being alkali-activated with potassium silicate and reinforced with short carbon fibers. However, the fracturing activity decreased quickly and noticeably, and the fracture mode shifted from ductile to brittle. Because of the increased interface bonding strength between the fiber and matrix, carbon fibers favor breaking rather than pulling out during loading. In addition, as the coating thickness is increased, the pliability of the carbon fibers decreases[16].

2.4 Performance Evaluation of Geopolymer Concrete Beams under Monotonic Loading

Saranya, Nagarajan, and Shashikala (2019) [21] conducted experimental and numerical research on steel fiber-reinforced geopolymer concrete (SFGPC) beams under monotonic loading. They compared the GPC and SFGPC's parameters, including the elasticity modulus (E_c), Poisson's ratio (ν), and ductility ratio, and found that the SFGPC had more advanced engineering features and developed stress block metrics. Their studies also emphasize the cracking behavior, load-deflection characteristics, and ultimate load capacity of the beam under monotonic loading.

In their research, they found that adding 0.75% steel fiber increased the material's compressive, tensile, and flexural strengths. It is discovered that the presence of steel fibers causes a rise in both the elastic modulus and Poisson's ratio. The ductility of SFGPC 0.75 is 2.5 times that of regular geopolymer concrete. Compared to geopolymer concrete reinforced with steel fibers, GPC has a

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

lesser load-carrying capacity. When compared to cement concrete, the ultimate loads for SFGPC 0.75, SFGPC 0.5, and SFGPC 0.25 specimens rose by 17%, 12%, and 9%, respectively. Compared to GPC, OPC concrete contains larger cracks, but SFGPC has a lot of smaller cracks.

2.5 Flexural Performance Parameters and Test Types for Fiber-reinforced Alkali-activated Concrete

2.5.1 Flexural Performance Parameters

The performance of various specimens can be compared using a set of metrics based on the load versus deflection curves generated from the test, per ASTM C1609 Standard. Equation (2.1) uses the specimen's size and the load resisted at the corresponding deflection to compute the strength of the specimen at any deflection value.

$$f_l = \frac{pl}{bd^2} \quad (2.1)$$

Where: f = flexural strength (psi, MPa), P = load (lb, N), L = span length (in., mm), b = specimen width (in., mm), and d = specimen depth (in., mm).

The modulus of rupture, which serves as a measure of the beam's flexural strength, is determined using Equation 1. The first peak flexural strength, f_1 , connected to the load just before fracture formation, P_1 , and the rupture modulus are extremely similar. The fibers in the mixture give the residual load-carrying capability at deflections greater than those corresponding to the first peak load. Residual strength refers to the ability of the FRC specimen to sustain load after cracking has occurred. When assessing the flexural performance of FRC mixes, toughness which is the energy absorbed by the specimen during the loading process can be thought of as a crucial factor. This is mostly because it measures the specimen's post-crack load-bearing capacity within the entire prescribed deflection range. In the final step, equation (2.2) is used to calculate the equivalent flexural strength ratio.

$$R_{T150} = \frac{150T_{150}}{f_1bd^2} \quad (2.2)$$

Where: RT_{150} = equivalent flexural strength ratio (%), f_1 = first peak strength (psi, MPa), RT_{150} = Toughness up to $L/150$ deflection (in.-lb, Joules), b = specimen width (in., mm), and d = specimen

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

depth (in., mm). A parameter that links the first peak flexural strength to the concrete's toughness is the equivalent flexural strength ratio. A high first peak strength and low toughness would result in a low RT150 rating, whereas the opposite would be true for low first peak strength and high toughness. The analysis of performance parameters along with the original load-deflection curves provides an in-depth insight into the promise of each fiber type and dosage[14].

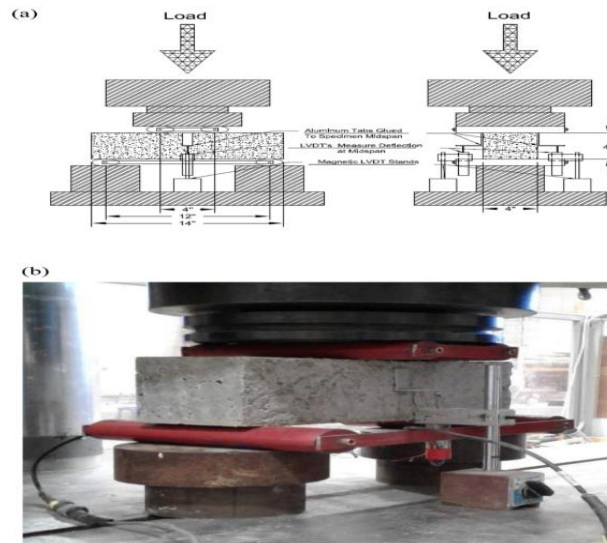


Figure 2-4: Flexural test setup [12]: (a) main dimensions; and (b) full configuration.

2.5.2 Flexural Strength Test Types

Flexural strength tests come in essentially two varieties. There is no support in the center of a long, rectangular sample of the material, but the ends are firm. The material is subsequently subjected to a load or force, which causes it to fail[34]. There are two types of flexural strength tests.

a) Three-point flexural strength test

In the 3-point bending strength test, a load is gradually increased in the middle of the sample until the material breaks or permanently bends. The force at the point of failure can be precisely measured by a flexural test instrument while increasing forces are applied[34]. The flexural strength calculation is shown in eq (3).

$$\sigma = \frac{3FL}{2wd^2} \quad (2.3)$$

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

Where: F: means the maximum force applied, L: is the length of the sample, w: is the width of the sample, and d: is the depth of the sample.

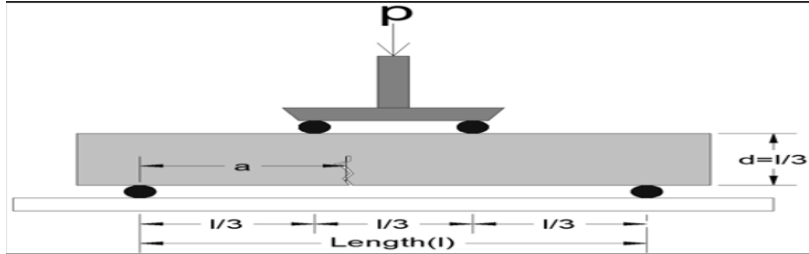


Figure 2-5: Three-point flexural strength test.

b) Four-point flexural test

A four-point bending test is essentially similar to a three-point test, with the exception that the force is applied simultaneously at two points, once again toward the center of the sample. With the addition of a fourth bearing, the beam's area between the two loading points is subjected to the greatest amount of stress, as opposed to merely the area directly beneath the central bearing in three-point bending. When one load or force is applied one-third of the way between the supports and the second is applied two-thirds of the way between them, calculating the flexural strength is the simplest[34]. The flexural strength calculation is shown in Eqn (4).

$$\sigma = \frac{FL}{wd^2} \quad (2.4)$$

Where: F: means the maximum force applied, L: is the length of the sample, w: is the width of the sample, and d: is the depth of the sample.

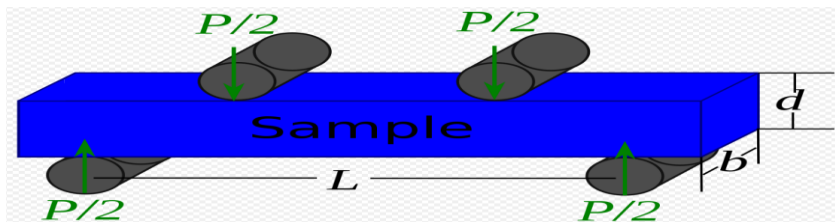


Figure 2-6: Four-point flexural strength test.

3. Chapter III-Research Methodology

3.1 Study Area

This research conducted experiments on an alkali-activated concrete beam to investigate its flexural strength, as well as the compressive and split tensile strengths of glass fiber-reinforced alkali-activated concrete. The experiments were performed at JIT University's laboratory in Jimma, Ethiopia.

3.2 Research Design

The research used an experimental research design method, which is illustrated in Figure 3.1 to show the workflow.

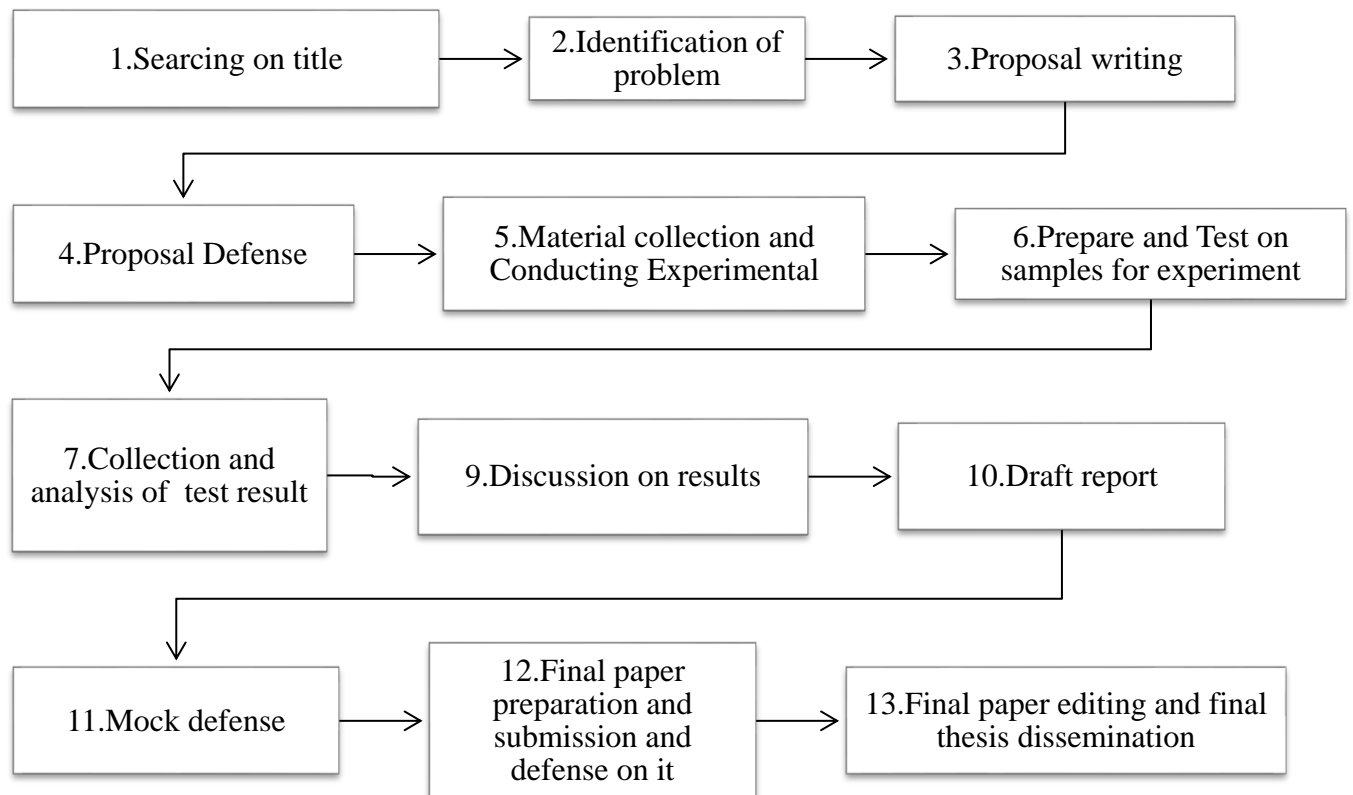


Figure 3-1: The flowchart in the methodology section illustrates the research design.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

3.3 Study Variables

The following study variables were determined for this investigation:

3.3.1 Dependent Variables

- ❖ The workability of alkali-activated concrete
- ❖ The flexural strength of an alkali-activated concrete

3.3.2 Independent Variables

- ❖ Effect of different percentages of glass fiber content (0.2, 0.4, and 0.6).

3.4 The total number of experimental samples, method, and size of study

The study used random sampling methods and required material tests and mix designs were conducted according to ASTM and ACI requirements. A total of 90 samples were scheduled for investigation, with each sample consisting of at least three specimens (sp1, sp2, and sp3) as shown in Table 3.1.

Table 3-1: The designed sample that was expected for this study.

S.No	Mix ID	Total test sample on the 7 th and 28 th day			Total
		For compressive test	For the split tensile test	For flexural test	
1	Control	6	6	6	18
2	0%GF	6	6	6	18
3	0.2%GF	6	6	6	18
4	0.4%GF	6	6	6	18
5	0.6%GF	6	6	6	18

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

3.5 Material Collection Procedure

To gain a deeper understanding of the study, relevant published papers were collected from the internet and magazines. Materials such as Portland pozzolana cement, white soil (Nech Afer) for binder and aggregates were obtained from selected areas in Jimma town for the experimental research. Glass fiber, activator solution, and admixtures such as sodium hydroxide, sodium silicate, and superplasticizer were sourced from Addis Ababa. Sufficient quantities of materials were collected from these areas for laboratory testing.

3.6 Materials Used For Experiment

The materials used in the experiment included white soil (Nech Afer), coarse aggregate, sand, Portland pozzolana cement, alkali-activated solution (sodium silicate and sodium hydroxide), glass fiber, superplasticizer, drinkable water, and placing equipment that met the same standards as normal concrete.

1. Cementitious Materials (Cement and White Soil)

Locally available white soil (Nech Afer) and standard cement were used to prepare the paste and concrete specimens for this investigation. The standard cement used in the concrete production was sourced from Yetebaberut in Jimma town, while the white soil (Nech Afer) was obtained from Marowa in the Jimma zone.



Figure 3-2: Nech Afer (white soil) used in experimental investigation.

2. Aggregates

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

The fine aggregate used in this research was chewaka sand passing through 4.75mm sieve sizes, while the maximum coarse aggregate size used was passing through 12.5mm sieve sizes. Both aggregates were purchased from Jimma town and brought to the laboratory for concrete production.

3. Alkaline Solution

The most commonly used activator for non-cement or geopolymer materials is a combination of sodium hydroxide (NaOH) and sodium silicate. The sodium hydroxide (99% pure pellets) and sodium silicate (with a mass composition of Na₂O = 14.7%, SiO₂ = 29.4%, and H₂O = 55.9%) were purchased from Allied Chemicals Trading PLC in Addis Ababa for this investigation.



Figure 3-3: Alkali-activating chemicals used for the experiment.

4. Water

Water suitable for drinking is generally suitable for making concrete. It should be free from acids, oils, alkalis, or other organic impurities. In this investigation, drinkable mixing water was taken from the JIT water supply.

5. Super-Plasticizer [High-Range Water Reducer]

Superplasticizers, also known as high-range water reducers, are additives used to produce high-strength concrete or self-compacting concrete. For this investigation, a high-range water-reducing superplasticizer was purchased from Sika Abyssinia Chemicals Manufacturing PLC to improve workability.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD



Figure 3-4: Superplasticizer used in the experiment.

6. Glass Fiber

Glass fibers are known for their high strength, temperature resistance, and corrosion resistance. For this investigation, chopped glass fibers with a length of 18mm and a nominal diameter of 0.015mm were used. The unit weight of the glass fiber was 2560 kg/m³



Figure 3-5: Glass fiber used in the experiment.

3.7 Data Requirement

For the experimental analysis of the glass fiber-reinforced alkali-activated concrete with the available universal testing machine the following properties were conducted.

1. Compressive strength
 2. Split tensile strength
 3. Flexural strength
-

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

3.8 Sources of Data

Two types of data sources would be used for this investigation.

3.8.1 Primary Data:

The expected data for this experimental research was taken from laboratory experiments.

3.8.2 Secondary Data:

Secondary data for this experimental research would be collected from previously published journal papers on the internet and organized in Mendelev desktop software.

3.9 Laboratory Result Presentation and Analysis

The gathered data was processed and presented in various formats, including tables and graphs. The laboratory test results were analyzed using MS Excel and PTC Mathcad. A conservative approach was taken in interpreting the results to ensure meaningful. The repeatable engineering parameters were obtained in line with appropriate standard procedures.

3.10 Experimental Works Procedure

3.10.1 Materials Physical Property Tests

1. Cementitious Materials (Cement and white soil(Nech Afer))

For the investigation of the physical properties of cementitious materials for the required application, different tests have been carried out which include the chemical composition of white soil (Nech Afer), consistency test, setting time test to confirm as per the requirements of ASTM C114 standards.

Table 3-2: Specific gravities for cementitious materials.

S.No	Materials	Sp.gr
1	Portland pozzolana Cement	2.9
2	White soil(Nech Afer)	2.4

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD



a) Specific gravity test for Nech Afer b) Normal Consistency test for binder.

Figure 3-6: Photos taken during the test of specific gravity and normal consistency.

2. Tests on Aggregates

The physical property test on aggregates was done as per the requirements of ASTM C33. Each physical property of the fine aggregate required for the mix design as per the specification was done in the laboratory.

Table 3-3: Summary of absorption capacity, specific gravity, unit weight, and total moisture content of aggregates.

S.No	Aggregate Types	Sp.gr(SS D)	Sp.gr(oven-dried)	Apparent. sp.gr	AC (%)	MC (%)
1	Fine Aggregate	2.655	2.633	2.693	0.84	0.516
2	Coarse Aggregate	2.72	2.70	2.76	0.62	0.74

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

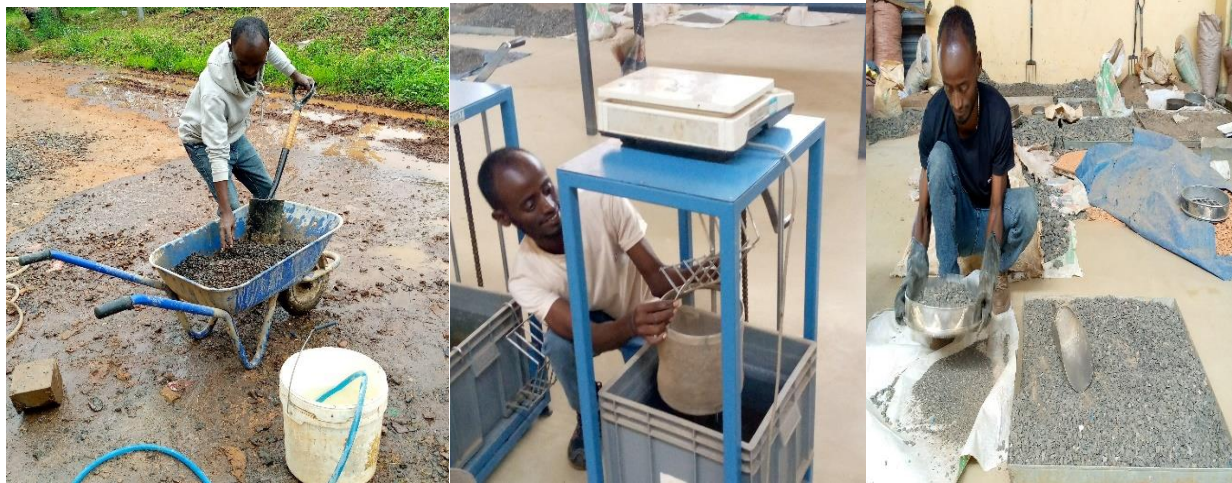


Figure 3-7: Photos taken during the test of coarse aggregate.

3.11 Mix Design, Mix Proportion, Mixing Procedure, and Specimen Preparations

3.11.1 Mix Design of Alkali-activated Concrete

Mix design is the process of determining the necessary characteristics of a concrete mixture, including its fresh properties and required mechanical properties such as strength and durability. It involves specifying the inclusion, exclusion, or limits on specific ingredients and ultimately results in the development of a concrete specification.

There is no standard or specification for the geopolymer concrete mix design procedure. A few mix design methodologies have been proposed earlier for GPC by different researchers. The mix design procedure developed for this study followed previous research investigation[35][36]. The mix proportion was designed for C20/25 standard cube compressive strength of alkali-activated concrete, and it was designed to give a slump value of 20-50mm according to ACI 211.1-81.

1. Fixing the Alkaline Activator Solution (AAS) Content [As per ACI211.1-81 Table 3-8]:

An appropriate alkaline-activator liquid (AAL) content selection is a crucial step in the design of any geopolymer concrete and is dependent on the binder content used in the mix. In normal concrete mix proportion, water content is fixed based on the maximum size of aggregate ACI211.1-81, this procedure is also adopted in this alkali-activated concrete for fixing the alkaline activator solution AAS[37]. The total water content in the mix should be limited to the maximum

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

water content shown in the table: Let's assume workability for a 12.5mm maximum Aggregate size of a slump of 20-50mm. Alkali-activation solution taken as standard water content was 199kg/m^3 .

