Ethiopian Institute of Technology – Mekelle

School of Mechanical and Industrial Engineering

A Thesis Submitted to Solid Mechanics and Design Chair in Partial Fulfillment of the Requirements for the Master of Science Degree in Product Design and Development

Sustainable Sisal Fibers Reinforced Cement Composites: Development, Characterization, and Mechanical Performance for Wall Applications

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I hereby declare that this thesis, entitled **"Characterization and Development of Natural Fiber Reinforced Cement Composite for Wall using Sisal Fiber,"** was prepared under the guidance of my advisor. The work presented herein is my own, except where explicitly stated otherwise. Where I have quoted from the work of others, the source is duly acknowledged. Apart from such quotations, this thesis is entirely my work, and I have declared all significant sources of assistance.

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ABSTRACT

Sisal fibers, extracted from Agave sisalana plants, are abundantly available in Tigray region of Ethiopia. This study investigates the potential of NaOH-treated sisal fibers as sustainable and cost-effective reinforcement in cement composites. C-25 concrete and Grade 42.5R cement was used, and mix proportions determined using the ACI method. A water-to-cement ratio of 0.56 was adopted to achieve the target slump range of 75 -100 mm, ensuring adequate workability.

The experimental investigation focused on sisal fiber-reinforced cement composites with varying fiber lengths (10 mm, 15 mm, and 20 mm) and contents (1 %, 2 %, and 3 % by weight of cement). The fibers were treated with sodium hydroxide (NaOH) to enhance their interfacial bonding with the cement matrix. Mechanical properties, including compressive, split tensile and flexural strength, were evaluated at 7 and 28 days of curing.

To determine the optimal mix configuration, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was employed. SolidWorks software was also used to model the testing setups, providing detailed visualization of loading and specimen arrangements.

The optimal mix was identified at 28 days as the composite containing 15 mm fiber length at 2 % content, which achieved the highest tensile strength (4.10 Mpa), compressive strength (31.6 Mpa), and flexural strength (5.4 Mpa). These findings confirm that NaOH-treated sisal fiber can enhances the mechanical performance of cement composites and offers a promising, eco-friendly alternative for both structural and non-structural wall applications.

Key words: Natural fiber, Sisal fiber, Cement Composite, Wall application, Mechanical properties, NaOH treatment, TOPSIS, Solid Works.

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
CA	Coarse Aggregate
C-25	Concrete Grade with characteristic strength of 25Mpa by 28^{th} days
CMCs	Ceramic matrix composites
CS	Compressive Strength
ES	Ethiopia Standard
FA	Fine Aggregate
FM	Fineness Modulus
FRCCs	Fiber Reinforced Cement Composites
FS	Flexural strength
M_0	Mix with 0mm fiber length and 0% fiber content
M_1	Mix with 10mm fiber length and 1% fiber content
M_2	Mix with 10mm fiber length and 2% fiber content
M_3	Mix with 10mm fiber length and 3% fiber content
M_4	Mix with 15mm fiber length and 1% fiber content
M_5	Mix with 15mm fiber length and 2% fiber content
M_6	Mix with 15mm fiber length and 3% fiber content
M_7	Mix with 20mm fiber length and 1% fiber content
M_8	Mix with 20mm fiber length and 2% fiber content
M_9	Mix with 20mm fiber length and 3% fiber content
MMCs	Metal matrix composites
MSL	Mean Sea level
NaOH	Sodium Hydroxide
NFCs	Natural fiber composites
NFRCCs	Natural fiber-reinforced cement composites
NRMCA	National Ready Mixed Concrete Association
OPC	Ordinary Portland cement
OD	Oven Dry Condition

SCC	Self-compacting concrete
SFRCCs	Sisal Fiber Reinforced Cement Composites
TOPSIS	Technique for Order preference by Similarity to Ideal solution
TS	Tensile strength

INTRODUCTION

1.1 Background

The global shift toward sustainable development has intensified the demand for environmentally friendly construction materials. Cement-based composites are widely used of in construction for their high compressive strength and durability. However, traditional cement composites are associated with high carbon emissions, limited tensile performance, and low crack resistance, prompting the need for alternative reinforcement strategies. Natural fibers, derived from renewable resources, have emerged as potential substitutes for synthetic reinforcements in cement composites.