2. Determination of Individual Activators Solution:

The sodium silicate-to-sodium hydroxide mass ratio has a critical impact on the geopolymerization reaction. From the available literature, it has been deduced that an empirical value of 2.5 was fixed for this study to keep the production cost of the AAC in check[38]. The individual weights of the NaOH and Na_2SiO_3 solutions are calculated from equation 3.1 and 3.2.

$$\frac{\text{Na}_2\text{SiO}_3}{\text{NaOH}} = x \quad (3.1)$$

Where: x was taken from previous literature=2.5

$$\text{Mass of Na}_2\text{SiO}_3 = \text{Mass of (NaOH} \cdot x) = \text{Mass of (2.5} \cdot \text{NaOH)} \quad (3.2)$$

Then,

$$\text{Mass of AAS} = \text{Mass of (Na}_2\text{SiO}_3 + \text{NaOH)} = \text{Mass of (2.5} \cdot \text{NaOH} + \text{NaOH)} \quad (3.3)$$

$$\text{Mass of AAS} = \text{Mass of NaOH (2.5+1)} \quad (3.4)$$

$$\text{Mass of NaOH} = \frac{\text{Mass of AAS}}{(1+2.5)} = \frac{199\text{kg/m}^3}{3.5} = 56.857\text{kg/m}^3$$

$$\text{Mass of Na}_2\text{SiO}_3 = \text{Mass of NaOH} \cdot 2.5 = 56.857\text{kg/m}^3 \cdot 2.5 = \mathbf{142.143\text{kg/m}^3}$$

3. Determination of Absolute Water-Cement Ratio [From ACI, 211.1.81, Table 3.1]:

After fixing the activator solution AAS, the normal concrete absolute water cement ratio of 0.5 was used as per ACI 211.1-83 table 3.1 [37]. Using the above aggregate determined data and the following concrete data the mix design has been calculated as follows; Grade of concrete = C20/25, Standard Cylinder Characteristic Strength (f_{ck}) = 20Mpa, Standard Cubic Characteristics strength (f_{cu}) = 25Mpa

a) Target mean strength value of concrete for standard cylinder compressive strength

The compressive strength of concrete is denoted by concrete strength classes which relate to the characteristic (5% of expected to fail) cylinder strength f_{ck} . The target mean strength, f_{cm} (f_{cr}), is

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

also the value used to establish the mix design and is intended to take account of the normal variability that will occur in concrete production. This margin of 8MPa for standard cylinders is consistent with a normal distribution with a standard deviation (SD) of about 5MPa[39]:

$$f_{cm} = (20+8) \text{ MPa} = 28 \text{ MPa} \quad [\text{As per ES EN 1992-2013 Table 3.1}]$$

$$f'_{cr} = f'_{c} + 8 \text{ Mpa (1200Psi)} = 28 \text{ Mpa} \quad [\text{As per ACI 214-02 Table 5.2}][40].$$

b) Target mean strength value of concrete for standard Cube compressive strength

The compressive strength of concrete is denoted by concrete strength classes which relate to the characteristic (6% of expected to fall) cube strength f_{cu} . The target mean strength, f_{cm} (f'_{cr}), is also the value used to establish the mix design and is intended to take account of the normal variability that will occur in concrete production. This margin of 10MPa for the cube is consistent with a normal distribution with a standard deviation (SD) of about 6Mpa.

$$f'_{cu} = f_{cm} - 1.64SD \text{ where } 1.64SD = 1.64 * 6 = 9.84 \text{ Mpa} \sim 10 \text{ Mpa} \quad [\text{As per EC-2}][39]$$

$$f'_{cr} = f'_{c} + 1.576SD \text{ where } 1.576 * 6 = 9.5 \text{ Mpa} \quad [\text{As per ACI 214R-11, 5.3. table 5.2}][40].$$

The mean compressive strength of the standard cube was 35Mpa, and 34.5Mpa for EC-2 and ACI 214R-11 respectively.

4. Determination of Binder Content:

After fixing the activator solution and w/c ratio, the binder content was determined as per the Eqn below

$$y_{\text{binder content}} = \frac{\text{AAS}}{w/c} \tag{3.5}$$

$$y_{\text{binder content}} = \frac{199 \text{ kg/m}^3}{0.5} = 398 \text{ kg/m}^3$$

Where 320 kg/m^3 is the minimum cement content for C20/25 with maximum size of 12.5mm

The amount of Portland pozzolana cement and nech afer is 50% of $398 \text{ kg/m}^3 = 199 \text{ kg/m}^3$ respectively.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

5. Determination of Water Content:

To calculate the water-to-solid binder ratio, the total amount of water in the activator solution should be calculated. The mass of the water in the NaOH solution and Na₂SiO₃ solution added together produces the entire amount of water in the alkaline activator solution.

By combining the flakes with water, D.Hardjito and B.V. Rangan [2005] [41] created a sodium hydroxide (NaOH) solution. In their study, they found that the mass of NaOH solids in a solution varied according to the solution's concentration, which was given in terms of molarity, M. For example, a liter of NaOH solution with a concentration of 12M contained 12x40 = 480 grams of solid NaOH, where 40 is the molecular weight of NaOH. For every kilogram of a 12M concentration NaOH solution, 361 grams of solid NaOH were detected. For the other concentrations, the mass of NaOH solids per kilogram of the solution was measured as 14M: 404 grams, 12M: 361 grams, and 16M: 444 grams.

a) Water Content in Sodium Hydroxide[NaOH]

Molarities selected for this research in NaOH were 12M, 14M, and 16M with the percentage of water content[42]. By using gravimetric analysis on a sample of NaOH solution with a molarity of 12M, 14M, and 16M per kg, the percentage of NaOH solids was calculated as follows: NaOH solids of 12M = $\left[\frac{361\text{gram}}{1000\text{gram}}\right]*100\% = 36.1\%$ of solids taken for dissolving with 63.9% of water content. The other molarities of solid and water content performed in similar ways as shown in the table 3.3 below.

Table 3-4: The solid and water content of 12M, 14M, and 16M of NaOH.

S.No	Selected NaOH Molarities	% of solid content	% of water content
1	12M	36.1	63.9
2	14M	40.4	59.6
3	16M	44.4	55.6

Let's take 14M of NaOH for illustration, in 40-gram solid content was = 40gram*0.404 = 16.16gram of solid 40gram of NaOH, but for 2.5 concentration for 199kg/m³ amount of NaOH

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

was determined above $=56.857\text{kg/m}^3$. The water content in 14M was determined as $56.857\text{kg/m}^3 * 0.596 = 33.887\text{kg/m}^3$ and solid content in 14M was determined as $= 56.857\text{kg/m}^3 - 33.887\text{kg/m}^3 = 22.97\text{kg/m}^3$.

Table 3-5: The summary of amounts (kg/m^3) of NaOH for different molarities.

S.No	NaOH Molarities	40gm of 1M of NaOH		56.857 kg/m^3 of NaOH	
		solid content(gm)	water content(gm)	Solid content(kg/m^3)	Water Content(kg/m^3)
1	12M	14.44	25.56	20.53	36.33
2	14M	16.16	23.84	22.97	33.89
3	16M	17.76	22.24	25.25	31.61

b) Water Content in Sodium Silicate [Na_2SiO_3]

The sodium silicate consists of water content in a percentage of 55.9% by mass of mixing proportion by manufacturing specification. Water content $= 0.559 * 142.143\text{kg/m}^3 = 79.5\text{kg/m}^3$.

6. Determination of ratio of liquid-to-solid [W_c/S]:

$$\frac{\text{Water content}}{\text{Solid content}} = \frac{[\text{wt.of NaOH} + \text{wt.of Na}_2\text{SiO}_3 + \text{wt.of extra water}] * \text{water}}{[\text{wt.of NaOH} + \text{wt.of Na}_2\text{SiO}_3 + \text{wt.of Binder content [PPC+NA]}] * \text{solid}} \quad (3.6)$$

For illustration,

$$\text{Total water content for 14M} = [33.887 + 79.46] \text{ kg/m}^3 = 113.347\text{kg/m}^3$$

$$\text{Total Solid Content for 14M} = [22.97 + 62.685 + 199 + 199] \text{ kg/m}^3 = 483.655\text{kg/m}^3$$

$$\text{The ratio of Water content to solid content} = \frac{113.347\text{kg/m}^3}{483.655\text{kg/m}^3} = 0.234$$

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

7. Determination of Total Aggregates Content:

The total aggregate content was determined as per the absolute volume method. The volume of total aggregates includes both the aggregates used in the study i.e. fine aggregate passing 4.75 mm and coarse aggregates passing 12.5 mm sieve.

$$\text{Total volume (1m}^3\text{) of concrete} = V_{\text{Binder content}} + V_{\text{AAS}} + V_{\text{air content}} + V_{\text{TA}} \quad (3.7)$$

$$V_{\text{BC}} = \frac{\text{Mass of Binder content[PPC+NA]}}{\text{Sp.gr.of Binder content[PPC+NA]*1000}} \quad (3.8)$$

$$V_{\text{BC}} = \frac{199\text{kg/m}^3}{2.9*1000} + \frac{199\text{kg/m}^3}{2.4*1000} = 0.15154\text{m}^3$$

$$V_{\text{AAS}} = \left[\frac{\text{Mass of NaOH}}{\text{Sp.gr.of NaOH*1000}} + \frac{\text{Mass of Na}_2\text{SiO}_3}{\text{Sp.gr.of Na}_2\text{SiO}_3*1000} \right] \quad (3.9)$$

$$V_{\text{AAS}} = \frac{\frac{56.857\text{kg}}{\text{m}^3}}{1.45*1000} + \frac{\frac{142.143\text{kg}}{\text{m}^3}}{1.35*1000} = 0.14449\text{m}^3$$

$$V_{\text{air content}} = \frac{2.5}{100} = 0.025\text{m}^3$$

$$V_{\text{Total Aggregate}} = 1\text{m}^3 - [V_{\text{Binder content}} + V_{\text{AAS}} + V_{\text{air content}}] \quad (3.10)$$

$$V_{\text{Total Aggregate}} = 1\text{m}^3 - (0.15154\text{m}^3 + 0.14449\text{m}^3 + 0.025\text{m}^3) = 0.679\text{m}^3$$

8. Determination of Fine and Coarse Aggregates Content:

The fine and coarse aggregate content was determined according to combined aggregate grading. Let the percentage of fine aggregate in the total aggregate be F% and that of the coarse aggregate be C%, and their values are 40% and 60% respectively in this research. Then for illustration,

$$V_{\text{FA}} = (0.4*0.679\text{m}^3*2.655*1000) = 721.1\text{kg/m}^3$$

$$V_{\text{CA}} = (0.6*0.679\text{m}^3*2.72*1000) = 1108.128\text{kg/m}^3$$

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table 3-6: The quantities of both aggregates for specific gravities.

S.No	Aggregate Type	wt. for SSD(kg/m ³)	wt. for oven-dried (kg/m ³)	wt. for apparent (kg/m ³)
1	Fine Aggregate	721.1	715.123	731.42
2	Coarse Aggregate	1108.128	1099.98	1124.424

9. Adjustments for Aggregates

a) Adjustments for Fine Aggregates.

The total moisture content and absorption capacity of fine aggregates tested were 0.516% and 0.84% respectively. So the aggregates are in air dry condition.

$$\frac{\text{Mass of water}}{\text{Mssd}} = \text{Mc}(\%) \quad (3.11)$$

The mass of water determined was $=\frac{0.516 \times 721.1 \text{ kg/m}^3}{100} = 3.721 \text{ kg/m}^3$, so the adjusted weight of fine aggregates $= 721.1 \text{ kg/m}^3 + 3.721 \text{ kg/m}^3 = 724.82 \text{ kg/m}^3$. The absorption capacity of FA determined was $=\frac{0.84 \times 721.1 \text{ kg/m}^3}{100} = 6.057 \text{ kg/m}^3$, so the adjusted weight for extra alkaline solution was $= 724.82 \text{ kg/m}^3 - 6.057 \text{ kg/m}^3 = 718.76 \text{ kg/m}^3$.

b) Adjustments for Coarse Aggregates.

The total moisture content and absorption capacity of coarse aggregates tested were 0.74% and 0.62% respectively. So the aggregates are in wet condition.

$$\frac{\text{Weight of Adjust for absorption}}{\text{Mssd}} = \text{Ab. c}(\%) \quad (3.12)$$

Adjusted for moisture content (%) determined was $=\frac{0.74 \times 1108.128 \text{ kg/m}^3}{100} = 8.2 \text{ kg/m}^3$, so the absorption capacity of CA determined was $=\frac{0.62 \times 1108.128 \text{ kg/m}^3}{100} = 6.87 \text{ kg/m}^3$. The adjusted weight for extra alkaline solution $= 1108.128 \text{ kg/m}^3 [0.74 - 0.62] / 100 = 1.33 \text{ kg/m}^3$, so the adjusted weight of coarse aggregate was $= 1108.128 \text{ kg/m}^3 + 6.87 \text{ kg/m}^3 = 1115 \text{ kg/m}^3$. The Adjustment for the additional

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

water=200kg/m³-[1.33kg/m³-2.336kg/m³]. So, the additional alkaline solution = 1.006kg/m³, and the adjusted amount of alkaline solution for this study was =201.0kg/m³.

10. Superplasticizer Content:

The trial mixes with 1.5% and 2% superplasticizer by binder content were added to the alkali-activated mortar and the best percentage of superplasticizer was selected for the mix to achieve a workable slump without affecting the compressive strength of the concrete.

$$\text{Mass of superplasticizer taken} = \frac{2 * \text{Binder Content} \left[\frac{\text{kg}}{\text{m}^3} \right]}{100} \quad (3.13)$$

$$\text{Mass of superplasticizer} = \frac{2 * [199 + 199] \text{kg/m}^3}{100} = 7.96 \text{kg/m}^3$$

11. Extra Water Content:

During trial mixes, a little extra water was added without affecting the concentration of the alkaline solution, and without adversely affecting the strength.

12. Glass Fiber Content:

Glass fibers are made of silicon oxide with the addition of a little number of other oxides. Glass fibers are characterized for their high strength, good temperature resistance, corrosion resistance, and availability at low prices. In this study chopped glass fiber of length 18mm and nominal diameter 15μm with a density of 2560Kg/m³ was used the above data provided by the supplier. The amount of glass fiber added for the mix design was 0.2%, 0.4%, and 0.6% by volume of concrete taken as per the early studied research [23][43]. For 1m³ of concrete; 1m³*0.002 = 0.002m³

$$0.2\% \text{ of glass fiber} = \frac{0.002 \text{m}^3 * 2560 \text{kg/m}^3}{100} = 5.12 \text{kg}$$

$$0.4\% \text{ of glass fiber} = \frac{0.004 \text{m}^3 * 2560 \text{kg/m}^3}{100} = 10.24 \text{kg}$$

$$0.6\% \text{ of glass fiber} = \frac{0.006 \text{m}^3 * 2560 \text{kg/m}^3}{100} = 15.36 \text{kg}$$

3.11.2 Mix Proportion of Alkali-activated Concrete

Mixture proportioning is a process of selecting suitable ingredients and determining their relative proportions to produce concrete having certain minimum workability, strength, and durability as economically as possible. It is used to determine the most economical and practical combination of readily available materials to produce concrete that will satisfy the performance requirements under particular conditions of use. The mix proportion used in this study was 1:1.82:2.8.

3.11.3 Mixing Procedure of Alkali-activated Concrete Preparation

The fine aggregate, coarse aggregate, and cementitious materials were dry-mixed for about 3 minutes. The glass fibers were added during the dry mix and sprayed very carefully to avoid the balling effect. This is then followed by the addition of two-thirds of the total mixing alkaline solution. After two minutes of mixing, the remaining mixing solution, superplasticizer, and some little extra water was added respectively. Mixing is ceased after four minutes for all mixes. The mix was checked for the slump, whether the concrete mix is in the range of recommended slump value or not, then finally, if the concrete mix is within the range of the recommended slump value concrete mix is ready for casting.

3.11.4 Specimen Preparation of Alkali-activated Concrete

The specimens for the testing of mechanical properties in the hardened state were cast using appropriate molds. For the compressive strength test 150×150×150mm, cubical molds were prepared and filled with fresh concrete into three layers, with each layer compacted by a rode for 35 blows. For the split tensile strength test 100mm diameter with 200mm length, cylindrical molds were prepared and filled with fresh concrete into three layers, with each layer compacted by a rode for 25 blows. For flexural strength beam molds having a dimension of 100×100×500mm were prepared and filled with fresh concrete like a cubical sample. Before the fresh concrete is filled into the molds, it was painted with boiled oil to easily detach the dry concrete sample from the mold.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD



Figure 3-8: The specimen preparation for the test.

3.12 Testing of Fresh Alkali-Activated Concrete

Fresh properties of alkali-activated mortar were tested using flow table apparatus and compared with cement mortar. Fresh properties of alkali-activated concrete were tested using slump test apparatus and compared with cement concrete.

3.12.1 Flow Rate Test for Workability of Alkali-activated Mortar

The workability of the trial alkali-activated mortar conducted in the laboratory was performed on 50 percent of the binder content. This is because of the investigation of suitable molarities of alkaline solution for the concrete. The workability of fresh alkali-activated mortar mixtures was tested by flow test as per ASTM C1437-07. A flow test was conducted immediately after mixing. The effect of molarities of alkaline solution with superplasticizer on the workability of alkali-activated mortars was investigated as shown in Figure 3.8 below.



Figure 3-9: Flow test measurement of trial alkali-activated mortar using flow test table.

3.12.2 Slump Test for Workability of Glass Fiber-reinforced Alkali-activated Concrete

The workability of a concrete mix is the relative ease with which concrete can be placed, compacted, and finished without separation or segregation of the individual materials. Slump tests per ASTM C-143 were performed for all mixes in the fresh state.

Concrete mixes with glass fiber for workability test results are expected to give above a design limit (which is (25-50) mm from the standards) of slump measurements. Fresh state concrete consists of ingredients of 50% of neat cement with Portland cement, sand, 12.5mm size of coarse aggregate, 14M of NaOH, 2.5 ratios of concentration of Na_2SiO_3 -to-NaOH, and 2% of superplasticizer as shown in Figure 3.9.



Figure 3-10: Slump test for the workability of alkali-activated concrete with fiber.

3.13 Testing of Hardened Alkali-Activated Concrete

3.13.1 Compressive Strength of Alkali-activated Mortar

Density and compressive strengths of alkali-activated mortar tests conducted on 7th-day. The molarities of alkaline solution (12M, 14M, and 16M) with 1.5% and 2% superplasticizer were used. The results were tested on the 7th-day compressive strength to investigate a promising alternative of alkaline solution and superplasticizer for alkali-activated concrete.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD



Figure 3-11: The hardened mortar cured at room temperature after 24hr.

3.13.2 Compressive Strength Test of Alkali-activated Concrete

The compression test is the most common test conducted on hardened concrete, partly because it is an easy test to perform and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength. The compression test is carried out on specimens of cubical shape and tested on a compression testing machine as per ASTM C-39 standards. Three samples for the 7th and three samples for the 28th-day test from each mix were cast. After 24 hours the molds are removed and the specimens are cured in the oven for 24hrs at 80°C and after 24hr cured at room temperature up to the date of the test. This test was done by using UTM which can apply a maximum load of 2000kN and records the peak load and the corresponding compressive stress of concrete. Compressive strength is determined from the basic formula by dividing the peak load of the specimen by the cross-section area of the specimen.

$$\text{Compressive stress } (\sigma) = \frac{\text{Peak Load}}{\text{Cross-sectional area}} = \frac{P}{A} \quad (3.14)$$

3.13.2.1 Compressive Strength of Concrete at various ages per ES EN 1992-2015

For early day strength of moist cured concrete ACI 214-02 gives a formula to calculate the expected compressive strength at specified days. The compressive strength of concrete at an age t depends on the type of cement, temperature, and curing conditions. For a mean temperature of 20°C and curing per ES EN 1992-2015(3.1.2(6)), (3.1.2(5)) the compressive strength of concrete

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

at various ages $f_{cm}(t)$ may be estimated from the following Expressions shown in equation(3.15 and 3.16).

$$f_{cm}(t) = \beta_{cc}(t) * f_{cm} @ t=28 \text{ days} \tag{3.15}$$

$$\beta_{cc}(t) = \exp\{s[1 - ((\frac{28}{t})^{0.5})]\}$$

$$f_{ck}(t) = f_{cm}(t) - 10(\text{Mpa}) \text{ for } 3 < t < 28 \text{ days} \tag{3.16}$$

$$f_{ck}(t) = f_{ck} \text{ for } t \geq 28 \text{ days}$$

Where: $f_{cm}(t)$ is the mean standard cylinder or cube compressive strength of concrete at an age of t days, f_{cm} is the mean standard cylinder or cube compressive strength at 28 days according to table 3.1, $\beta_{cc}(t)$ is a coefficient which depends on the age of the concrete (t), t is the age of the concrete in days, s is a coefficient which depends on the type of cement: where $s = 0.20$ for cement of strength Classes CEM 42.5 R, CEM 52.5 N and CEM 52.5R (Class R), $s = 0.25$ for cement of strength Classes CEM 32.5 R, CEM 42.5 N (Class N), $s = 0.38$ for cement of strength Classes CEM 32.5 N (Class S).

For this research, the following parameters have been used as concrete grade C20/25 (on the 28th day, $f_{ck}=20\text{Mpa}$, $f_{cu}=25\text{Mpa}$, and $f_{cm} = 35\text{Mpa}$) Cement of strength Classes = CEM 32.5N = 0.38.

Table 3-7:ES EN code's cubic, cylindrical, and their f_{cm} at 7th and 28th days.

S.No	Time(t) of days	$\beta_{cc}(t)$	$f_{ck}(t)$ for cube	$f_{cm}(t)$ for cube	$f_{ck}(t)$ for cylinder	$f_{cm}(t)$ for cylinder
1	7	0.68	13.94	23.94	11.15	19.15
2	28	1	25	35	20	28

3.13.3 Stress-Strain Relationship Curve of Fiber-reinforced Alkali-activated Concrete

A complete stress strain is necessary for the non-linear analysis of the concrete member. It influences the accuracy of the analytical results of ultimate stress distribution in ductility and load-carrying capacity. The stress and strain relations for cube specimens on the 7th and 28th days are

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

measured by using a strain gauge measuring instrument attached to a universal testing machine. The gauge measures the change in the depth of the cube under UTM and is recorded at a gradually applied axial load. The axial stresses are calculated by using the basic formula. It is calculated at various axial loading conditions.

$$\text{Stress } (\sigma) = \frac{P}{A} \quad (3.17)$$

Where: P is the gradually applied load, and A is the actual area of the concrete. The corresponding normal strain is found by using the Empirical formula written Ethiopian code of standard for concrete ES EN 1992-2015 (3.1.5(1)).

3.13.3.1 Stress-strain relationship curves analysis under ES EN1992-2015

The relation between σ_c and ϵ_c shown in Figure 3.2 (compressive stress and shortening strain shown as absolute values) for short-term uniaxial loading is described by ES EN1992-2015 (3.1.4(1)) the Expression (3.14) shown in equation:

$$\frac{\sigma_c}{f_{cm}} = \frac{k\eta - \eta^2}{1 + (k-2)\eta} \quad (3.18)$$

$$E_{cm} = 22 \left[\left(\frac{f_{cm}}{10} \right) \right]^{0.3} \quad (3.19)$$

$$E_{cm}(t) = \left[\frac{f_{cm}(t)}{f_{cm}} \right]^{0.3} * E_{cm} \quad (3.20)$$

Where: $E_{cm}(t)$ and $f_{cm}(t)$ are the values at an age of t days, and E_{cm} and f_{cm} are the values determined at an age of 28 days. The relation between $f_{cm}(t)$ and f_{cm} follows from ES EN1992-2015 table Expression (3.1) shown in the equation.

$$\epsilon_{c1} (0/00) = \text{minimum of } \{0.7 * f_{cm}^{0.3}, 2.8\} \quad (3.21)$$

$$\epsilon_{cu} (0/00) = 3.5 \leq C50/60 \quad (3.22)$$

$$k = 1.05 E_{cm} | \epsilon_{c1} / f_{cm} \quad (3.23)$$

$$\eta = \frac{\epsilon_c}{\epsilon_{c1}} \quad (3.24)$$

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Expression (3.14) is valid for $0 < |\epsilon_c| < \epsilon_{cu1}$ where ϵ_{cu1} is the nominal ultimate strain. The other idealized stress-strain relations may be applied, if they adequately represent the behavior of the concrete considered.

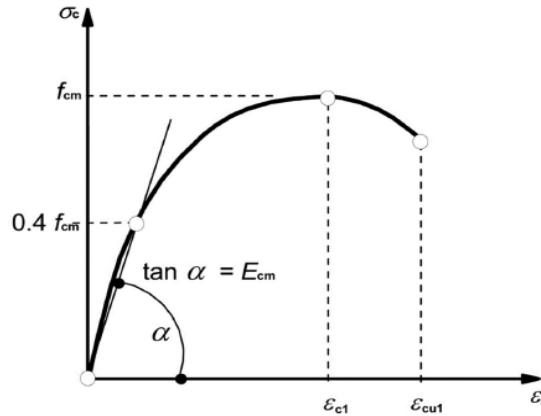


Figure 3-12: Schematic representation of the stress-strain relation of structural analysis (the use of $0.4f_{cm}$ for the definition of E_{cm} is approximate).

3.13.3.2 Analytical Stress-Strain Curves for Alkali-activated Concrete

The stress-strain relationships commonly used in concrete engineering were primarily developed for traditional concrete, and there is currently a shortage of dependable models for predicting the stress-strain behavior of geopolymer concrete. **Hardjito and Sarker**[44][45] modified the Popovics model of the stress-strain relationship for conventional concrete and predicted accurately the compressive behavior of geopolymer concrete.

This model is expressed mathematically by Eq. (3.25)

$$\frac{\sigma_c}{f_{cm}} = \eta * \frac{n}{n-1+(\eta)^{np}} \quad (3.25)$$

$$\eta = \frac{\epsilon_c}{\epsilon_{c'}} \quad (3.26)$$

where: f_c is concrete compressive stress, ϵ_c is a compressive strain of concrete, f_c' (in MPa) is the concrete cylinder strength, $\epsilon_{c'}$ is the concrete strain at f_c which is calculated by Eq. (3.29), the curve fitting factors n and p are presented in Eqs. (3.27) and (3.28), and the elastic modulus of

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

geopolymer concrete is calculated by using the empirical Eq.(3.30) proposed by Hardjito as follows:

$$n = 0.8 + \frac{f_{c'}}{12} \quad (3.27)$$

$$p = 0.67 + \frac{f_{c'}}{62} \text{ when } \frac{\epsilon_c}{\epsilon_{c'}} > 1 \text{ and } p = 1 \text{ when } \frac{\epsilon_c}{\epsilon_{c'}} \leq 1 \quad (3.28)$$

$$\epsilon_{c'} = \frac{f_{c'}}{E_c} * \frac{n}{n-1} \quad (3.29)$$

$$E_c = 2707 * \sqrt{f_{c'}} + 5300 \text{ (MPa)} \quad (3.30)$$

Where E_c is the modulus of elasticity(Mpa)

3.13.4 Split Tensile Strength Test of Alkali-Activated Concrete

One of the common methods used to measure the tensile strength of concrete is the split tensile strength test. The test was conducted as per ASTM C-496 specification for split tensile strength. The samples were cast by using steel cylinder molds having 100mm diameter and 200mm length. After 24hr the samples were removed from the molds and placed in the oven for 24hr at 80°C and after 24hr it was cured at room temperature for the 7th and 28th days of testing dates. The test was conducted by placing the cylinder sample in the opposite direction to its longitudinal axis and the load is gradually applied and peak load versus stress was recorded. The stress was determined by using the following formula;

$$\text{Split tensile Stress } (f_{ct, sp}) = \frac{2p}{\pi DL} \quad (3.31)$$

Where: p is the peak load, D is the diameter of the cylinder, and L is the length of the cylinder.

3.13.4.1 Split tensile Strength of Concrete at various ages per ES EN 1992-2015

The tensile strength refers to the highest stress reached under concentric tensile loading. Where the tensile strength is determined as the splitting tensile strength, $f_{ct, sp}$, an approximate value of the axial tensile strength, f_{ct} , may be taken as per ES EN1992-2-2015 shown in equation 3.32 below.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

$$f_{ct} = 0.9 * f_{ct,sp} \tag{3.32}$$

The development of tensile strength with time is strongly influenced by curing and drying conditions as well as by the dimensions of the structural members. As a first approximation, it may be assumed that the tensile strength $f_{ctm}(t)$ is equal to:

$$f_{ctm}(t) = (\beta_{cc}(t))^{\alpha} * f_{ctm} \tag{3.33}$$

Where:

$$\alpha = 1 \text{ for } t < 28 \text{ days}$$

$$\alpha = 2/3 \text{ for } t > 28 \text{ days}$$

$$F_{ctm} (@ t=28) = 2.2 \tag{3.34}$$

Table 3-8: ES EN code's splitting tensile strength and its mean, characteristics on the 7th and 28th days.

S.No	Time(t) of days	$\beta_{cc}(t)$	α	$f_{ctm}(t)$	$f_{ctk,0.95}(t)=1.3*f_{ctm}(t)$	$f_{ct,sp}=f_{ct}/0.9$
1	7	0.68	1	1.50	1.96	2.17
2	28	1	2/3	2.2	2.86	3.18

3.13.5 Flexural Strength Test of Alkali-Activated Concrete

Flexural strength, also known as modulus of rupture, bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test. The test was carried out as per ASTM C78 standard specification requirements. Three samples for the 7th and three samples for the 28th-day test from each mix were cast. After 24 hours the molds are removed and the specimens are cured in the oven for 24hrs at 80°C and after 24hr cured at room temperature up to the date of the test. A two-point loaded flexural strength testing machine having 2000kN was used. The beam sample was marked at 10cm from each end and at the mid-span. The

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

loads are applied at one-third from the support on both sides as shown in the following flexural strength setup. The strength was determined from the general formula of flexural stress.

Case1: When failure within the middle third of the span;

$$M.R = \frac{P*L}{b*d^2} \quad (3.35)$$

Case2: When failure occurs outside the middle third of the span length by not more than 5% of the span length;

$$M.R = \frac{3*P*a}{b*d^2} \quad (3.36)$$

Where: M.R= modulus of rupture (MPa); P = maximum applied load (N); L = span length (mm); b = average width of the specimen (mm); d = average depth of specimen (mm); a = average distance between the line of fracture and the nearest support measured on the tension surface of the beam (mm).

3.13.5.1 Flexural Tensile Strength of Concrete at Various Ages per ES EN1992-2015

The mean flexural tensile strength of reinforced concrete members depends on the mean axial tensile strength and the depth of the cross-section. The following relationship may be used:

$$f_{cm, fl} = \max \left\{ \left[1 - \frac{h}{1000} \right] * f_{ctm}, f_{ctm} \right\} \quad (3.37)$$

Where: h is the total member depth in mm = (100mm), and f_{ctm} is the mean axial tensile strength.

Table 3-9: ES EN code's mean and characteristic flexural tensile strength on the 7th and 28th days.

S.No	Time(t) of days	$\beta_{cc}(t)$	α	$f_{ctm}(t)$	$(1.6-h/1000)f_{ctm}$	$f_{cm,fl}$	$f_{ctk,0.95}(t)$	$f_{ct, sp}$
1	7	0.68	1	1.50	2.26	2.26	1.96	2.173
2	28	1	0.667	2.2	3.30	3.30	2.86	3.178

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

3.14 Mixing and Casting of the Specimen

A nominal mix of the proportions (1:1.82:2.80) (Cement: Fine aggregate: Coarse aggregate) by weight, with a binder content of 398 kg/m^3 and a water-cement ratio of 0.5 was maintained throughout the study. All the required materials for preparing the concrete were weighed as per the required proportions based on the mix design, and the sand and cement are dry-mixed. Then the coarse aggregate and glass fiber were added with a little amount of alkaline solution step by step. Finally, the remaining amount of alkaline solution, superplasticizer, and add little extra water were added to mix until getting evenly mixed fiber-reinforced alkali-activated concrete without affecting strength.



Figure 3-13: Mixing and casting of concrete for testing.

3.14.1 Curing Temperature of Alkali-activated Concrete

The curing temperature of geopolymer concrete refers to the temperature at which the concrete is maintained during the curing process. Curing is a critical step in the production of concrete, as it allows the material to gain strength and durability over time. In the case of geopolymer concrete, curing typically involves maintaining a temperature range of 60°C to 90°C for several hours or days. It depends on the specific mix of design and application requirements. This temperature range is necessary to activate the chemical reactions that create the geopolymer binder, which gives the concrete its strength and durability. Proper curing is essential for ensuring that geopolymer concrete reaches its full potential in terms of strength and durability. All the specimens

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

were kept in molds for 24hrs at room temperature and after 24hrs all the specimens demoulded were cured in an oven at 80°C for another 24hrs. Once hardened, the specimens were carefully taken from the oven kept carefully, and cured at room temperature until all test dates.



Figure 3-14: Curing the alkali-activated concrete for 24hrs at 80°C.

4. Chapter IV-Results and Discussion

4.1 Test Results Conducted on Cementitious Materials

4.1.1 Normal Consistency test results for Binder Content

This test method is intended to be used to determine the amount of water required to prepare hydraulic cement pastes for testing. The test was performed as per ASTM C-187 code standards.

Table 4-1: Normal consistency test results for binder content.

S.No	Percentage of Binder Content	Consistency Water (%)
1	Control	33
2	50% of Nech Afer+50% Portland cement	33

Both ordinary cement and an alkali-activated binder showed adequate workability at a 33% water-to-cement ratio, according to the laboratory experiment results shown in Table 4.1 above. The results are listed in Table 1 of Appendix A-1.

4.1.2 Setting Time of Binder Content

ASTM C 191 states that “The Vicat initial time of setting is the time elapsed between the initial contact of cement and water and the time when the penetration is measured or calculated to be 25 mm. The Vicat final time of setting is the time elapsed between initial contact of cement and water and the time when the needle does not leave a complete circular impression in the paste surface.”

Table 4-2: Setting time of binder content.

S.No	Mix ID	Initial Setting Time(min)	Final Setting Time(min)
1	Control	46	145
2	50% of NA+50% PC	34	60

Alkali-activated binder's setting time for both the initial and final setting times was found to be shorter than that of regular cement, according to the Table 4.2 laboratory investigation result.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

It takes less time for an alkali-activated binder to firm up. Because it doesn't go through the same chemical processes as regular cement and doesn't need water. Alkali-activated binder, in conclusion, sets more quickly than regular cement because the hydration process is sped up. The results were computed according to the table in Appendix A-1 table-2.

4.2 Physical Properties Test Result of Aggregates

4.2.1 Silt Content of Fine Aggregate

According to the Ethiopian standard manual it is recommended to wash the sand or reject it if the silt content exceeds a value of 6%.



Figure 4-1: Washing of sand to remove decant materials.

An average silt percentage of 1.93% was calculated using the reported sand silt test data. The sand's silt concentration was below the maximum allowed by Ethiopian standards. Appendix A-2, Table 1, provided the procedures and details.

4.2.2 Particle Size Distribution of Fine Aggregate

Sieve analysis was done to determine the fineness modulus of aggregate and the relative amount of various sizes of particles present in the aggregate using sieve series of round openings starting with the largest.

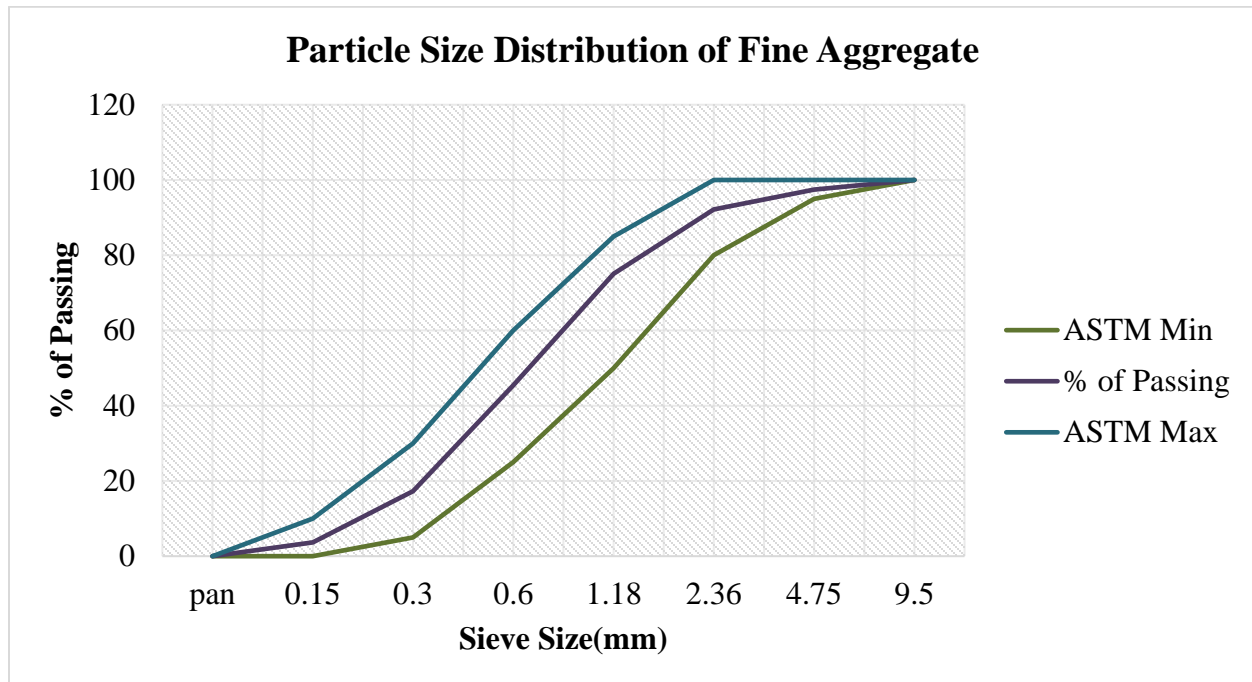


Figure 4-2: Fine aggregate particle size distributions.

Fine aggregate completely passes through the 9.5mm and 0.15mm sieve sizes, according to the laboratory study for the particle size distribution test that is displayed. The average fineness modulus (uniformity of grading) used for mix design was estimated based on the data on particle size distribution, and it was found to be 2.7. Figure 4.3 displays the ASTM maximum and minimum limit bounds as well as the fine aggregate grading. In Appendix A-2, table 2, you can see a complete breakdown of the cumulative percentage passing, percentage maintained, fineness modulus, and required range according to ASTM C33.

4.2.3 Particle Size Distribution of Coarse Aggregate

The maximum size of the coarse aggregate used was 12.5mm. For the sieve analysis, the coarse aggregate passing the sieve sizes between 20mm and 2.36mm sieve according to ASTM C33[38] sieve size was used.

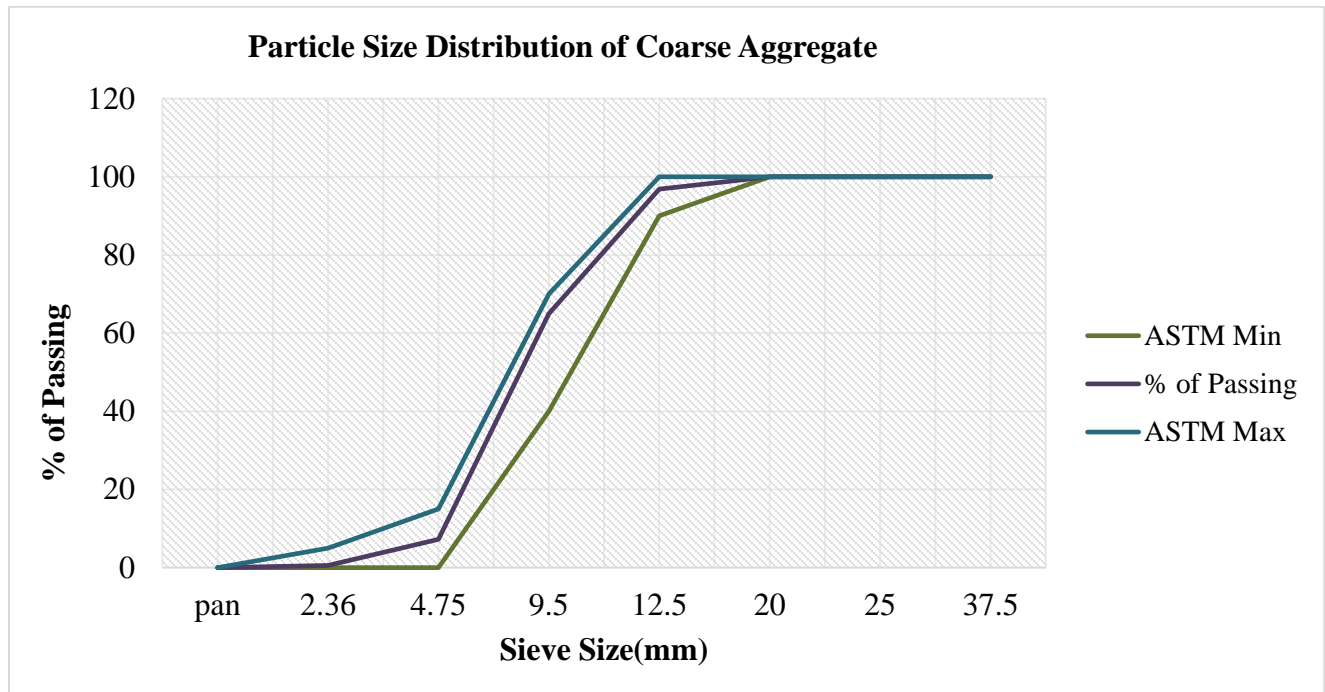


Figure 4-3: Coarse aggregate particle size distributions.

The average fineness modulus (uniformity of grading) used for mix design was computed based on laboratory research for the particle size distribution test of coarse aggregate and was 7.3. Figure 4.4 above illustrates the coarse aggregate grading and upper and lower limit limitations. The calculations were made under Table 6 in Appendix A-2.

4.2.4 Absorption Capacity, Specific Gravity, Moisture Content, and Unit Weight of Aggregates as per ASTM Standards

All the tests conducted in the laboratory were based on ASTM standards. The following tables 4.3 and 4.4 show investigated results under ASTM standard limits.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table 4-3: Summary of physical property test result of fine aggregate.

S.No	Description	Standards used for test	Test Result	Standard Limits
1	Mean Silt Content (%)	ASTM C-33	1.93%	≤6%
2	Moisture Content (%)	ASTM C-33	0.516%	0% -10%
3	Bulk Specific gravity(SSD)	ASTM C-128	2.655	2.4-3.0
4	Bulk Specific gravity(OD)	ASTM C-128	2.633	2.3-2.9
5	Apparent specific gravity	ASTM C-128	2.693	2.4-2.9
6	Absorption capacity (%)	ASTM C-128	0.84%	0.5%-1%
7	Loose unit weight(kg/m ³)	ASTM C-33	1450	1320-1680
8	Rodded unit weight(kg/m ³)	ASTM C-33	1515	1320-1680

Table 4-4: Summary of physical property test result of coarse aggregate

S.No	Description	Standards used for test	Test Result	Standard Limits
1	Moisture Content (%)	ASTM C-33	0.74%	0% -10%
2	Bulk Specific gravity(SSD)	ASTM C-127	2.72	2.4-3.0
3	Bulk Specific gravity(OD)	ASTM C-127	2.7	2.3-2.9
4	Apparent specific gravity	ASTM C-127	2.76	2.4-2.9
5	Absorption capacity (%)	ASTM C-127	0.62%	0.5%-1%
6	Loose unit weight(kg/m ³)	ASTM C-33	1347	1320-1680
7	Rodded unit weight(kg/m ³)	ASTM C-33	1495	1320-1680

Based on the laboratory analysis of all the physical properties of aggregates, tables 4.3 and 4.4 shows that all test results met the requirements. Tables 3 to 9 in Appendix A-2 were used to show the results in detail.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

4.3 Test Results Conducted on Fresh Alkali-activated Concrete

4.3.1 Flow Test Results conducted on Alkali-activated Mortar

The workability of alkali-activated mortar was examined in a laboratory experiment to determine the effect of molarities of alkaline solution. The flow rate of molarities such as 12M, 14M, and 16M with 1.5% and 2% superplasticizer was conducted as shown in Table 4.5 below.

Table 4-5: Flow rate value of mortar workability for different molarities.

S.No	Mix ID	w/c	SP (%)	Flow Rate (mm) from different Molarities		
				12M	14M	16M
1	Control	0.55	0	220	220	220
			1.5	150	140	113
2	Mix12	0.55	2	150	185	140



a) Workability of mortar with w/c of 0.5 b) Workability of mortar with w/c of 0.55

Figure 4-4: The workability of alkali-activated mortar with 1.5% of SP for 14M.

During laboratory trial observation for the workability of alkali-activated mortar, the workability of mortar has shown good improvements with w/c increasing from 0.5 to 0.55 molarities and 14M

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

NaOH for 2% superplasticizer by binder content as shown in Figure 4.4. The maximum flow rate and softest workability were found in 14M of alkaline solution with a 2% superplasticizer, according to the test results. A list of the flow rate experiments for w/c of 0.5 and 0.55 with 1.5% and 2% superplasticizers were found in Appendix B tables 1 and 2.

4.3.2 Slump Test Results Conducted on Fresh Fiber-reinforced Alkali-activated Concrete

All mixes were tested for slump under ASTM C-143 standards when they were in their fresh state. A common test procedure for hydraulic-cement concrete slump is ASTM C-143. It is used to determine how cohesive and workable freshly mixed concrete is.