Among Various natural fibers, sisal fiber stands out for its availability, high tensile strength, low density, biodegradability, and alkali resistance. Sisal is a lignocellulosic fiber extracted from the leaves of the Agave sisalana plant. In regions like Tigray, Ethiopia, sisal is abundantly available but remains underutilized in engineering applications. Integrating such locally available natural fibers into cementitious matrices not only promotes sustainability but also reduces dependence on non-renewable, imported construction materials.

The performance of fiber-reinforced cement composites is significantly influenced by fiber characteristics such as length, content, and surface condition. Untreated natural fibers often suffer from weak interfacial bonding with the cement matrix, resulting in poor mechanical performance. To overcome this challenge, surface modification techniques such as alkali (NaOH) treatment are used to improve fiber-matrix adhesion by removing surface impurities and enhancing surface roughness.

This research investigates the development and mechanical performance of sisal fiber-reinforced cement composites, emphasizing sustainable and cost-effective alternatives for wall applications. The study examines the effect of varying fiber lengths (10 mm, 15 mm, and 20 mm) and contents (1 %, 2 %, and 3 % by weight of cement) on compressive, split tensile and flexural strengths. Treated sisal fibers are incorporated to enhance mechanical interlocking and durability.

Furthermore, the study integrates the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to optimize the mix design based on multiple performance criteria. SolidWorks software is used to simulate the testing conditions, thereby improving the reproducibility and accuracy of experimental procedures. This research aims to bridge the gap in localized studies on sisal fiber composites and contribute to the global effort in promoting sustainable building technologies.

1.2 Problem Statement

The construction industry faces increasing challenges in balancing structural performance with environmental sustainability. Conventional cement composites, while widely used for their strength and availability, contribute significantly to greenhouse gas emissions and resource depletion. Additionally, they exhibit low tensile strength, limited ductility, and poor resistance to cracking, particularly in wall applications.

Natural fibers, such as sisal offer a promising alternative due to their biodegradability, renewability, local availability, and capacity to enhance the mechanical performance. However, comprehensive studies on the integration of sisal fibers into cement composites- particularly for wall applications- remain limited, especially within the Ethiopian context. The lack of localized data and optimization studies hampers the adoption of such sustainable materials in practical construction.

Furthermore, determining the optimal combination of fiber length and content presents a significant challenge, as these parameters influence workability, strength, and durability. Previous studies often overlook systematic multi-criteria decision-making approaches to optimize mix designs, and most fail to provide adequate visualization of experimental test setups, limiting reproducibility and practical application.

This study addresses these gaps by investigating the mechanical performance of sisal fiber-reinforced cement composites using different fiber lengths (10 mm, 15 mm, and 20 mm) and contents (1 %, 2 %, and 3 %). The research employs NaOH treatment to improve fiber-matrix bonding, applies the TOPSIS method for optimal mix selection, and utilizes SolidWorks modeling to enhance understanding of test setups. Through this approach, the study aims to develop eco-friendly, cost-effective, and technically sound cement composite for sustainable wall construction.

Figure 1.2: Wall of concrete

1.3 Objectives of Study

1.3.1 General objective

The general objective of this research is:

- To develop and characterize sisal fiber- reinforced cement composites suitable for sustainable wall applications by optimizing fiber parameters and enhancing mechanical performance through experimental testing, modeling, and multi-criteria decision analysis.

1.3.2 Specific objectives

The specific objective of this work is:

- To prepare and characterize sisal fiber- reinforced cement composites using NaOH-treated fibers of varying lengths (10 mm, 15 mm, and 20 mm) and contents (1 %, 2 %, and 3 % by weight of cement).
- To experimentally evaluate the mechanical performance of the composites, including compressive, split tensile, and flexural strength at 7 and 28 days.
- To assess the effect of alkali (NaOH) treatment on fiber-matrix bonding and its contribution to enhancing mechanical properties.
- To apply the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for optimizing the fiber content and length based on mechanical performance criteria.