Figure 4-5: Slump test result for the workability of alkali-activated concrete for different mixes.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

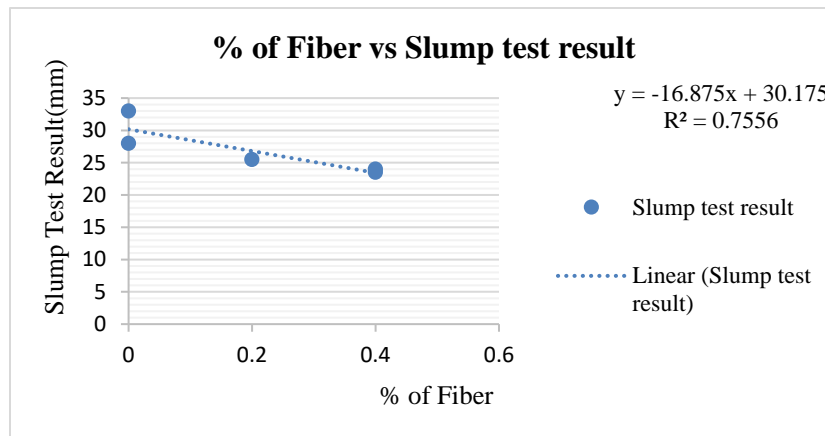


Figure 4-6: Percentages of glass fiber vs slump test results by simple linear regression.

Based on the results of the percentage of fiber versus slump test, the linear regression analysis produced an R-square value of 0.7556 and a linear equation of $y = -16.875x + 30.175$. The R-square value indicates that approximately 76% of the variation in the slump test results can be explained by the percentage of fiber. This suggests that there is a good correlation between the two variables.

The negative slope of the linear equation (-16.875) suggests that as the percentage of fiber increases, the slump test result decreases. Overall, these results suggest that adding fiber to the alkali-activated can have a significant impact on the slump test result. This is because the alkaline solution caused the glass fibers to clump together, which was more difficult to work with.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

4.4 Test Results Conducted on Hardened Alkali-activated Concrete

4.4.1 Mass and Density of Hardened Mortar

The mass and density of alkali-activated and cement mortar cubes crushed on the 7th day are calculated and shown in Table 4.6 below.

Table 4-6: The mass and density of 7th-day hardened mortar.

S.No	Molarity	w/c	SP	Mass of mortar cube on 7 th day (kg)				Density(kg/m ³)
1	Control	0.55		C-1	C-2	C-3	Average	[2000 to 2500]
				0.275	0.274	0.271	0.273	2184
2	12M	0.55	1.5	0.26	0.255	0.259	0.258	2064
			2	0.254	0.2605	0.26	0.258	2064
3	14M	0.55	1.5	0.253	0.257	0.255	0.255	2040
			2	0.261	0.262	0.26	0.261	2088
4	16M	0.55	1.5	0.256	0.257	0.259	0.257	2056
			2	0.249	0.247	0.248	0.248	1984

Based on the results of the mass versus density of the alkali-activated mortar shown in Table 4.7, it was found that at 2% superplasticizer, the mass and density of the alkali-activated mortar decrease as the molarity of NaOH increases. In comparison to the alkali-activated mortar, the control cement mortar had a higher density. This is because the lower density of the cementitious materials and increasing the molarity of the alkaline solution used in alkali-activated mortar potentially decreased the density of the mortar to 80°C. The higher molarity solutions can cause more dissolution of the solid components in the mixture, leading to a decrease in density.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

4.4.2 Mass and Density of hardened Alkali-activated Concrete

The mass and density of the concrete cubes crushed on the 7th and 28th days are determined and shown in tables 4.7 and 4.8 below.

Table 4-7: The mass and density of 7th-day hardened concrete.

S.No	Mix ID	Mass of cubes for 7 th day(kg)				Density
		C-1	C-2	C-3	Average	kg/m ³
1	Control	8.08	8.2	8.5	8.26	2447.41
2	0%GF	7.85	7.89	7.45	7.73	2290.37
3	0.2%GF	7.96	8.036	8.12	8.037	2381.33
4	0.4%GF	7.82	7.94	7.54	7.767	2301.33
5	0.6%GF	7.82	7.86	8.08	7.92	2346.67

Note:0%GF indicates plain alkali-activated concrete without glass fiber

Table 4-8: The mass and density of 28th-day hardened concrete.

S.No	Mix ID	Mass of cubes for 28 th day(kg)				Density
		C-1	C-2	C-3	Average	kg/m ³
1	Control	8.134	8.4	8.61	8.38	2482.96
2	0%GF	7.87	7.92	7.46	7.75	2296.30
3	0.2%GF	8.169	7.843	7.711	7.91	2343.70
4	0.4%GF	7.8	7.69	7.96	7.82	2317.04
5	0.6%GF	7.896	8.129	8.224	8.083	2394.96

Note:0%GF indicates plain alkali-activated concrete without glass fiber

According to the test result recorded in Tables 4.8 and 4.9, the density of glass fiber-reinforced alkali-activated concrete was lower than that of control concrete. This is because the density of Nech Afer and glass fiber caused the density to decrease at a curing temperature of 80°C. In general, the rise in the amount of glass fiber showed that all mixes' concrete densities have decreased. The table in Appendix B listed the mass and density of the split tensile test and the flexural beam testing.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

4.4.3 Compressive Strength Test Results Conducted on Alkali-activated Mortar

The hardened property of the alkali-activated mortar was tested by checking the 7th-day compressive strength of the mortar cube. The allowable stress for geopolymer mortar would depend on the specific mix design and the intended use of the material.

Table 4-9: The average compressive stress of hardened mortar on the 7th -day.

S.No	Molarity	w/c	SP (%)	Peak Load of mortar cube on 7 th -day(kN)				Avg. compressive stress
				C-1	C-2	C-3	Average(kN)	MPa
1	Control	0.55	0	56.01	44.0	53	51.003	20.40
				70.3	72	57	66.433	26.57
2	12M	0.55	1.5	54	69.2	71	64.733	25.89
			2	50	54.8	57.6	54.133	21.65
3	14M	0.55	1.5	62	65	78	68.333	27.333
			2	52	49.7	49.7	50.467	20.19
4	16M	0.55	1.5	52.3	50	59.6	53.967	21.59
			2					

All the alkaline solutions with 1.5% and 2% superplasticizers comply with alkali-activated mortar, according to the test findings shown in Table 4.10. According to the data, maximum average compressive strength was recorded in 12M and 14M of alkaline solution respectively. The most effective molarity was 14M of alkaline solution with a 2% superplasticizer.

4.4.4 Compressive Strength Test Results Conducted on Alkali-activated Concrete

The compressive strength test was done for concrete cubes cast and cured on the 7th and 28th days. In each mix, three cube specimens were cast and tested and their mean value was given in Table 4.10 below respectively.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table 4-10: Compressive strength of alkali-activated concrete test result on the 7th and 28th days.

S.No	Mix ID	7 th day test result		28 th -day test result	
		Average peak Load(KN)	Average Compressive Stress(Mpa)	Average Peak Load(kN)	Average Compressive Stress(Mpa)
1	Control	469	20.8444	565.2	25.12
2	0%GF	568.39	25.2618	619.333	27.526
3	0.2%GF	618.73	27.4991	729.267	32.412
4	0.4%GF	622.7967	27.6799	663.22	29.476
5	0.6%GF	611.94	27.1973	658.13	29.250

Note:0%GF indicates plain alkali-activated concrete without glass fiber and this mix was prepared with 14M of alkaline solution with 2% superplasticizer only.

Based on the compressive strength results presented in Table 4.10, it was found that the alkali-activated concrete's compressive strength rose as the curing date increased. The maximum average compressive strength was recorded for all mixes with glass fiber on the 7th day of tests. All the glass fiber mixes showed a high result as compared to the control. As the percentage of glass fiber increases in the mix, the compressive strength of alkali-activated concrete increases.

All the compressive strength test result given in the above table conforms to the ES EN1992-2015 standards. In general, it can be concluded that the maximum compressive strength of 27.7Mpa and 32.4Mpa was recorded at 0.4% and 0.2% of glass fiber on the 7th and 28th days respectively. The detailed compressive stress on the 7th and 28th-day tests are listed under Appendix B.

4.4.5 Stress-Strain Relationship for Compressive Strength as per ES EN1992-2015

The engineering stress and strains are calculated for all mixes as per ES EN code standards for standard cubes shown in the table below. Table 4.12 and Figure 4.7 illustrate peak compressive stress and the corresponding strain for the 7th and 28th days' test results. The detailed standard cube stress-strain relation for the 7th and 28th-day tests are listed under Appendix C and D.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table 4-11: The mean compressive strength for standard cylinder and standard cube.

Concrete Grade	C12/15	C16/20	C20/25	C25/30	C30/37
f_{cm}	20/25	24/30	28/35	33/40	38/47
$\epsilon_c(0/00)$	1.8/1.9	1.9/2	2/2.1	2.1/2.2	2.2/2.225

Note: All peak strain is interpolated from the following table for average compressive stress or mean compressive stress (f_{cm}).

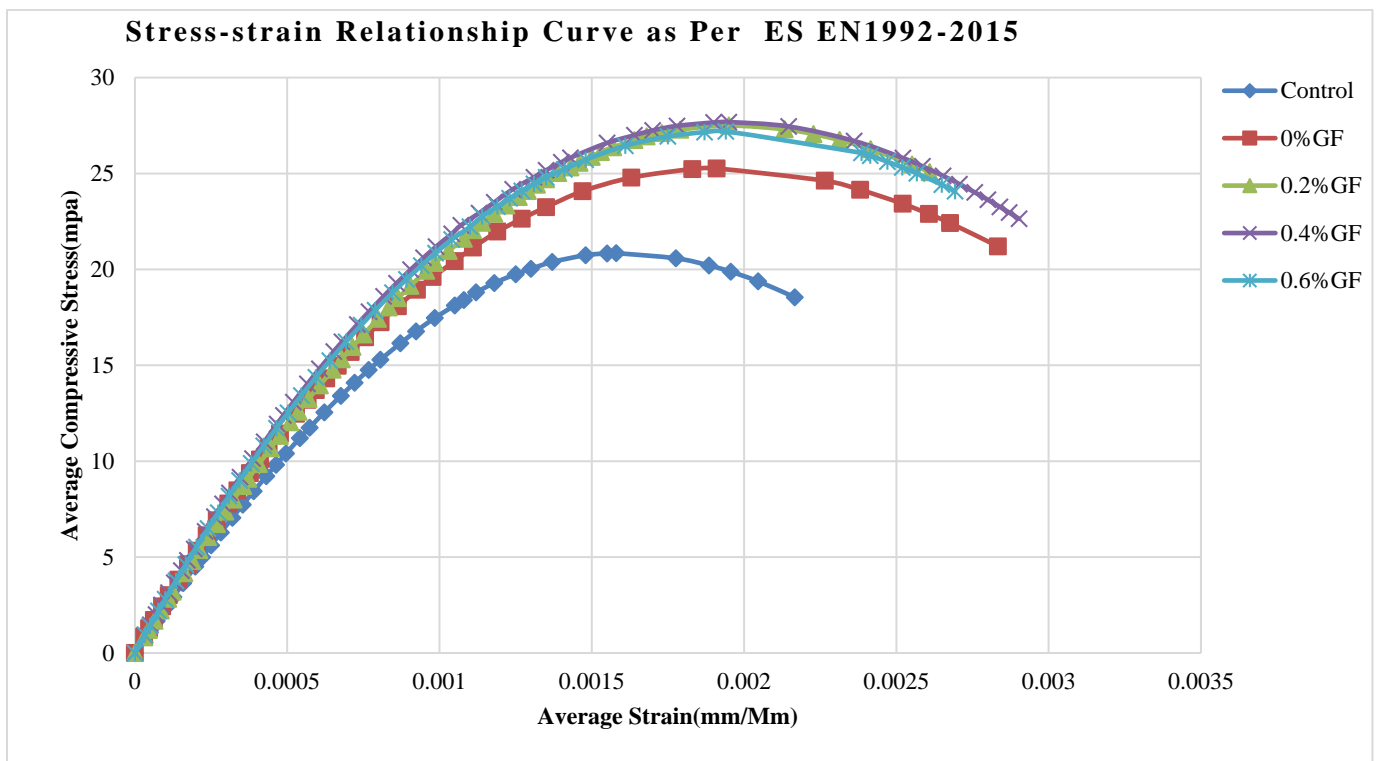


Figure 4-7: The cube compressive stress-strain curve by ES EN1992-2015 on the 7th-day result.

From the above figure 4.7 of the 7th-day stress-strain curve, the following observations are drawn. The maximum compressive stress and the corresponding average strain were observed when the 0.4% GF, 0.2% GF, and 0.6% GF respectively on the 7th day. The 0.4%, 0.2%, and 0.6% overlapped each other because their compressive strength result recorded was closest to each other. Alkali-activated concrete with glass fiber showed that it gained 28th-day strength on the 7th day. After the ultimate load carrying capacity, 0.4%, and 0.2% GF showed good extent until the rupture or failure.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

After the point of ultimate load, the duration of strain up to the point of rupture for glass fiber-reinforced concrete was greater than the point of failure of control. In general, all mixes with glass fiber added to alkali-activated concrete extended the time strain up to the point of rupture than the time strain of plain concrete on the 7th day.

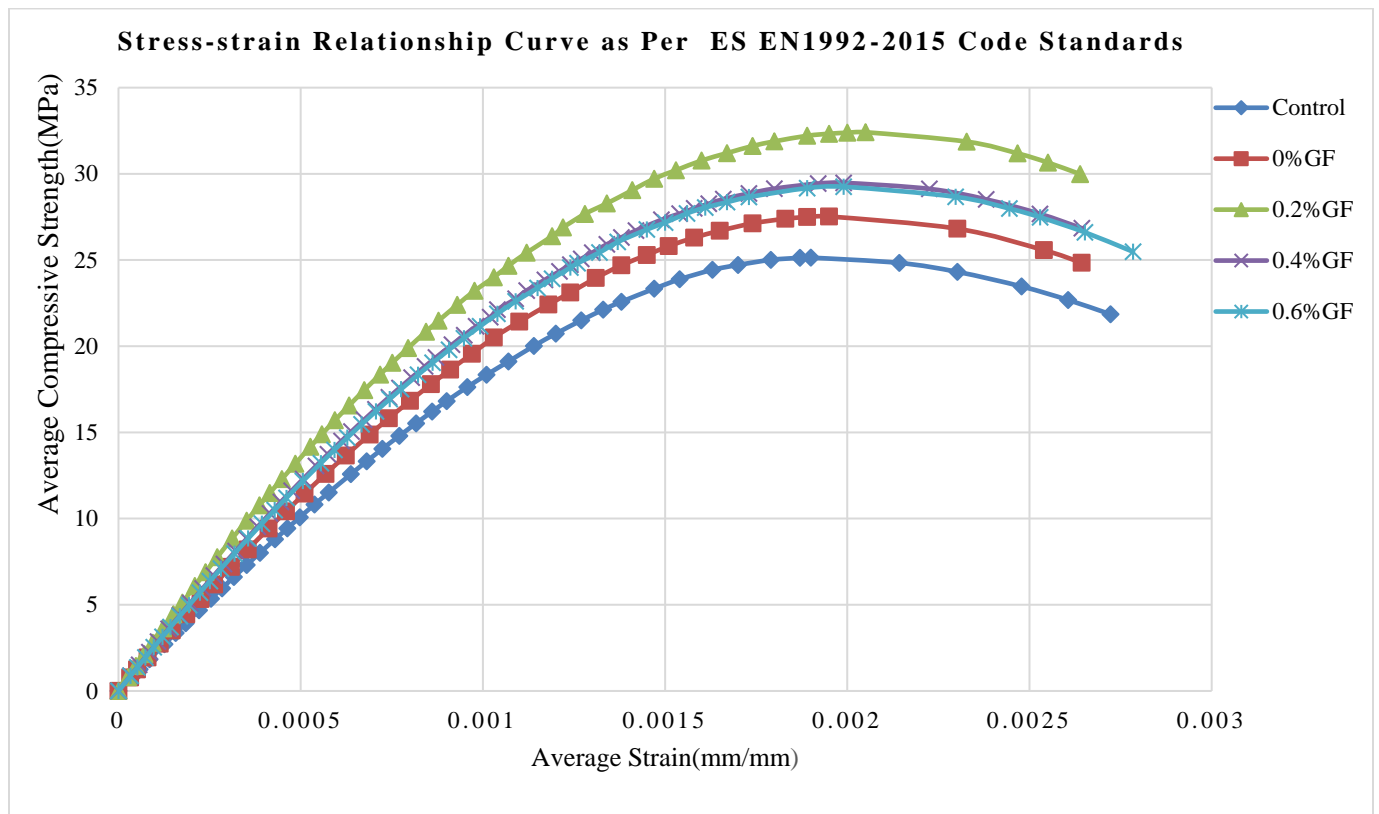


Figure 4-8: The cube compressive stress-strain curve by ES EN1992-2015 on the 28th day result. From the above figure 4.7 of the 28th-day stress-strain curve, the following observations are drawn. As the date of curing increased the average compressive strength and strain of alkali-activated concrete increased. The maximum compressive stress and the corresponding average strain were observed at 0.2% GF on the 28th day. This is because the percentage of fiber increased balling effect has happened in the concrete. After the point of ultimate load, the duration of strain up to the point of rupture for fiber-reinforced alkali-activated concrete was greater than the point of failure of control. In general, for all mixes with glass fiber added to concrete the time strain up to the point of rupture was closest to the time strain of plain concrete on the 28th day. This is because all mixes gained enough strength on the 28th day.

4.4.6 Stress-Strain Relationship Curve for Geopolymer Concrete

Based on the previous prediction on geopolymer concrete stress-strain curve by Hardjito and Sarker[45], [46] the following relationship curves were drawn.

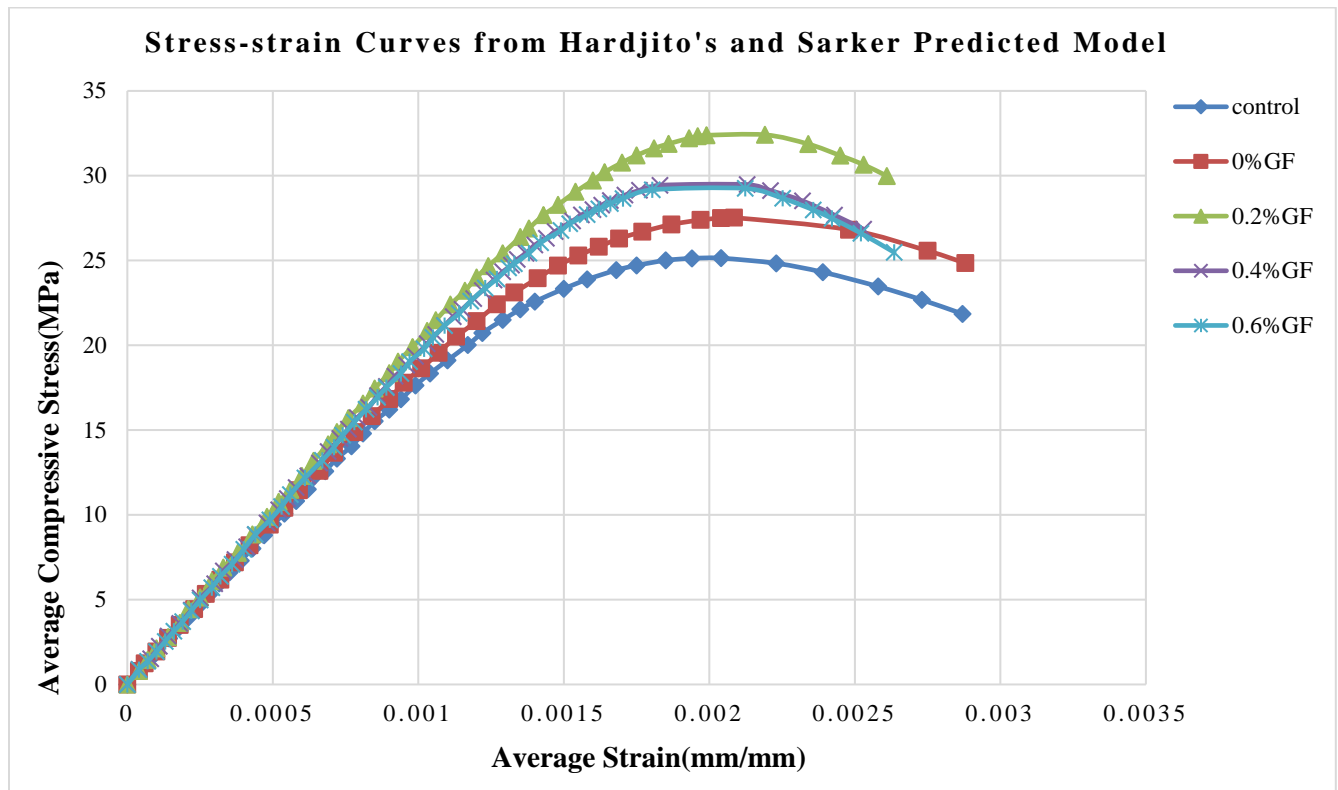


Figure 4-9: The cube compressive stress-strain curve by Hardjito and Sarker[45], [46] prediction model on the 28th-day result.

From the above figure 4.8 of the 28th-day stress-strain curve of Hardjito's and Sarker's models, the following observations are drawn. Based on the curve relationship elasticity was extended to above 0.005 strain by Hardjito and Sarker's prediction model. The normal concrete curve of both ES EN1992-2015 and Hardjito and Sarker's prediction model for the stress-strain curve was similar. The mixes with 0.2%, 0.4%, and 0.6% of glass fiber have a short time after peak load until the rupture. The curves showed that alkali-activated concrete can carry the ultimate load than normal concrete. In conclusion, the stress-strain curve relationship of standard ES EN1992-2015 estimated the alkali-activated concrete as normal concrete. But Hardjito and Sarker's model showed the duration of alkali-activated concrete was less than that of normal concrete.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

4.4.7 The Elastic Modulus from Compressive Cube Test Result

The formula for calculating the modulus of elasticity of concrete from compression cube test results according to ES EN1992-2015 table 3.1 and expression 3((3.5) standards by non-linear structural analysis.

Table 4-12: The elastic modulus of alkali-activated concrete at 28th day compressive stress.

S.No	Mix ID	ES EN1992-2015			Hardjito and Sarker Model[45][46]	
		Av.g Stress(Mpa)	Av.g Strain	Ecm(GPa)	Av.g Strain	Ec(GPa)
1	Control	25.12	0.001903	29.1	0.00204	18.9
2	0%GF	27.526	0.00195	29.81	0.002085	19.5
3	0.2%GF	32.412	0.00205	31.31	0.002191	21
4	0.4%GF	29.476	0.0019895	30.43	0.00213	20
5	0.6%GF	29.25	0.001985	30.39	0.002123	19.94

Based on Table 4.12 above, it was observed that, the modulus of elasticity of alkali-activated concrete increases with an increase in compressive stress. The maximum elastic modulus was shown in 0.2%GF on the 28th-day result of the compressive strength test. The modulus of elasticity for all mixes was within the general range of 20 to 50 GPa for geopolymer concrete as per ES EN1992-2015 Code standards. But for Hardjito and Sarker's model the only mixes with 0.2% and 0.4% satisfied for the range. In conclusion, the elastic modulus of alkali-activated concrete by ES EN1992-2015 was considered similar to normal concrete. But the modulus of elasticity determined from Hardjito and Sarker's was considered similar to geopolymer concrete.

4.4.8 Split Tensile Strength Test Results Conducted on Alkali-activated Concrete

The split cylinder test is a method of determining the tensile strength of concrete indirectly. The average split tensile strength of control, 0%, 0.2%, 0.4%, and 0.6%GF at the age of 7th and 28th days for 24 hours of heat curing at 80°C is given in Table 4.15 and 4.16 below.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table 4-13: Split tensile load stress of alkali-activated concrete on the 7th-day result.

S.No	Mix ID	Split tensile Load on the 7 th day				Split tensile stress
		C-1	C-2	C-3	Average	
1	Control	48.90	54.00	68.00	56.97	1.81
2	0%GF	70.00	89.00	85.00	81.33	2.59
3	0.2%GF	75.00	75.00	65.00	71.67	2.28
4	0.4%GF	63.00	70.00	68.00	67.00	2.13
5	0.6%GF	72.80	63.36	75.00	70.39	2.24

Note:0%GF indicates plain alkali-activated concrete without glass fiber and this mix was prepared with 14M of alkaline solution with 2% superplasticizer only.

From Table 4.13, it was observed that the maximum split tensile strength was recorded at 0%, 0.2%, and 0.6% of glass fiber on the 7th day respectively. The study found that on the 7th test dates, the split tensile strength increased by 26%, 18%, and 24% for mixes containing 0.2%, 0.4%, and 0.6% of glass fiber, respectively.

Table 4-14: Split tensile load stress of alkali-activated concrete at the 28th-day result.

S.No	Mix ID	Split tensile Load on the 28 th day				Split tensile stress
		C-1	C-2	C-3	Average	
1	Control	74.10	89.5	90.00	84.53	2.69
2	0%GF	86.40	90.30	91.00	89.23	2.84
3	0.2%GF	89.00	95.00	88.00	90.67	2.89
4	0.4%GF	67.00	76.70	60.00	67.90	2.16
5	0.6%GF	72.10	72.80	74.56	73.15	2.33

Note:0%GF indicates plain alkali-activated concrete without glass fiber and this mix was prepared with 14M of alkaline solution with 2% superplasticizer only.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

From above table 4.14, it was observed that the maximum split tensile strength of 2.89Mpa was recorded at 0.2% of glass fiber on the 28th day. As the percentage of glass fiber increases from 0% to 0.2%, the split tensile strength of concrete on the 28th day increased by 6%, and 7% respectively.

The lowest stress result was recorded when the percentage of GF was at 0.4% and 0.6% with a split tensile stress of 2.16 Mpa, and 2.33 Mpa respectively. This is because the increased percentage of glass fiber was clumped in the presence of an alkaline solution and resulted in a balling effect on concrete. An increase in the percentage of glass fiber was shown that a decrease in the split tensile strength at the 28th day test result. In conclusion, as the age of concrete increased from the 7th day to the 28th day, split tensile strength also increased for all mixes. The curing temperature was one of the reasons for the reduction of split tensile strength.

4.4.9 Flexural Tensile Strength Test Results Conducted on Alkali-activated Concrete Beam

The average flexural stresses were calculated from the average rupture loads recorded from the testing machine. The average flexural tensile strength of control, 0%, 0.2%, 0.4%, and 0.6%GF at the age of 7th and 28th days for 24 hours of heat curing at 80°C was given in Table 4.15 and 4.16 below respectively.

Table 4-15: The average flexural stress (modulus of rupture) of the alkali-activated concrete beam at the 7th-day test.

S.No	Mix ID	Rupture load recorded on 7 th day				Modulus of Rupture Mpa
		C-1	C-2	C-3	Average	
1	Control	17.56	18.9	18.19	18.217	5.47
2	0%GF	18.75	15.56	19.83	18.047	5.41
3	0.2%GF	19.85	20.43	20.89	20.39	6.12
4	0.4%GF	19.31	20.12	19.25	19.560	5.87
5	0.6%GF	19.35	20.54	20.23	20.04	6.01

Note:0%GF indicates plain alkali-activated concrete beam without glass fiber and this mix was prepared with 14M of alkaline solution with 2% superplasticizer only.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

From Table 4.15 it was observed that the maximum flexure tensile strength of 6.12MPa was recorded at 0.2% of glass fiber on the 7th day. As the percentage of glass fiber increases from 0.2% to 0.6 %GF, the flexural tensile strength of concrete on the 7th day increased by 11.93%, 7.37%, and 10.01% for 0.2%, 0.4%, and 0.6% respectively. In conclusion, an increase in the percentage of glass fiber was shown that an increase in the flexural tensile strength at the 7th-day test result.

Table 4-16: The average flexural stress (modulus of rupture) of alkali-activated concrete beam at the 28th-day test.

S.No	Mix ID	Rupture load recorded on 28 th day				Modulus of Rupture
		C-1	C-2	C-3	Average	
1	Control	25.05	24.154	25.21	24.80	Mpa 7.44
2	0% of GF	20.75	21.87	20.83	21.15	6.35
3	0.2% of GF	25.5	27.4	26.8	26.57	7.97
4	0.4% of GF	26.2	26	25.5	25.90	7.77
5	0.6% of GF	25.79	26.98	26.67	26.48	7.94

Note:0%GF indicates plain alkali-activated concrete beam without glass fiber and this mix was prepared with 14M of alkaline solution with 2% superplasticizer only.

From Table 4.16, it was observed that the maximum flexural tensile strength of 7.97MPa was recorded at 0.2% of glass fiber on the 28th day. As the percentage of glass fiber increases from 0.2% to 0.6%, the flexural tensile strength of concrete on the 28th day increased by 7.10%, 4.42%, and 6.75% respectively. The lowest modulus of rupture result was recorded when the percentage of GF was at 0% with a flexural tensile stress of 6.35Mpa respectively compared to normal concrete. An increase in the percentage of glass fiber was shown that an increase in the flexural tensile strength at the 28th-day test result.

In conclusion, as the age of concrete and percentage of glass fiber increased from the 7th day to the 28th day, flexural tensile strength also increased for all mixes. The ultimate load-carrying capacity of the fiber-reinforced alkali-activated beam was increased both on the 7th and 28th days.

4.4.10 Failure Mode of Alkali-activated Concrete Observed During Test

4.4.10.1 Failures observed on Cube Concrete

The addition of glass fiber gave an effective result in the compression test for all mixes as compared to alkali-activated concrete without fiber and normal concrete. The first macro crack observed on compressive strength of both 0%GF and normal concrete was nearest to the ultimate load. After the first macro crack was observed for both 0%GF and normal concrete, the duration until the ultimate load was too short. But the mixes with glass fiber show the first macro crack at half of the ultimate load and have a good duration until the ultimate. It can stay with macro-crack than that of 0%GF and normal concrete until the ultimate load.

In general, the macro crack on the glass fiber reinforced concrete was bridged by fibers that can carry additional load after the peak load is reached before failure. The addition of glass fiber into alkali-activated concrete improved the cube concrete carrying capacity duration after the first macro crack observation until the rupturing of compressed concrete.



a) Normal concrete under compression b) Glass fiber reinforced concrete under compression

Figure 4-10: Crack pattern observed on cube under UTM for normal and glass fiber reinforced concrete.

4.4.10.2 Failure Mode Observed on Cylinder Concrete

The failure behavior observed in split tensile strength of 0% of glass fiber and normal concrete was less resistance to tensile load and ultimately causing failure. The vertical crack that splits the specimen into two parts was observed on the alkali-activated concrete. But the crack on the fiber-reinforced concrete was bridged by fibers that can carry additional load after the peak load is reached before failure. In general, the addition of glass fiber to the mixes the duration of carrying tensile load applied on cylinder concrete than that of normal concrete as shown in figure 4.11 below.



a) Normal concrete under tension load b) Glass fiber reinforced concrete under tension load

Figure 4-11: Crack pattern observed on cylinder under UTM for normal and glass fiber reinforced concrete.

4.4.10.3 Failures observed on Flexural Beam

All the beam specimens tested under the test machine for flexural strength showed vertical cracks at the mid-span of the beam. During a crack observation on mixes with fiber and normal concrete beams, there is a variation in the crack bridging mechanism. For a normal concrete beam, it was

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

observed that there is an immediate collapse once the ultimate load is reached such that there is no warning before failure as shown in the figure 4.12 below.

The crack propagation on a normal concrete beam under flexural load was very short until the time of rupture this shows its brittleness more. However, the alkali-activated flexural beam with glass fiber reinforced gave crack resistance gradually until the point of rupture. In general, the addition of glass fiber improved the ductility of the beam to resist the high flexural load. It was observed that the increasing percentage of glass fiber increased the flexural strength of the beam.



a) Normal concrete under flexural load b) Glass fiber reinforced concrete under flexural load

Figure 4-12: Crack pattern observed on the flexural beam under UTM for normal and glass fiber reinforced concrete.

5. Chapter V-Conclusion and Recommendation

5.1 Conclusion

The investigation of the effect of fiber with varying percentages can still be promising work as there is always a need to solve the problem of the brittleness of concrete. The overall aim of this experimental investigation was to improve the flexural performance and mechanical properties of alkali-activated concrete beams made from locally available cementitious materials under monotonic loading by fiber addition. The results presented in this research provide important insights into the effect of glass fibers on the workability, compressive strength, split tensile strength, and flexural strength of alkali-activated concrete. The following conclusions were drawn from the investigation;

1. The experimental investigation showed that the specimen with 14M of alkaline solution and 2% of superplasticizer resulted in a better flow rate and workability of mortar.
2. It was observed that the presence of an activator and glass fiber showed the reduction of workability of alkali-activated concrete than normal concrete for all mixes. This is due to the presence of silicate in an alkaline solution creating a sticky characteristic and clumping fiber in the concrete.
3. The compressive strength on the 7th-day test results of mortar, 14M of NaOH with 2% superplasticizer showed an increment of 33.98% from the normal cement mortar. The maximum result of compressive strength was found at 0.2% of glass fiber showing an improvement of 31.93% and 29.03% on the 7th and 28th days test results respectively.
4. The maximum split tensile strength was found at 0.2% of glass fiber after the 7th day until the 28th-day test. As the percentage of glass fiber increases from 0.2% to 0.6 %GF, the split tensile strength of concrete on the 7th day increased by 26%, 18%, and 24% for 0.2%, 0.4%, and 0.6% respectively as compared to normal concrete.
5. The maximum flexural tensile strength of 6.12Mpa and 7.97MPa was found at 0.2% of glass fiber on the 7th and 28th day respectively.
6. As the age of concrete and percentage of glass fiber increased from the 7th day to the 28th day, compressive, split tensile, and flexural tensile strength was shown to increase for all concrete mixes.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

7. The fiber-reinforced alkali-activated concrete beam load-carrying capacity was greater than that normal concrete beam.
8. In conclusion, the maximum compressive, split tensile, and flexural tensile strength was found at 0.2% of glass fiber.

5.2 Recommendation

From the overall observation done in this research, the following recommendations are drawn.

1. To overcome the problem of workability affecting the consistency of fresh concrete, a detailed investigation of different water-to-cement ratios will be included in future work.
2. Investigating the effect of different types of fibers at various lengths with different percentage combinations and for different concrete grades will be included in future research.
3. Further investigation is needed for the curing temperature of alkali-activated concrete in future work.
4. Not only the strength, for durability purposes, but it also needs detailed investigation of nech afer with fiber and without fiber will need further study in the future.
5. To overcome the stress-strain curve relationship, it is better to develop a mathematical model prediction for geopolymer concrete in the future.

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**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

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**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

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**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

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**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Appendix

Appendix-A: Test Results Conducted Materials

A-1: Test Results Conducted on Cementitious Materials

1. Chemical Composition of Nech Afer.

	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:- Esrael Yohannes Issue Date:-15/05/2023

Sample type :-Soil Request No:- GLD/RQ/1143/23

Sample Preparation: -200 Mesh Report No:- GLD/RN/1806/23

Date Submitted:- 13/04/2023 Number of Sample:-One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: LiBO₂ FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC and AAS

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
EY-12	80.82	5.47	4.36	<0.01	0.18	0.52	1.02	0.20	0.07	0.73	1.51	4.53	500.00gm

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


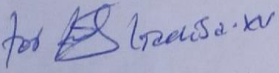

<u>Analysts</u>	<u>Checked By</u>	<u>Approved By</u>	
Haimanot Bayeh			
Gadisa Wakuma	Lidet Endeshaw	Yohannes Getachew	
Nigist Fikadu			

Figure 1: Chemical composition of nech afer laboratory analysis result.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

2. Consistency Properties of Cementitious Materials

Table 1: Normal consistency test results

S.No	% of BC	Amount of Cement	Amount of NA(gm)	W/C (%)	Amount of water(gm)	Penetration(mm)			Limits of NC
						Initial Reading	Final Reading	PD	
1	Control								10±1
		400	0	30	120	95	100	5	failed
		400	0	32	128	97	105	8	failed
		400	0	33	132	96	106	10	ok
2	50%NA	200	200	30	120	94	98	2	failed
		200	200	32	128	97	103	7	failed
		200	200	33	132	98	107	9	ok

Note: NA, PD, and NA stand for nech afer, penetration depth, and normal consistency respectively.

3. Setting Time Test of Cementitious Materials

Table 2: Trial investigated Setting time data details.

S.No	BC	Amount of Cement(gm)	(w/c)*0.85	Recorded data for setting time							
				Time(min)	30	45	60	75	90	IS	F S
	Control	400gm	28.05gm	Initial Reading(mm)	33	33	33	33	33	-	-
				Final Reading(mm)	0	7	20	24	27		
				Penetration depth(mm)	33	26	13	9	6	46	145

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

S.No	% of BC	NA(gm)	Water	Recorded data for setting time					IST	FST	
	50%NA	200gm	28.05gm	Time(min)	30	45	60	75	90	-	-
				Initial Reading(mm)	35	35	35	35	35		
				Final Reading(mm)	5	25	35	35	35		
				Penetration depth(mm)	30	10	0	0	0	34	60

Note: BC, NA, IST, and FST stand for binder content, nech afer, initial setting time, and Final setting time.

A-2: Physical Properties of Aggregates

To investigate the physical properties of Aggregates for the required application, different tests have been carried out which include: silt content, sieve analysis and fineness modules, specific gravity and absorption capacity, moisture content, and unit weight.

A) Silt Content of Fine Aggregates

A sample of the aggregate was washed in a prescribed manner, using plain water. The loss in mass resulting from the wash treatment was calculated as mass percent of the original sample and was reported as the percentage of material finer than a 75- μm (No. 200) sieve by washing.

❖ Procedures to test silt content in Fine Aggregates

Dry the test sample to constant mass at a temperature of $110 \pm 50^\circ\text{C}$, and determine the mass to the nearest 0.1% of the test sample, (record as M1). The minimum mass of the test sample after drying shall conform to the following.

NMS of aggregates(mm)	4.75	9.5	19	37.5
Minimum test sample(g)	300	1000	2500	5000

2. After being dried and weighed, place it in a vessel and add sufficient washing water to cover it.
3. Agitate the content of the vessel vigorously to separate all particles finer than 75- μm (No. 200) sieve from the coarser particles, and to bring the fine material into suspension.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

4. Immediately pour the wash water over a 75- μ m (No. 200) sieve. Add a second charge of water to the sample in the container, agitate, and decant as before. Repeat this operation until the wash water is clear.

5. Return all material retained on a sieve by flushing to the washed sample and dry it to constant mass at a temperature of 110 \pm 50C and determine the mass to the nearest 0.1%, (record as M2).

6. Calculate the percentage of material passing a 75- μ m (No. 200) sieve by washing as follows:

$$\text{Silt Content (Sc \%)} = \left[\frac{M1-M2}{M1} \right] * 100\% \quad \text{Eqn()}$$

Where: M1 is the original dry mass of sample (g), and M2 is a 24-hr oven-dried mass of the sample after washing (g).

For illustration, silt content calculated for the Trial-1 sample as

$$\text{Sc [\%]} = \frac{1000-982.4}{1000} * 100 = 1.76\%$$

Mean Silt Content Sc% = $\frac{(1.76+1.88+2.14)}{3} = 1.9267\%$ which is less than the 6% accepted.

Table1: The percentage of silt content in chewaka sand from Agaro

S.No	Description	Samples taken for trials[T]			Remarks
		T-1	T-2	T-3	
1	Wt. of sand taken for washing(gm)	1000	1000	1000	-
2	Wt.of oven-dried for 24 hr(gm)	982.4	981.2	978.6	-
*a	Silt content (%)	1.76	1.88	2.14	<6% ok!

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

B) Particle Size Distribution of Fine Aggregate

According to ASTM C 136-96a, The size of 2kg test samples after drying, separated through a series of sieves of progressively smaller openings was used for the determination of particle size distribution and fineness modulus of fine aggregate.

Table 2: The particle size distribution of fine aggregates.

Sieve size (mm)	Mass Retained(gm)				%Retained	%Cumulative Retained	% of passing	ASTM Limit		Remark
	T-1	T-2	T-3	Avg.				Mini	Max	
9.5	0	0	0	0	0	0	100.00	100	100	Ok!
4.75	54.5	47.2	52.7	51.467	2.5733	2.57	97.43	95	100	Ok!
2.36	107.7	99.3	108.5	105.17	5.2583	7.83	92.17	80	100	Ok!
1.18	324.8	352.5	348.4	341.9	17.095	24.93	75.07	50	85	Ok!
0.6	577.4	602.6	599.6	593.2	29.66	54.59	45.41	25	60	Ok!
0.3	569.7	570.6	546.9	562.4	28.12	82.71	17.29	5	30	Ok!
0.15	282.2	264.4	270.8	272.47	13.623	96.33	3.67	0	10	Ok!
Pan	81.9	61.6	72.6	72.033	3.6017	99.93	0	0	0	Ok!
Sum	1998	1998.2	1999.5	1998.6	-	268.96				

$$\text{Fineness Modulus [FM]} = \frac{\Sigma(\% \text{ cumulative retained})}{100} = \frac{268.96}{100} = 2.7$$

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

C) Specific Gravity and Absorption Capacity of Fine Aggregates

According to ASTM C 127-88 (Reapproved 1993) the test was performed with the following procedures.

❖ Procedures to determine specific gravity and Absorption capacity of fine aggregate

Step-1: A sample of 500g fine aggregate which is at free-flowing condition without moisture measured and placed into the pycnometer then filled up with water at 90 % capacity of the pycnometer.

Step-2: Using the rod the air bubbles are eliminated with adjusted temperature and the water level of the pycnometer is filled up to its calibrated capacity.

Step-3: the total weight of the pycnometer, sample, and water recorded,

$$C = 0.9976V_a + 500 + w \quad (2.)$$

Where: C is the weight of the pycnometer filled with sample plus water, V_a is the volume of water added to the pycnometer, and w is the weight of the pycnometer empty

Step-4: Oven-dried the aggregate removed from the pycnometer at $105 \pm 5^\circ\text{C}$ for an hour then cooled and measured

$$B = 0.9976V + w \quad ()$$

Where: B is the weight of the flask filled with water, V is the volume of the flask, and w is the weight of the flask.

$$\text{a) Bulk Specific gravity[OD]} = \frac{500}{B + 500 - C} \quad \text{Eqn(0)}$$

$$\text{b) Bulk Specific gravity[SSD]} = \frac{500}{B + 500 - C} \quad \text{Eqn(0)}$$

$$\text{c) Apparent specific gravity} = \frac{500}{B + 500 - C} \quad \text{Eqn(0)}$$

$$\text{d) Absorption Capacity} = \frac{[500 - A]}{A} \quad \text{Eqn(0)}$$

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table3: Specific Gravity and Absorption Capacity of Fine Aggregates

S.No	Description	Number of sample trials[T]			Mean
		T-1	T-2	T-3	
1	Initial Sample taken(gm)	500	500	500	-
2	Wt. of pycno+samle+H2O	1865.2	1867.7	1867	-
3	Wt. of pycnometer	1555	1555	1555	-
4	Wt. of oven-dried sample for 24hr(gm)	498.15	493.5	496	
*a	Bulk sp.gr[SSD]	2.63	2.67	2.66	2.655
*b	Bulk sp.gr[oven-dried]	2.62	2.63	2.64	2.633
*c	Apparent sp. gr	2.65	2.73	2.70	2.693
*d	Absorption Capacity (%)	0.37	1.32	0.84	0.84

Note: The test was done as per ASTM C 127-88 standards.

D) Moisture Content of Fine Aggregates

The following procedures. The 500gm of samples were prepared initially. It was oven-dried for about 24-hrs with a temperature of 105 ± 5 °C and then it was cooled sufficiently minimum for 1-hrs. Then, measure the mass and compute the moisture content by subtracting the mass of the dried sample from the mass of the original sample and dividing the weight difference by the oven-dry weight, and multiplying by a hundred.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table4: Moisture content of fine aggregates

S.No	Description	Number of sample trials[T]			Mean
		T-1	T-2	T-3	
1	Wt. of Sand in the air(gm)	500	500	500	-
2	Wt. of oven-dried sand for 24hr(gm)	498.2	497.5	497	-
3	Wt. of water in the sand(gm)	1.8	2.5	3.4	-
*e	Moisture Content (%)	0.361	0.503	0.685	0.516

Note: The test was done as per ASTM C566-97 standards. According to ASTM C 566-97 the moisture content of fine aggregate was performed

E) Unit Weight of Fine Aggregates

Unit weight was determined simply by filling a fine aggregate in a container of 0.01m^3 of known volume and weighing it. Then, dividing the aggregate weight by the volume of the container gives the unit weight of the aggregate.

Table5: The unit weight of fine aggregate.

S.No	Description	Number of sample trials[T]						Mean
		TL-1	TR-1	TL-2	TR-2	TL-3	TR-3	
1	Wt. of sample+cylinder(kg)	8.914	9.2366	8.95	9.2645	8.891	9.23	-
2	Wt. of Empty cylinder(kg)	1.669	1.669	1.669	1.669	1.669	1.669	-
3	Wt. of a sample only(kg)	7.245	7.5676	7.281	7.5955	7.222	7.561	-
4	Volume of cylinder(m^3)	0.005	0.005	0.005	0.005	0.005	0.005	-
*f	Loose Bulk density(kg/m^3)	1449	-	1456.2	-	1444.4	-	1449.87
*g	Rodded bulk density(kg/m^3)	-	1513.5	-	1519.1	-	1512.2	1514.94

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Note: The test was done as per ASTM C 29/C 29M-97. This test method covers the determination of bulk density (“unit weight”) of aggregate in a compacted or loose condition and calculated voids between particles in fine, coarse, or mixed aggregates based on the same procedure.

1. Coarse Aggregate

The physical properties of the coarse aggregate test investigated include sieve analysis, specific gravity and absorption capacity, moisture content, and unit weight have been carried out.

F) Sieve Analysis, and Fineness Module of Coarse Aggregates

Table6: The particle size distribution of coarse aggregates

Sieve size (mm)	Mass Retained(gm)				%Retained	%Cumulative Retained	% of passing	ASTM Limit		Remark
	T-1	T-2	T-3	Avg.				Mini	Max	
37.5	0	0	0	0	0	0	100	100	100	Ok!
25	0	0	0	0	0	0.00	100	100	100	Ok!
20	0	0	0	0	0	0.00	100	100	100	Ok!
12.5	68.5	86	83	79.167	3.167	3.17	96.83	90	100	Ok!
9.5	452	584.2	1355.2	797.13	31.89	35.05	64.95	40	70	Ok!
4.75	1735.4	1644.2	950	1443.2	57.73	92.78	7.22	0	15	Ok!
2.36	236.1	175.2	88.5	166.6	6.664	99.44	0.56	0	5	Ok!
Pan	5.3	2.4	7.8	5.1667	0.207	0.00	0			Ok!
Sum	2497.3	2492	2484.5	2491.3	-	230.44				

$$\text{Fineness Modulus [FM]} = \frac{\Sigma(\% \text{ cumulative retained})}{100} = \frac{230.44+500}{100} = 7.3$$

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

G) Specific Gravity, and Absorption Capacity of Coarse Aggregates.

Table 7: The specific gravity and absorption capacity of coarse aggregate.

S.No	Description	Number of sample trials[T]			mean
		T-1	T-2	T-3	
1	The initial sample was taken for the test(gm)	2000	2000	2000	-
1	Wt of CA with H ₂ O in the bucket(gm)	1893.5	1750.5	1820	-
2	Wt. of the empty bucket(gm)	617	502	545	-
3	Wt. of surface dried in the air [MSSD](gm)	2003	2002.5	2002.9	-
4	Wt. of oven-dried for 24hr[MD](gm)	1990.1	1983.9	1989.3	-
5	Wt. of saturated surface dried [Mw](gm)	1276.5	1248.5	1275	-
*a	Bulk sp. gr [SSD]	2.76	2.66	2.75	2.72
*b	Bulk sp. gr [oven-dried]	2.74	2.63	2.73	2.70
*c	Apparent sp. gr	2.79	2.70	2.78	2.76
*d	Absorption Capacity %	0.50	0.81	0.54	0.62

Note: The test was done as per ASTM C 127-88 standards.

H) Moisture Content of Coarse Aggregates

Table 8: The moisture content of coarse aggregates.

S.No	Description	Number of sample trials[T]			Mean
		T-1	T-2	T-3	
1	Wt. of aggregate in the air(gm)	2000	2000	2000	-
2	Wt. of Oven-dried aggregate(gm)	1988.2	1978.5	1989	-
3	Wt. of water in aggregate(gm)	11.8	21.5	11	-
*e	Moisture content (%)	0.59	1.09	0.55	0.74

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

I) Bulk Density or Unit Weight of Coarse Aggregates(kg/m³)

Table 9: Bulk density of coarse aggregates

S.No	Description	Number of sample trials[T]						Mean
		TL-1	TR-1	TL-2	TR-2	TL-3	TR-3	
1	Wt. of sample+cylinder(kg)	21.103	22.515	21.066	22.62	21.09	22.57	-
2	Wt. of Empty cylinder(kg)	7.621	7.621	7.621	7.621	7.621	7.621	-
3	Wt. of the sample only(kg)	13.482	14.894	13.445	15	13.47	14.95	-
4	Volume of cylinder(m ³)	0.01	0.01	0.01	0.01	0.01	0.01	-
*f	Loose Bulk density(kg/m ³)	1348.2	-	1344.5	-	1347	-	1346.53
*g	Rodded bulk density(kg/m ³)	-	1489.4	-	1500	-	1495	1494.55

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Appendix-B: Tests Conducted on Alkali-Activated Concrete

B-1: Test Results Conducted on Fresh Alkali-activated Concrete

A) Flow Test Results conducted on Alkali-activated Mortar

Table 1: Flow rate (mm) results with w/c of 0.5 and 0.55 with 1.5% of superplasticizer

S.No	w/c	Binder content	Flow Rate (mm) result on 3-molarities			SP(%)
			12M	14M	16M	
1	0.5	50%NA	112	120	110	1.5
2	0.55	50%NA	150	140	113	

Table 2: Flow rate (mm) results with w/c of 0.5 and 0.55 with 2% of superplasticizer

S.No	w/c	Binder content	Flow Rate (mm) result on 3-molarities			SP(%)
			12M	14M	16M	
1	0.5	50%NA	117	125	110	2
2	0.55	50%NA	150	185	140	

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

B-2: Test Results Conducted on Hardened Alkali-activated Concrete

a) Mass and Density of 7th and 28th day Alkali-activated Concrete

Table 1: Mass and density of split cylinder on the 7th day.

S.No	Mix ID	Mass of cylinder concrete on the 7 th day				Density (Kg/m ³)	Increment (%)
		C-1	C-2	C-3	Average		
1	Control	3.66	3.709	3.73	3.70	2355.28	-
2	0%GF	3.70	3.69	3.654	3.68	2343.82	0.49
3	0.2%GF	3.69	3.51	3.53	3.58	2275.92	3.37
4	0.4%GF	3.68	3.67	3.59	3.65	2321.54	1.43
5	0.6%GF	3.631	3.596	3.614	3.61	2300.53	2.32

Table 2: Mass and density of split cylinder on the 28th day.

S.No	Mix ID	Mass of cylinder concrete on the 28 th day				Density28th (kg/m ³)	Increment (%)
		C-1	C-2	C-3	Average		
1	Control	3.7071	3.715	3.74	3.72	2368.67	
2	0% GF	3.73	3.70	3.70	3.71	2362.07	0.28
3	0.2% GF	3.547	3.69	3.65	3.71	2361.86	0.29
4	0.4%GF	3.7	3.61	3.69	3.67	2334.27	1.45
5	0.6%GF	3.616	3.63	3.61	3.62	2303.50	2.75

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table4: Mass and Density of flexural beam on 7th day

S.No	Mix ID	Mass of flexure beam on 7th day				Density at 7 th (kg/m ³)	Increment (%)
		C-1	C-2	C-3	Average		
1	Control	12.56	12.47	11.07	12.033	2406.67	
2	0%GF	11.25	11.89	12.34	11.827	2365.33	-1.72
3	0.2%GF	11.121	11.98	11.78	11.628	2325.60	-3.37
4	0.4%GF	11.9167	11.61	11.57	11.699	2339.85	-2.78
5	0.6%GF	11.837	11.97	11.56	11.789	2357.80	-2.03

Table4: Mass and Density of flexural beam on the 28th day

S.No	Mix ID	Mass of flexure beam on 28th day				Density at 28 th kg/m ³	Increment (%)
		C-1	C-2	C-3	Average		
1	Control	12.963	13.056	12.5	12.84	2567.93	
2	0%GF	11.985	12.2063	12.687	12.29	2458.55	-4.26
3	0.2%GF	12.068	11.838	12.347	12.08	2416.87	-5.88
4	0.4%GF	12.68	12.43	13.0875	12.73	2546.50	-0.83
5	0.6%GF	12.473	11.856	12.508	12.279	2455.80	-4.37

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

b) Compressive Strength Result of Alkali-activated Concrete on the 7th and 28th day

Table 5: Compressive stress of cube concrete on the 7th day

S.No	% of fiber added	Test Day	Specimen	Peak Load(KN)	Compressive Stress(Mpa)	Average Compressive Stress(Mpa)
1		7	1	455.4	20.2	20.8
			2	512.1	22.8	
			3	439.5	19.5	
2	0%GF	7	1	673.69	29.9	25.3
			2	489.63	21.8	
			3	541.85	24.1	
3	0.2%GF	7	1	612.82	27.2	27.5
			2	598	26.6	
			3	645.38	28.7	
	0.4%GF	7	1	626.08	27.8	27.7
			2	664.99	29.6	
			3	577.3	25.7	
5	0.6%GF	7	1	580.95	25.8	27.2
			2	642.99	28.6	
			3	611.89	27.2	

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table6: Compressive stress of cube concrete on the 28th day

S.No	% of fiber added	Test Day	Specimen	Peak Load(KN)	Compressive Stress(Mpa)	Average Compressive stress(Mpa)
1	Control	28	1	563.54	25.0	25.1
			2	571.05	25.4	
			3	562.096	25.0	
2	0%GF	28	1	677.74	30.1	27.5
			2	545.99	24.3	
			3	634.25	28.2	
3	0.2%GF	28	1	733.5	32.6	32.4
			2	732.8	32.6	
			3	721.5	32.1	
4	0.4%GF	28	1	644.79	28.7	29.5
			2	675.99	30.0	
			3	668.89	29.7	
5	0.6%GF	28	1	682	30.3	29.3
			2	632.4	28.1	
			3	660	29.3	

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Appendix-C: Stress and Strain Relationship of Cube Compression Test

C-1: Stress and Strain Result of Cube on 7th-Day Average Load.

Table 1: Stress and strain resulting from the 7th-day control average load.

Load(KN)	Stress(Mpa)	7 th Day Control				Average Load	Average Stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -2			
0	0	0	0	0	0	0.00	0	0
20	0.889	19	0.8444	18	0.8	19.00	0.844	0.0000356
32	1.422	26	1.1556	29	1.3	29.00	1.289	0.0000547
45	2.000	31	1.3778	37	1.6	37.67	1.674	0.0000713
68	3.022	39	1.7333	54	2.4	53.67	2.385	0.0001023
83	3.689	46	2.0444	68	3.0	65.67	2.919	0.000126
98	4.356	62	2.7556	86	3.8	82.00	3.644	0.0001585
119	5.289	86	3.8222	99	4.4	101.33	4.504	0.0001979
134	5.956	99	4.4000	104	4.6	112.33	4.993	0.0002207
149	6.622	110	4.8889	120	5.3	126.33	5.615	0.0002501
166	7.378	120	5.3333	138	6.1	141.33	6.281	0.0002821
188	8.356	132	5.8667	156	6.9	158.67	7.052	0.0003199
201	8.933	146	6.4889	175	7.8	174.00	7.733	0.0003541
220	9.778	160	7.1111	189	8.4	189.67	8.430	0.0003899
238	10.578	185	8.2222	199	8.8	207.33	9.215	0.0004312
254	11.289	198	8.8000	210	9.3	220.67	9.807	0.0004631
270	12.000	206	9.1556	226	10.0	234.00	10.400	0.0004959
296	13.156	220	9.7778	240	10.7	252.00	11.200	0.0005413

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

305	13.556	232	10.3111	256	11.4	264.33	11.748	0.0005734
320	14.222	246	10.9333	281	12.5	282.33	12.548	0.0006218
337	14.978	272	12.0889	296	13.2	301.67	13.407	0.0006762
352	15.644	289	12.8444	310	13.8	317.00	14.089	0.0007213
370	16.444	299	13.2889	327	14.5	332.00	14.756	0.0007674
384	17.067	312	13.8667	336	14.9	344.00	15.289	0.0008059
410	18.222	327	14.5333	353	15.7	363.33	16.148	0.0008717
415	18.444	346	15.3778	371	16.5	377.33	16.770	0.0009227
419	18.622	372	16.5333	388	17.2	393.00	17.467	0.0009844
422	18.756	389	17.2889	412	18.3	407.67	18.119	0.0010477
426	18.933	401	17.8222	415	18.4	414.00	18.400	0.0010771
431	19.156	420	18.6667	418	18.6	423.00	18.800	0.0011218
437	19.422	444	19.7333	421	18.7	434.00	19.289	0.0011826
439	19.511	469	20.8444	425	18.9	444.33	19.748	0.0012485
443	19.689	480	21.3333	429	19.1	450.67	20.030	0.0012958
448	19.911	497	22.0889	431	19.2	458.67	20.385	0.0013687
454	20.178	510	22.6667	436	19.4	466.67	20.741	0.0014829
455	20.222	512	22.7556	439	19.5	468.67	20.830	0.001547
455.4	20.240	512.1	22.7600	439.5	19.5	469.00	20.844	0.0015841
450	20.000	509	22.6222	430	19.1	463.00	20.578	0.0017762
441	19.600	500	22.2222	423	18.8	454.67	20.207	0.0018848
432	19.200	489	21.7333	421	18.7	447.33	19.881	0.001956
427	18.978	469	20.8444	412	18.3	436.00	19.378	0.002046

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

400	17.778	451	20.0444	401	17.8	417.33	18.548	0.0021664
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Table 2: Stress and strain resulting from the 7th-day 0%GF average load.

Load(KN)	stress(Mpa)	7 th Day 0%GF				Average Load	Average Stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -2			
0	0	0	0	0	0	0	0	0
19	0.844	18	0.80	20	0.889	19.00	0.844	0.0000304
29	1.289	25	1.11	33	1.467	29.00	1.289	0.0000467
41	1.822	29	1.29	46	2.044	38.67	1.719	0.0000626
60	2.667	37	1.64	67	2.978	54.67	2.430	0.0000892
75	3.333	44	1.96	84	3.733	67.67	3.007	0.00011120
98	4.356	61	2.71	99	4.400	86.00	3.822	0.0001427
120	5.333	72	3.20	120	5.333	104.00	4.622	0.0001743
141	6.267	85	3.78	134	5.956	120.00	5.333	0.000203
167	7.422	99	4.40	148	6.578	138.00	6.133	0.0002359
191	8.489	109	4.84	167	7.422	155.67	6.919	0.000269
219	9.733	118	5.24	189	8.400	175.33	7.793	0.0003068
242	10.756	127	5.64	203	9.022	190.67	8.474	0.0003369
278	12.356	136	6.04	219	9.733	211.00	9.378	0.0003779
299	13.289	145	6.44	237	10.533	227.00	10.089	0.000411
307	13.644	158	7.02	256	11.378	240.33	10.681	0.0004393
329	14.622	171	7.60	272	12.089	257.33	11.437	0.0004763

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

362	16.089	184	8.18	296	13.156	280.67	12.474	0.0005289
389	17.289	197	8.76	305	13.556	297.00	13.200	0.0005671
398	17.689	208	9.24	319	14.178	308.33	13.704	0.0005943
411	18.267	217	9.64	338	15.022	322.00	14.311	0.000628
433	19.244	226	10.04	352	15.644	337.00	14.978	0.0006662
455	20.222	235	10.44	369	16.400	353.00	15.689	0.0007084
480	21.333	249	11.07	382	16.978	370.33	16.459	0.000756
499	22.178	258	11.47	407	18.089	388.00	17.244	0.0008069
520	23.111	279	12.40	421	18.711	406.67	18.074	0.0008636
549	24.400	292	12.98	437	19.422	426.00	18.933	0.0009261
562	24.978	312	13.87	449	19.956	441.00	19.600	0.0009778
585	26.000	328	14.58	466	20.711	459.67	20.430	0.0010469
602	26.756	347	15.42	478	21.244	475.67	21.141	0.0011111
620	27.556	371	16.49	492	21.867	494.33	21.970	0.0011939
632	28.089	389	17.29	507	22.533	509.33	22.637	0.0012687
645	28.667	410	18.22	514	22.844	523.00	23.244	0.001346
659	29.289	444	19.73	522	23.200	541.67	24.074	0.0014746
668	29.689	472	20.98	533	23.689	557.67	24.785	0.0016312
673	29.911	489	21.73	541	24.044	567.67	25.230	0.0018339
673.69	29.942	489.63	21.76	541.85	24.082	568.39	25.262	0.0019052
670	29.778	471	20.93	521	23.156	554.00	24.622	0.0022649
657	29.200	459	20.40	514	22.844	543.33	24.148	0.0023814
634	28.178	442	19.64	505	22.444	527.00	23.422	0.0025208

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

615	27.333	431	19.16	499	22.178	515.00	22.889	0.0026069
601	26.711	422	18.76	490	21.778	504.33	22.415	0.0026766
534	23.733	412	18.31	485	21.556	477.00	21.200	0.0028337

Table 3: Stress and strain resulting from the 7th-day 0.2%GF average load.

Load(KN)	Stress(Mpa)	7 th Day 0.2%GF				Average load	Average Stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -2			
0	0	0	0	0	0	0	0	0
19	0.84	19	0.84	17	0.76	18.33	0.81	0.0000307
28	1.24	25	1.11	28	1.24	27.00	1.20	0.0000456
39	1.73	36	1.60	39	1.73	38.00	1.69	0.0000645
52	2.31	47	2.09	51	2.27	50.00	2.22	0.0000852
63	2.80	59	2.62	69	3.07	63.67	2.83	0.0001091
73	3.24	61	2.71	82	3.64	72.00	3.20	0.0001238
103	4.58	84	3.73	94	4.18	93.67	4.16	0.0001623
115	5.11	103	4.58	106	4.71	108.00	4.80	0.0001884
122	5.42	118	5.24	122	5.42	120.67	5.36	0.0002115
136	6.04	133	5.91	139	6.18	136.00	6.04	0.0002399
149	6.62	149	6.62	156	6.93	151.33	6.73	0.0002691
159	7.07	165	7.33	174	7.73	166.00	7.38	0.000297

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

172	7.64	184	8.18	184	8.18	180.00	8.00	0.0003241
185	8.22	198	8.80	205	9.11	196.00	8.71	0.0003555
195	8.67	205	9.11	213	9.47	204.33	9.08	0.0003721
205	9.11	235	10.44	225	10.00	221.67	9.85	0.0004071
222	9.87	252	11.20	247	10.98	240.33	10.68	0.0004456
235	10.44	268	11.91	261	11.60	254.67	11.32	0.0004759
247	10.98	286	12.71	279	12.40	270.67	12.03	0.0005101
264	11.73	304	13.51	281	12.49	283.00	12.58	0.0005371
274	12.18	314	13.96	306	13.60	298.00	13.24	0.0005701
282	12.53	338	15.02	322	14.31	314.00	13.96	0.000607
298	13.24	356	15.82	343	15.24	332.33	14.77	0.0006495
312	13.87	367	16.31	355	15.78	344.67	15.32	0.0006791
327	14.53	382	16.98	368	16.36	359.00	15.96	0.0007143
339	15.07	395	17.56	387	17.20	373.67	16.61	0.000751
358	15.91	415	18.44	403	17.91	392.00	17.42	0.0007981
372	16.53	425	18.89	419	18.62	405.33	18.01	0.0008336
380	16.89	436	19.38	433	19.24	416.33	18.50	0.0008639
398	17.69	447	19.87	447	19.87	430.67	19.14	0.0009045
419	18.62	464	20.62	462	20.53	448.33	19.93	0.0009568
427	18.98	471	20.93	475	21.11	457.67	20.34	0.000985
443	19.69	483	21.47	489	21.73	471.67	20.96	0.001029
455	20.22	498	22.13	505	22.44	486.00	21.60	0.0010766
467	20.76	506	22.49	515	22.89	496.00	22.04	0.0011107

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

478	21.24	512	22.76	524	23.29	504.67	22.43	0.001142
493	21.91	521	23.16	532	23.64	515.33	22.90	0.0011814
506	22.49	528	23.47	541	24.04	525.00	23.33	0.0012191
515	22.89	532	23.64	558	24.80	535.00	23.78	0.0012606
526	23.38	535	23.78	565	25.11	542.00	24.09	0.0012906
538	23.91	536	23.82	574	25.51	549.33	24.41	0.0013229
544	24.18	538	23.91	585	26.00	555.67	24.70	0.0013537
553	24.58	540	24.00	596	26.49	563.00	25.02	0.0013895
562	24.98	541	24.04	606	26.93	569.67	25.32	0.0014251
568	25.24	545	24.22	612	27.20	575.00	25.56	0.0014553
577	25.64	548	24.36	621	27.60	582.00	25.87	0.0014972
584	25.96	552	24.53	627	27.87	587.67	26.12	0.0015338
588	26.13	559	24.84	633	28.13	593.33	26.37	0.0015739
603	26.80	565	25.11	637	28.31	601.67	26.74	0.0016423
609	27.07	569	25.29	640	28.44	606.00	26.93	0.0016839
612	27.20	575	25.56	643	28.58	610.00	27.11	0.0017302
612	27.20	585	26.00	645	28.67	614.00	27.29	0.001789
612.82	27.24	598	26.58	645.38	28.68	618.73	27.50	0.00195
611	27.16	590	26.22	642	28.53	614.33	27.30	0.0021331
608	27.02	580	25.78	638	28.36	608.67	27.05	0.0022281
600	26.67	576	25.60	629	27.96	601.67	26.74	0.0023135
584	25.96	569	25.29	620	27.56	591.00	26.27	0.0024154
552	24.53	560	24.89	607	26.98	573.00	25.47	0.0025513

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

547	24.31	555	24.67	590	26.22	564.00	25.07	0.0026094
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Table 4: Stress and strain resulting from the 7th-day 0.4%GF average load.

Load(KN)	Stress(Mpa)	7 th Day 0.4%GF				Average Load	Average stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -2			
0	0	0	0	0	0	0	0	0
20	0.889	22	0.978	21	0.933	21.000	0.933	0.000032
29	1.289	38	1.689	32	1.422	33.000	1.467	5.06E-05
37	1.644	52	2.311	46	2.044	45.000	2.000	6.93E-05
41	1.822	61	2.711	67	2.978	56.333	2.504	8.72E-05
49	2.178	79	3.511	84	3.733	70.667	3.141	0.00011
58	2.578	90	4.000	99	4.400	82.333	3.659	0.000129
69	3.067	101	4.489	120	5.333	96.667	4.296	0.000153
80	3.556	112	4.978	134	5.956	108.667	4.830	0.000173
93	4.133	125	5.556	148	6.578	122.000	5.422	0.000195
110	4.889	151	6.711	167	7.422	142.667	6.341	0.00023
125	5.556	172	7.644	183	8.133	160.000	7.111	0.000261
137	6.089	185	8.222	203	9.022	175.000	7.778	0.000288
151	6.711	193	8.578	219	9.733	187.667	8.341	0.000311
166	7.378	215	9.556	238	10.578	206.333	9.170	0.000345
182	8.089	247	10.978	255	11.333	228.000	10.133	0.000386

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

199	8.844	272	12.089	272	12.089	247.667	11.007	0.000425
220	9.778	290	12.889	296	13.156	268.667	11.941	0.000467
221	9.822	310	13.778	305	13.556	278.667	12.385	0.000487
243	10.800	321	14.267	319	14.178	294.333	13.081	0.00052
262	11.644	347	15.422	338	15.022	315.667	14.030	0.000566
276	12.267	372	16.533	352	15.644	333.333	14.815	0.000606
295	13.111	397	17.644	369	16.400	353.667	15.719	0.000653
309	13.733	404	17.956	382	16.978	365.000	16.222	0.00068
326	14.489	423	18.800	407	18.089	385.333	17.126	0.00073
339	15.067	441	19.600	421	18.711	400.333	17.793	0.000768
351	15.600	467	20.756	437	19.422	418.333	18.593	0.000816
367	16.311	484	21.511	450	20.000	433.667	19.274	0.000859
383	17.022	499	22.178	467	20.756	449.667	19.985	0.000905
402	17.867	510	22.667	479	21.289	463.667	20.607	0.000948
415	18.444	522	23.200	493	21.911	476.667	21.185	0.000989
429	19.067	539	23.956	507	22.533	491.667	21.852	0.001039
441	19.600	551	24.489	513	22.800	501.667	22.296	0.001074
458	20.356	569	25.289	521	23.156	516.000	22.933	0.001127
472	20.978	582	25.867	532	23.644	528.667	23.496	0.001177
496	22.044	595	26.444	541	24.044	544.000	24.178	0.001242
509	22.622	612	27.200	553	24.578	558.000	24.800	0.001307
520	23.111	620	27.556	559	24.844	566.333	25.170	0.00135
535	23.778	629	27.956	563	25.022	575.667	25.585	0.001401

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

543	24.133	633	28.133	567	25.200	581.000	25.822	0.001433
583	25.911	640	28.444	572	25.422	598.333	26.593	0.001555
600	26.667	648	28.800	574	25.511	607.333	26.993	0.001636
611	27.156	653	29.022	575	25.556	613.000	27.244	0.0017
622	27.644	657	29.200	576	25.600	618.333	27.481	0.001782
626	27.822	664	29.511	577	25.644	622.333	27.659	0.001898
626.08	27.826	664.99	29.555	577.3	25.659	622.797	27.680	0.001954
620	27.556	663	29.467	570	25.333	617.667	27.452	0.0021463
608	27.022	647	28.756	547	24.311	600.667	26.696	0.0023614
601	26.711	620	27.556	521	23.156	580.667	25.807	0.0025215
590	26.222	609	27.067	514	22.844	571.000	25.378	0.0025854
582	25.867	592	26.311	505	22.444	559.667	24.874	0.0026535
571	25.378	580	25.778	499	22.178	550.000	24.444	0.0027072
560	24.889	571	25.378	490	21.778	540.333	24.015	0.0027575
555	24.667	555	24.667	485	21.556	531.667	23.630	0.0028004
544	24.178	546	24.267	480	21.333	523.333	23.259	0.0028398
537	23.867	537	23.867	476	21.156	516.667	22.963	0.0028703
529	23.511	530	23.556	469	20.844	509.333	22.637	0.0029029

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table 5: Stress and strain result from the 7th-day 0.6%GF average load.

Load(KN)	Stress(Mpa)	7 th Day 0.6%GF				Average Load	Average Stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -2			
0	0	0	0	0	0	0	0	0
18	0.80	23	1.022	23	1.022	21.333	0.948	0.000033
24	1.07	35	1.556	36	1.600	31.667	1.407	0.0000492
54	2.40	52	2.311	42	1.867	49.333	2.193	0.0000773
73	3.24	60	2.667	56	2.489	63.000	2.800	0.0000994
94	4.18	92	4.089	68	3.022	84.667	3.763	0.0001349
113	5.02	116	5.156	82	3.644	103.667	4.607	0.0001668
135	6.00	139	6.178	99	4.400	124.333	5.526	0.0002021
157	6.98	168	7.467	113	5.022	146.000	6.489	0.0002401
178	7.91	188	8.356	128	5.689	164.667	7.319	0.0002736
198	8.80	210	9.333	144	6.400	184.000	8.178	0.000309
213	9.47	235	10.444	159	7.067	202.333	8.993	0.0003434
236	10.49	258	11.467	173	7.689	222.333	9.881	0.0003818
258	11.47	278	12.356	193	8.578	243.000	10.800	0.0004227
279	12.40	305	13.556	207	9.200	263.667	11.719	0.0004648
298	13.24	325	14.444	222	9.867	281.667	12.519	0.0005025
310	13.78	351	15.600	245	10.889	302.000	13.422	0.0005464

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

333	14.80	377	16.756	260	11.556	323.333	14.370	0.0005942
353	15.69	398	17.689	278	12.356	343.000	15.244	0.0006399
374	16.62	422	18.756	299	13.289	365.000	16.222	0.0006932
391	17.38	444	19.733	319	14.178	384.667	17.096	0.0007429
404	17.96	463	20.578	339	15.067	402.000	17.867	0.0007887
424	18.84	488	21.689	356	15.822	422.667	18.785	0.0008459
436	19.38	503	22.356	376	16.711	438.333	19.481	0.0008914
448	19.91	519	23.067	396	17.600	454.333	20.193	0.0009403
458	20.36	534	23.733	415	18.444	469.000	20.844	0.0009872
473	21.02	553	24.578	429	19.067	485.000	21.556	0.0010416
484	21.51	568	25.244	448	19.911	500.000	22.222	0.0010957
494	21.96	581	25.822	461	20.489	512.000	22.756	0.0011418
503	22.36	589	26.178	479	21.289	523.667	23.274	0.0011894
515	22.89	592	26.311	493	21.911	533.333	23.704	0.0012314
522	23.20	598	26.578	506	22.489	542.000	24.089	0.0012714
528	23.47	605	26.889	518	23.022	550.333	24.459	0.0013122
535	23.78	610	27.111	529	23.511	558.000	24.800	0.0013524
542	24.09	618	27.467	542	24.089	567.333	25.215	0.0014056
551	24.49	625	27.778	560	24.889	578.667	25.719	0.0014784
564	25.07	632	28.089	589	26.178	595.000	26.444	0.0016109
575	25.56	638	28.356	605	26.889	606.000	26.933	0.0017463
580	25.78	642	28.533	611	27.156	611.000	27.156	0.0018659
580.95	25.82	642.99	28.577	611.89	27.195	611.943	27.197	0.0019439

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

575	25.56	576	25.600	609	27.067	586.667	26.074	0.0023854
580	25.78	571	25.378	599	26.622	583.333	25.926	0.0024145
579	25.73	566	25.156	584	25.956	576.333	25.615	0.0024707
572	25.42	561	24.933	576	25.600	569.667	25.319	0.0025195
568	25.24	555	24.667	565	25.111	562.667	25.007	0.002567
546	24.27	551	24.489	551	24.489	549.333	24.415	0.0026493
534	23.733	549	24.400	542	24.089	541.667	24.074	0.002693

C-2: STRESS AND STRAIN RESULT OF CUBE ON 28TH- DAY AVERAGE LOAD.

Table 6: Stress and strain resulting from the 28th-day control average load.

Load(KN)	Stress(Mpa)	28 th -day Control				Average Load	Average Stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -2			
0	0	0	0	0	0	0	0	0
20	0.89	19	0.84	21	0.93	20.00	0.89	0.0000409
29	1.29	26	1.16	30	1.33	28.33	1.26	0.0000581
45	2.00	35	1.56	44	1.96	41.33	1.84	0.0000851
68	3.02	47	2.09	68	3.02	61.00	2.71	0.0001261
89	3.96	59	2.62	79	3.51	75.67	3.36	0.000157
101	4.49	71	3.16	93	4.13	88.33	3.93	0.0001844
120	5.33	84	3.73	112	4.98	105.33	4.68	0.0002208
134	5.96	103	4.58	124	5.51	120.33	5.35	0.0002537
149	6.62	118	5.24	135	6.00	134.00	5.96	0.000284

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

167	7.42	132	5.87	147	6.53	148.67	6.61	0.0003166
185	8.22	148	6.58	160	7.11	164.33	7.30	0.0003517
205	9.11	164	7.29	172	7.64	180.33	8.01	0.0003882
220	9.78	185	8.22	189	8.40	198.00	8.80	0.0004295
239	10.62	199	8.84	199	8.84	212.33	9.44	0.0004635
256	11.38	212	9.42	212	9.42	226.67	10.07	0.0004974
272	12.09	237	10.53	221	9.82	243.33	10.81	0.0005378
295	13.11	250	11.11	232	10.31	259.00	11.51	0.0005768
306	13.60	287	12.76	256	11.38	283.00	12.58	0.0006378
320	14.22	304	13.51	275	12.22	299.67	13.32	0.000681
340	15.11	319	14.18	289	12.84	316.00	14.04	0.0007241
361	16.04	339	15.07	299	13.29	333.00	14.80	0.0007707
380	16.89	356	15.82	312	13.87	349.33	15.53	0.0008167
399	17.73	372	16.53	323	14.36	364.67	16.21	0.0008607
410	18.22	383	17.02	342	15.20	378.33	16.81	0.0009006
422	18.76	398	17.69	370	16.44	396.67	17.63	0.0009571
438	19.47	412	18.31	388	17.24	412.67	18.34	0.0010079
452	20.09	437	19.42	401	17.82	430.00	19.11	0.0010655
466	20.71	465	20.67	420	18.67	450.33	20.01	0.0011367
481	21.38	480	21.33	438	19.47	466.33	20.73	0.0011974
499	22.18	498	22.13	454	20.18	483.67	21.50	0.0012671
512	22.76	512	22.76	469	20.84	497.67	22.12	0.0013279
522	23.20	521	23.16	481	21.38	508.00	22.58	0.0013766

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

534	23.73	542	24.09	499	22.18	525.00	23.33	0.0014651
541	24.04	559	24.84	512	22.76	537.33	23.88	0.001541
557	24.76	564	25.07	528	23.47	549.67	24.43	0.0016344
559	24.84	568	25.24	541	24.04	556.00	24.71	0.0016956
562	24.98	570	25.33	556	24.71	562.67	25.01	0.0017903
563	25.02	571	25.38	562	24.98	565.33	25.13	0.0018719
563.54	25.05	571.05	25.38	562.096	24.98	565.56	25.14	0.0019028
556	24.71	560	24.89	560	24.89	558.67	24.83	0.0021429
543	24.13	547	24.31	551	24.49	547.00	24.31	0.0023023
530	23.56	510	22.67	544	24.18	528.00	23.47	0.0024782
521	23.16	498	22.13	512	22.76	510.33	22.68	0.0026062
489	21.73	488	21.69	498	22.13	491.67	21.85	0.0027222

Table 7: Stress and strain resulting from the 28th-day 0%GF average load.

Load(KN)	Stress (Mpa)	28 th day 0% GF				Average Load	Average Stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -2			
0	0	0	0	0	0	0	0	0
16	0.71	19	0.84	18	0.80	17.667	0.785	0.0000321
25	1.11	29	1.29	30	1.33	28.000	1.244	0.000051
41	1.82	47	2.09	43	1.91	43.667	1.941	0.0000799

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

58	2.58	69	3.07	58	2.58	61.667	2.741	0.0001135
76	3.38	88	3.91	73	3.24	79.000	3.511	0.0001462
99	4.40	110	4.89	91	4.04	100.000	4.444	0.0001863
121	5.38	129	5.73	110	4.89	120.000	5.333	0.0002252
142	6.31	149	6.62	126	5.60	139.000	6.178	0.0002626
168	7.47	169	7.51	149	6.62	162.000	7.200	0.0003087
192	8.53	181	8.04	181	8.04	184.667	8.207	0.0003549
220	9.78	220	9.78	196	8.71	212.000	9.422	0.000412
243	10.80	234	10.40	226	10.04	234.333	10.415	0.0004597
279	12.40	245	10.89	249	11.07	257.667	11.452	0.0005108
301	13.38	273	12.13	276	12.27	283.333	12.593	0.0005684
329	14.62	290	12.89	303	13.47	307.333	13.659	0.0006239
361	16.04	310	13.78	333	14.80	334.667	14.874	0.0006893
384	17.07	326	14.49	358	15.91	356.000	15.822	0.0007421
410	18.22	343	15.24	383	17.02	378.667	16.830	0.0008002
432	19.20	359	15.96	410	18.22	400.333	17.793	0.0008578
451	20.04	376	16.71	431	19.16	419.333	18.637	0.0009103
479	21.29	390	17.33	451	20.04	440.000	19.556	0.00097
499	22.18	412	18.31	473	21.02	461.333	20.504	0.0010346
520	23.11	429	19.07	497	22.09	482.000	21.422	0.0011009
548	24.36	445	19.78	520	23.11	504.333	22.415	0.0011776
561	24.93	460	20.44	539	23.96	520.000	23.111	0.0012354
584	25.96	475	21.11	558	24.80	539.000	23.956	0.0013113

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

600	26.67	489	21.73	578	25.69	555.667	24.696	0.0013847
619	27.51	499	22.18	589	26.18	569.000	25.289	0.0014501
633	28.13	510	22.67	599	26.62	580.667	25.807	0.0015141
644	28.62	519	23.07	612	27.20	591.667	26.296	0.0015835
658	29.24	525	23.33	619	27.51	600.667	26.696	0.0016507
668	29.69	536	23.82	627	27.87	610.333	27.126	0.001744
676	30.04	541	24.04	632	28.09	616.333	27.393	0.0018323
677	30.09	545	24.22	634	28.18	618.667	27.496	0.0018947
677.74	30.12	545.99	24.27	634.25	28.19	619.327	27.526	0.0019505
674	29.96	520	23.11	616	27.38	603.333	26.815	0.002302
642	28.53	486	21.60	598	26.58	575.333	25.570	0.0025396
626	27.82	476	21.16	575	25.56	559.000	24.844	0.0026434

Table 8: Stress and strain result from the 28th-day 0.2% GF average load.

Load(KN)	Stress (Mpa)	28 th day 0.2%GF				Average Load	Average Stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -2			
0	0	0	0	0	0	0	0	0
15	0.667	19	0.84	20	0.889	18	0.80	0.0000264
24	1.067	33	1.47	41	1.822	32.67	1.45	0.0000481
37	1.644	45	2.0	62	2.756	48.00	2.13	0.0000711
55	2.444	56	2.49	78	3.467	63.00	2.80	0.0000939
77	3.422	74	3.29	94	4.178	81.67	3.63	0.0001225

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

93	4.133	95	4.22	112	4.978	100.00	4.44	0.0001508
106	4.711	109	4.84	131	5.822	115.33	5.13	0.0001752
129	5.733	129	5.73	153	6.800	137.00	6.09	0.0002097
145	6.444	146	6.49	174	7.733	155.00	6.89	0.0002388
161	7.156	168	7.47	195	8.667	174.67	7.76	0.000271
183	8.133	193	8.58	221	9.822	199.00	8.84	0.0003117
209	9.289	216	9.60	242	10.756	222.33	9.88	0.0003517
233	10.356	237	10.53	257	11.422	242.33	10.77	0.0003867
255	11.333	251	11.16	269	11.956	258.33	11.48	0.000415
272	12.089	271	12.04	287	12.756	276.67	12.30	0.0004484
293	13.022	293	13.02	304	13.511	296.67	13.19	0.0004853
320	14.222	315	14.00	321	14.267	318.67	14.16	0.0005264
335	14.889	332	14.76	338	15.022	335.00	14.89	0.000558
353	15.689	351	15.60	356	15.822	353.33	15.70	0.0005939
372	16.533	375	16.67	371	16.489	372.67	16.56	0.0006329
389	17.289	396	17.60	393	17.467	392.67	17.45	0.0006743
412	18.311	419	18.62	408	18.133	413.00	18.36	0.0007178
428	19.022	433	19.24	424	18.844	428.33	19.04	0.0007512
449	19.956	451	20.04	443	19.689	447.67	19.90	0.0007947
473	21.022	472	20.98	462	20.533	469.00	20.84	0.0008438
487	21.644	486	21.60	477	21.200	483.33	21.48	0.0008784
504	22.400	512	22.76	496	22.044	504.00	22.40	0.0009298
519	23.067	528	23.47	520	23.111	522.33	23.21	0.000977

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

538	23.911	554	24.62	528	23.467	540.00	24.00	0.001025
555	24.667	569	25.29	541	24.044	555.00	24.67	0.0010674
572	25.422	585	26.00	559	24.844	572.00	25.42	0.001117
593	26.356	602	26.76	586	26.044	593.67	26.39	0.0011852
600	26.667	617	27.42	598	26.578	605.00	26.89	0.0012224
612	27.200	636	28.27	620	27.556	622.67	27.67	0.0012839
632	28.089	649	28.84	628	27.911	636.33	28.28	0.0013355
649	28.844	663	29.47	649	28.844	653.67	29.05	0.0014063
666	29.600	682	30.31	658	29.244	668.67	29.72	0.0014746
677	30.089	696	30.93	666	29.600	679.67	30.21	0.00153
688	30.578	704	31.29	685	30.444	692.33	30.77	0.0016015
697	30.978	714	31.73	695	30.889	702.00	31.20	0.001665
710	31.556	719	31.96	705	31.333	711.33	31.61	0.001737
719	31.956	722	32.09	711	31.600	717.33	31.88	0.0017952
728	32.356	728	32.36	718	31.911	724.67	32.21	0.0018931
732	32.533	730	32.44	720	32.000	727.33	32.33	0.0019502
733	32.578	732	32.53	721	32.044	728.67	32.39	0.0019993
733.5	32.600	732.8	32.57	721.5	32.067	729.27	32.41	0.0020482
721	32.044	720	32.00	710	31.556	717.00	31.87	0.0023275
701	31.156	704	31.29	700	31.111	701.67	31.19	0.0024674
689	30.622	690	30.67	690	30.67	689.67	30.65	0.0025507
674	29.956	679	30.18	671	29.822	674.67	29.99	0.0026388

Table 9: Stress and strain result from the 28th-day 0.4% GF average load.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Load (KN)	Stress (Mpa)	28 th day 0.4%GF				Average Load	Average Stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -1			
0	0	0	0	0	0	0	0	0
20	0.889	21	0.933	19	0.844	20.00	0.889	0.0000332
29	1.289	42	1.867	31	1.378	34.00	1.511	0.0000568
43	1.911	63	2.800	46	2.044	50.67	2.252	0.000085
56	2.489	76	3.378	61	2.711	64.33	2.859	0.0001084
72	3.200	95	4.222	76	3.378	81.00	3.600	0.0001373
86	3.822	113	5.022	97	4.311	98.67	4.385	0.0001683
101	4.489	128	5.689	115	5.111	114.67	5.096	0.0001967
115	5.111	156	6.933	130	5.778	133.67	5.941	0.0002308
126	5.600	177	7.867	149	6.622	150.67	6.696	0.0002618
137	6.089	192	8.533	168	7.467	165.67	7.363	0.0002895
152	6.756	210	9.333	186	8.267	182.67	8.119	0.0003214
166	7.378	233	10.356	197	8.756	198.67	8.830	0.0003517
181	8.044	247	10.978	215	9.556	214.33	9.526	0.0003819
199	8.844	267	11.867	229	10.178	231.67	10.296	0.0004158
215	9.556	281	12.489	244	10.844	246.67	10.963	0.0004456
227	10.089	299	13.289	258	11.467	261.33	11.615	0.0004752
241	10.711	318	14.133	271	12.044	276.67	12.296	0.0005066
257	11.422	336	14.933	288	12.800	293.67	13.052	0.0005421

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

271	12.044	352	15.644	304	13.511	309.00	13.733	0.0005747
285	12.667	367	16.311	327	14.533	326.33	14.504	0.0006123
293	13.022	387	17.200	336	14.933	338.67	15.052	0.0006395
310	13.778	403	17.911	349	15.511	354.00	15.733	0.000674
322	14.311	419	18.622	362	16.089	367.67	16.341	0.0007054
337	14.978	437	19.422	376	16.711	383.33	17.037	0.0007422
348	15.467	451	20.044	387	17.200	395.33	17.570	0.0007709
362	16.089	466	20.711	399	17.733	409.00	18.178	0.0008044
372	16.533	485	21.556	414	18.400	423.67	18.830	0.0008413
383	17.022	497	22.089	426	18.933	435.33	19.348	0.0008712
396	17.600	512	22.756	448	19.911	452.00	20.089	0.0009153
406	18.044	523	23.244	464	20.622	464.33	20.637	0.0009489
415	18.444	536	23.822	477	21.200	476.00	21.156	0.0009816
426	18.933	547	24.311	491	21.822	488.00	21.689	0.0010161
434	19.289	556	24.711	503	22.356	497.67	22.119	0.0010447
449	19.956	568	25.244	519	23.067	512.00	22.756	0.0010886
458	20.356	579	25.733	531	23.600	522.67	23.230	0.0011225
470	20.889	591	26.267	549	24.400	536.67	23.852	0.0011687
482	21.422	598	26.578	563	25.022	547.67	24.341	0.0012068
488	21.689	609	27.067	572	25.422	556.33	24.726	0.0012379
496	22.044	617	27.422	579	25.733	564.00	25.067	0.0012664
505	22.444	623	27.689	588	26.133	572.00	25.422	0.0012973
518	23.022	632	28.089	599	26.622	583.00	25.911	0.0013419

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

532	23.644	638	28.356	606	26.933	592.00	26.311	0.0013805
541	24.044	644	28.622	618	27.467	601.00	26.711	0.0014215
567	25.200	649	28.844	629	27.956	615.00	27.333	0.0014913
579	25.733	653	29.022	637	28.311	623.00	27.689	0.0015356
588	26.133	657	29.200	645	28.667	630.00	28.000	0.0015779
599	26.622	661	29.378	648	28.800	636.00	28.267	0.0016178
607	26.978	664	29.511	655	29.111	642.00	28.533	0.001662
620	27.556	669	29.733	659	29.289	649.33	28.859	0.0017254
635	28.222	670	29.778	662	29.422	655.67	29.141	0.0017956
644	28.622	675	30.000	668	29.689	662.33	29.437	0.0019231
644.79	28.657	675.99	30.044	668.89	29.728	663.22	29.477	0.0019895
642	28.533	670	29.778	654	29.067	655.33	29.126	0.0022253
619	27.511	665	29.556	641	28.489	641.67	28.519	0.002381
597	26.533	651	28.933	620	27.556	622.67	27.674	0.0025289
572	25.422	645	28.667	595	26.444	604.00	26.844	0.0026437

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

Table 10: Stress and strain result from the 28th-day 0.6%GF average load.

Load (KN)	Stress (Mpa)	28 th day 0.6%GF				Average Load	Average Stress	Average Strain
		Pu-1	σ -1	Pu-2	σ -2			
0	0	0	0	0	0	0	0	0
20	0.889	19	0.844	20	0.889	19.67	0.874	0.000033
34	1.511	25	1.111	33	1.467	30.67	1.363	0.0000517
51	2.267	37	1.644	43	1.911	43.67	1.941	0.0000739
68	3.022	44	1.956	59	2.622	57.00	2.533	0.0000968
83	3.689	56	2.489	73	3.244	70.67	3.141	0.0001206
97	4.311	65	2.889	88	3.911	83.33	3.704	0.0001428
117	5.200	77	3.422	99	4.400	97.67	4.341	0.0001682
134	5.956	89	3.956	113	5.022	112.00	4.978	0.0001938
156	6.933	103	4.578	126	5.600	128.33	5.704	0.0002234
177	7.867	114	5.067	139	6.178	143.33	6.370	0.0002509
195	8.667	128	5.689	156	6.933	159.67	7.096	0.0002812
215	9.556	152	6.756	171	7.600	179.33	7.970	0.0003182
231	10.267	180	8.000	186	8.267	199.00	8.844	0.0003558
253	11.244	195	8.667	207	9.200	218.33	9.704	0.0003936
277	12.311	210	9.333	221	9.822	236.00	10.489	0.0004286
294	13.067	224	9.956	238	10.578	252.00	11.200	0.0004609
314	13.956	251	11.156	257	11.422	274.00	12.178	0.0005061
338	15.022	277	12.311	277	12.311	297.33	13.215	0.0005554

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

357	15.867	292	12.978	295	13.111	314.67	13.985	0.0005928
374	16.622	305	13.556	313	13.911	330.67	14.696	0.0006281
392	17.422	319	14.178	333	14.800	348.00	15.467	0.0006671
410	18.222	331	14.711	354	15.733	365.00	16.222	0.0007064
426	18.933	344	15.289	373	16.578	381.00	16.933	0.0007442
442	19.644	357	15.867	383	17.022	394.00	17.511	0.0007756
461	20.489	370	16.444	407	18.089	412.67	18.341	0.000822
478	21.244	383	17.022	424	18.844	428.33	19.037	0.0008621
498	22.133	398	17.689	440	19.556	445.33	19.793	0.000907
513	22.800	410	18.222	458	20.356	460.33	20.459	0.0009479
529	23.511	427	18.978	472	20.978	476.00	21.156	0.0009922
545	24.222	447	19.867	485	21.556	492.33	21.881	0.0010402
558	24.800	465	20.667	503	22.356	508.67	22.607	0.0010904
574	25.511	487	21.644	517	22.978	526.00	23.378	0.0011464
587	26.089	498	22.133	529	23.511	538.00	23.911	0.0011872
607	26.978	507	22.533	544	24.178	552.67	24.563	0.0012396
614	27.289	514	22.844	547	24.311	558.33	24.815	0.0012608
625	27.778	525	23.333	567	25.200	572.33	25.437	0.0013155
637	28.311	538	23.911	583	25.911	586.00	26.044	0.0013731
646	28.711	569	25.289	592	26.311	602.33	26.770	0.0014491
654	29.067	581	25.822	599	26.622	611.33	27.170	0.0014955
663	29.467	597	26.533	610	27.111	623.33	27.704	0.0015646
669	29.733	608	27.022	616	27.378	631.00	28.044	0.0016148

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

675	30.000	617	27.422	622	27.644	638.00	28.356	0.0016672
679	30.178	626	27.822	629	27.956	644.67	28.652	0.001726
681	30.267	632	28.089	656	29.156	656.33	29.170	0.0018912
682	30.311	632.4	28.107	660	29.333	658.13	29.250	0.001985
680	30.222	625	27.778	630	28.000	645.00	28.667	0.0022972
676	30.044	600	26.667	613	27.244	629.67	27.985	0.0024447
667	29.644	587	26.089	601	26.711	618.33	27.481	0.0025293
637	28.311	570	25.333	589	26.178	598.67	26.607	0.002652
606	26.933	545	24.222	569	25.289	573.33	25.481	0.0027841

Appendix-D: Stress-Strain Relationship Curve from Compression Test

D-1: Stress-strain relationship curve on 7th and 28th-day average compressive load.

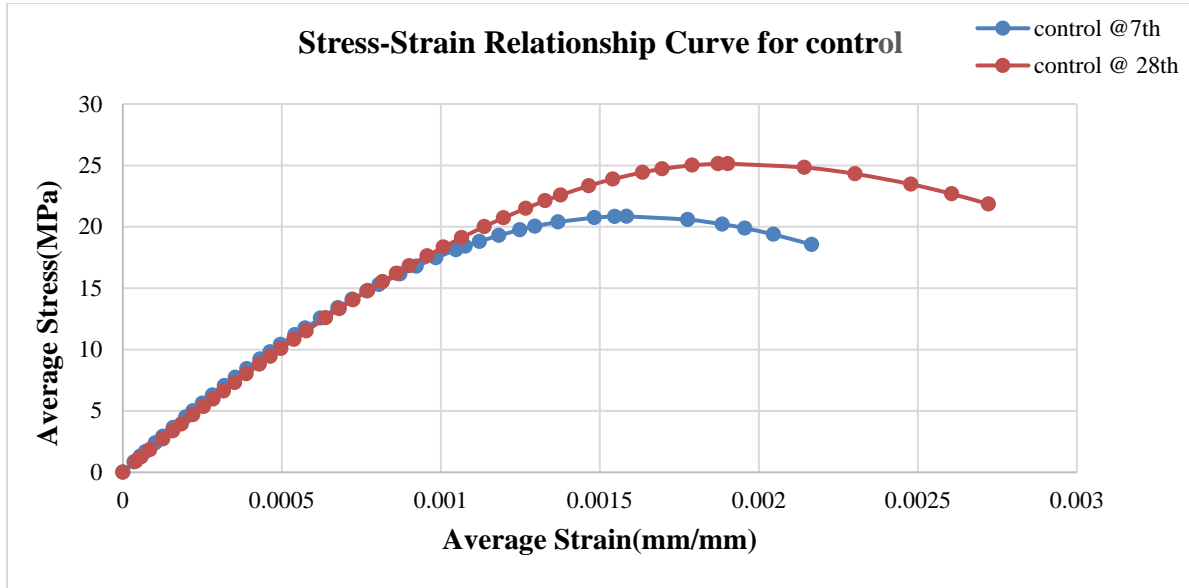


Figure D-1: Stress-Strain relationship curve for control on the 7th and 28th day

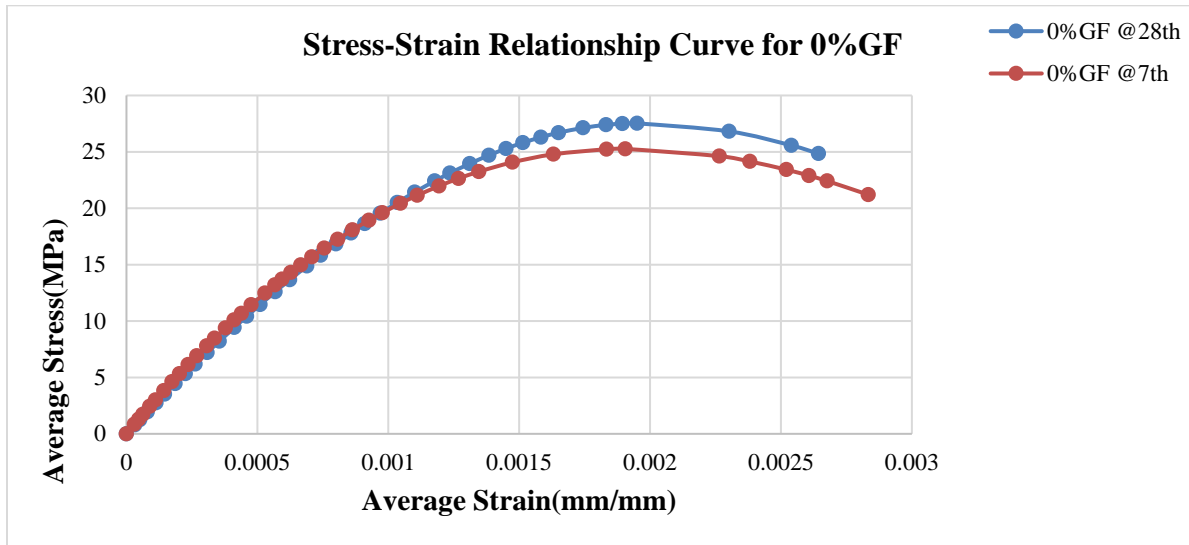


Figure D-2: Stress-Strain relationship curve for 0%GF on the 7th and 28th day.

**FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE
BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER
MONOTONIC LOAD**

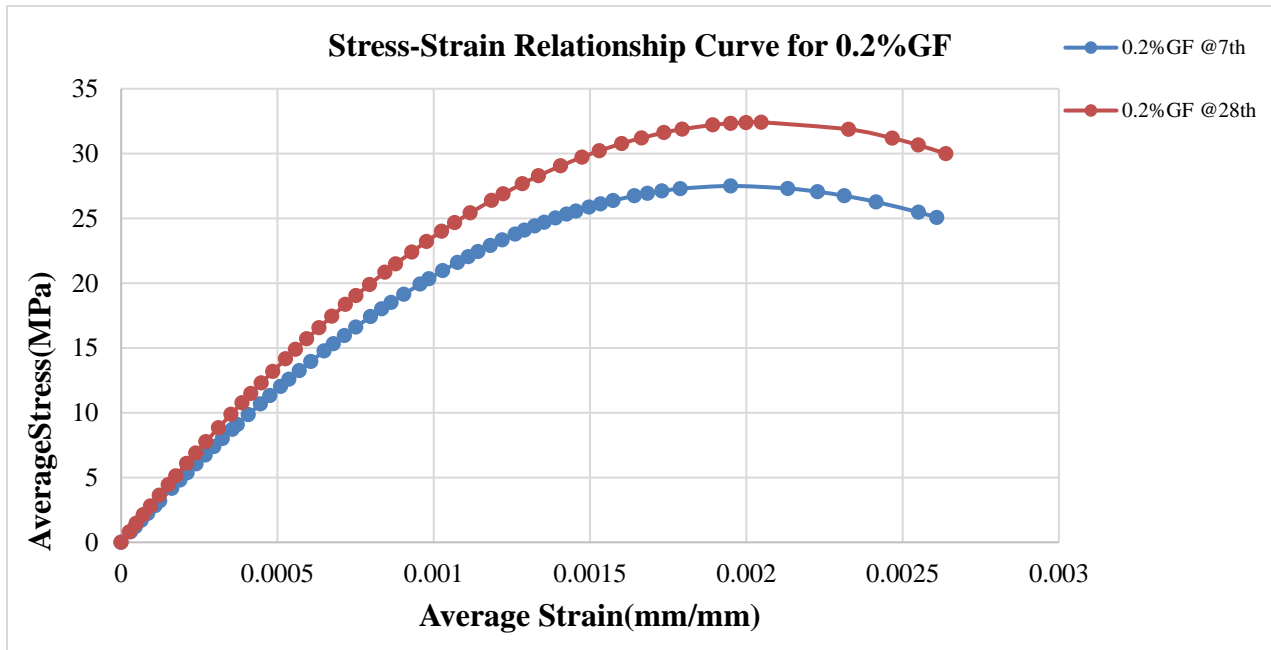


Figure D-3: Stress-Strain relationship curve for 0.2%GF on the 7th and 28th day.

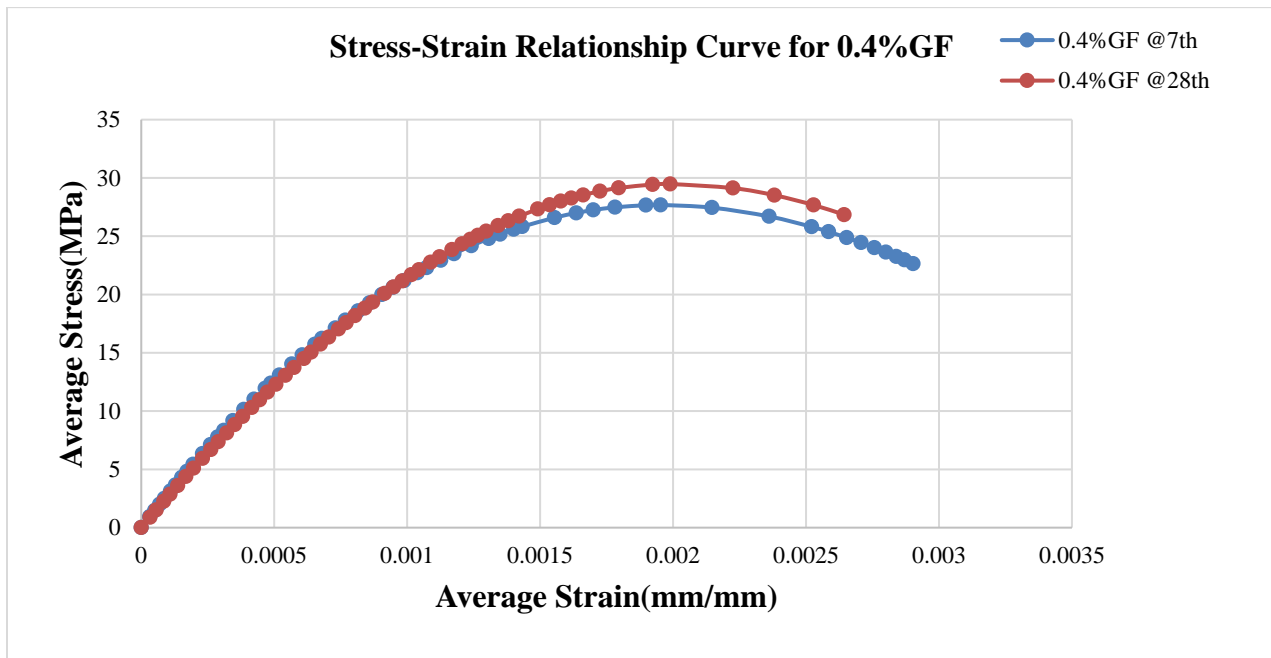


Figure D-4: Stress-Strain relationship curve for 0.4%GF on the 7th and 28th day.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

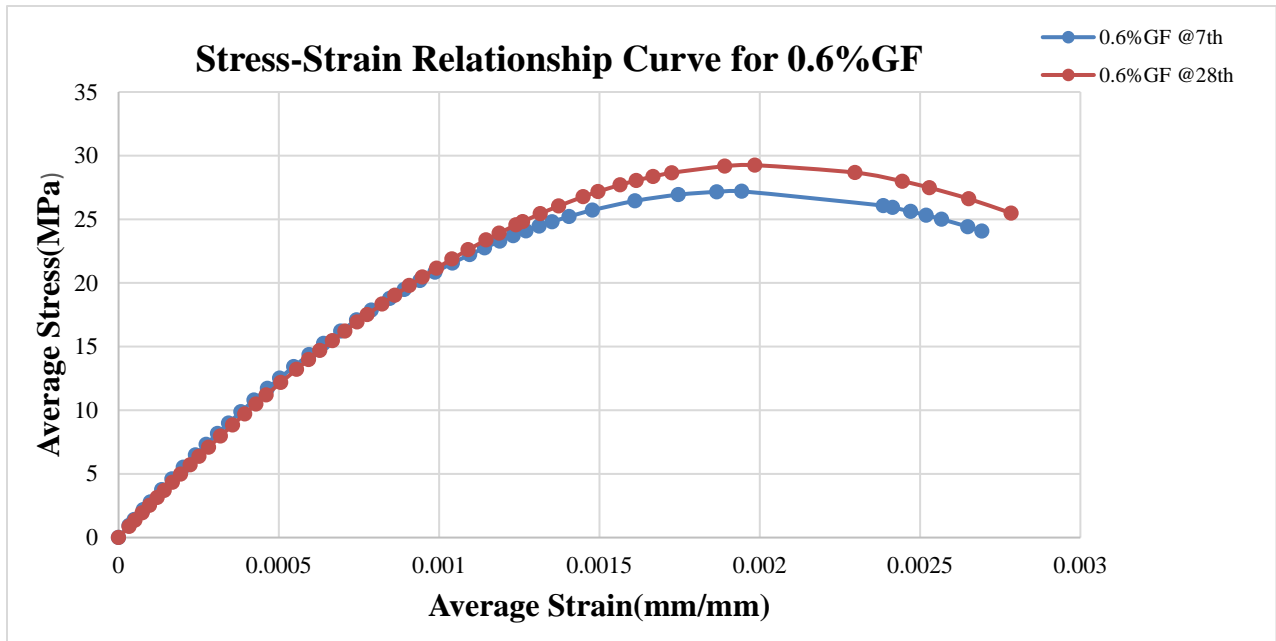


Figure D-5: Stress-Strain relationship curve for 0.6% GF on the 7th and 28th day.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD

Appendix-E: Photos Taken During Laboratory Test



Figure E-1: Photos captured during the test for normal consistency and setting time.



Figure E-2: Photos captured during the test for coarse aggregate physical properties.



Figure E-3: Photos captured during the dry mix and wet concrete in a mixer.

FLEXURAL STRENGTH OF FIBER REINFORCED ALKALI-ACTIVATED CONCRETE BEAM MADE FROM LOCALLY AVAILABLE CEMENTITIOUS MATERIAL UNDER MONOTONIC LOAD



Figure E-4: Photos captured during mold painting and compacting concrete.

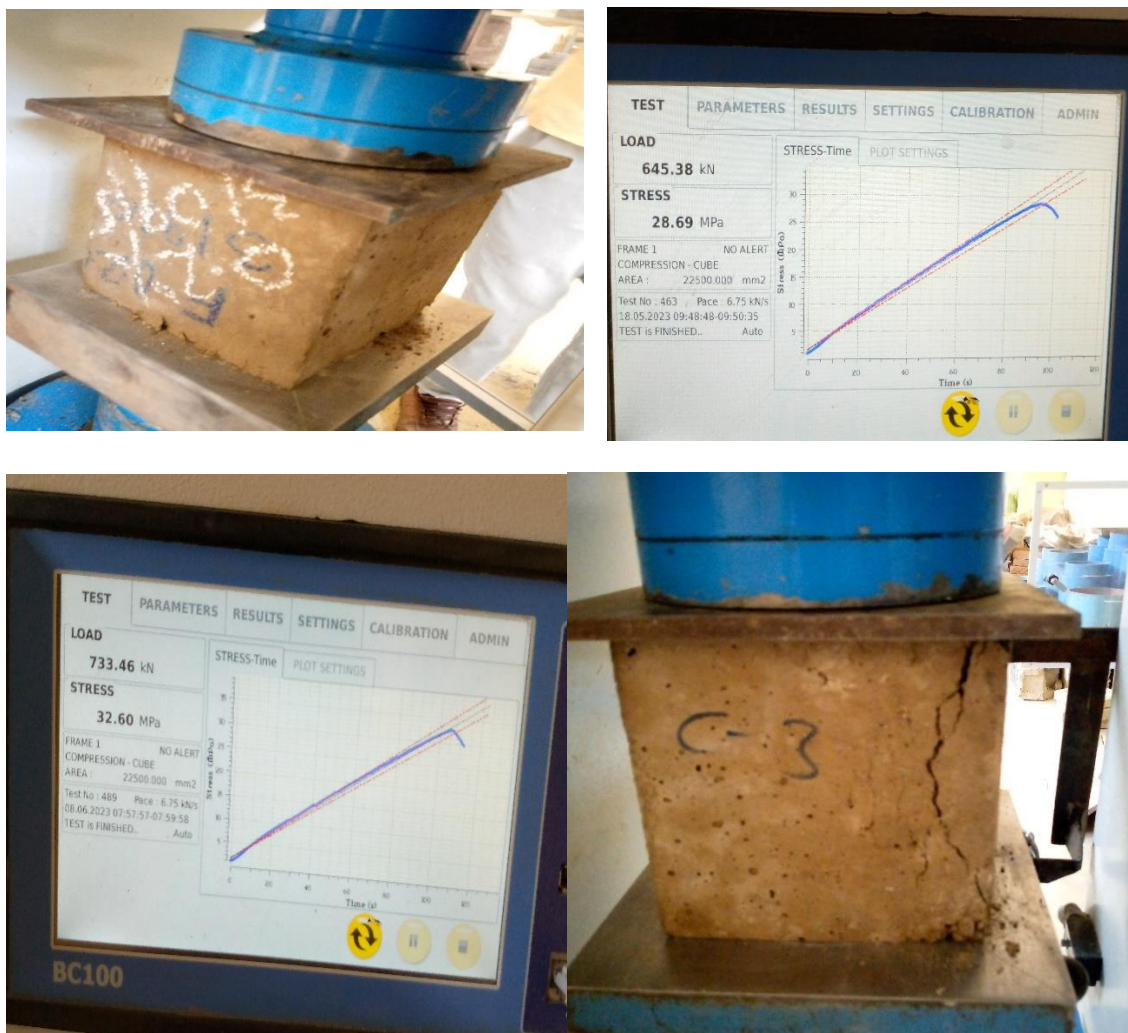


Figure E-5: Photos captured during testing of cube specimen concrete.