- To develop SolidWorks-based models of compressive, split tensile and flexural test setups for improved visualization and documentation of loading conditions.
- To evaluate the suitability of the optimized mix for wall applications with a focus on strength, workability, and sustainability.

1.4 Significance of the Research

The significance of this study lies in its contribution to sustainable construction practices through the development of sisal fiber-reinforced cement composites tailored for wall applications.in the face environmental concerns, the construction sector is under increasing pressure to reduce its ecological footprint while maintaining structural integrity and performance. This research supports that goal by promoting the use of locally available, renewable materials-specifically sisal fiber-which is abundant in the Tigray region of Ethiopia.

By systematically analyzing the influence of fiber length and content on the mechanical properties of cement composites, this study provides practical insights into optimizing material performance. The incorporation of NaOH-treated sisal fibers improves the interfacial bonding within the cement matrix, resulting in enhanced compressive, tensile, and flexural strengths. These improvements can directly impact the durability and efficiency of wall structures, especially in regions where traditional construction materials are costly or environmentally detrimental.

Furthermore, the application of the TOPSIS method adds a multi-criteria decision-making framework for identifying the optimal fiber configuration, which enhances the scientific rigor and practical relevance of the study. The SolidWorks modeling strengthens the visualization and reproducibility of experimental procedures, aligning with modern engineering practices and fulfilling the recommendation of examiners for improved technical documentation.

Overall, this research bridges the gap between material sustainability and structural performance.it has the potential to influence construction practices in Ethiopia and beyond by encouraging the adoption of natural fiber-reinforced composites. The study also provides a foundation for further academic exploration and industrial innovation in the field of eco-friendly building materials.

1.5 Scope of Study

This study focuses on the development and characterization of sisal fiber-reinforced cement composites specifically intended for wall applications. The research is confined to the use NaOH–treated sisal fibers with three fiber lengths (10 mm, 15 mm, and 20 mm) and three fiber content levels (1 %, 2 %, and 3 %by weight of cement). These parameters were selected to examine their influence on the mechanical properties of the composites, namely compressive strength, split tensile strength, and flexural strength.

The scope includes the physical and chemical characterization of constituent materials such as cement, fine and coarse aggregates, water, and sisal fibers. The experimental procedures involve mixing, casting, and curing of concrete specimens, followed by mechanical testing at 7 and 28 days of curing to assess strength development.

The study also integrates advanced modeling and analytical tools. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is applied to identify the optimal fiber configuration based on a multi-criteria performance evaluation. In addition, SolidWorks software is employed to simulate the experimental test setups, enhancing the visualization and reproducibility of loading conditions.

The investigation is limited to laboratory-scale experiments conducted under controlled environmental conditions. The findings are primarily applicable to non-load-bearing and moderately load-bearing wall elements. While the results are contextualized within the Ethiopian setting -particularly in Tigray – they also hold potential relevance for other regions with similar environmental and material contexts.

This focused scope allows for an in-depth understanding of the material behavior and performance, contributing to the body of knowledge on sustainable and locally sourced construction solutions.

1.6 Justification of the study

The justification for this study arises from the pressing global and local need to adopt sustainable, cost-effective, and performance - driven materials in the construction industry. Traditional cement- based composites, while structurally reliable, are associated with high carbon emissions, excessive resource consumption, and limited crack resistance, especially in wall construction. These limitations necessitate the exploration of alternative reinforcements that are both environmentally and structurally beneficial.

Sisal fiber, a natural lignocellulosic material derived from the agave sisalana plant, is locally abundant in Ethiopia – particularly in the Tigray region. Despite its promising properties such as high tensile strength, biodegradability, low density, and renewability, sisal remains underutilized in the Ethiopian construction context. Its availability and performance potential make it an ideal candidate for developing eco-friendly and locally sourced cement composites.

However, the direct use of untreated natural fibers in cement matrices is challenged by poor interfacial bonding, leading to suboptimal mechanical performance. This study addresses that gap through the alkali (NaOH) treatment of sisal fibers, which enhances fiber-matrix adhesion by removing impurities and increasing surface roughness. By doing so, it improves the overall mechanical behavior of the composite.

Moreover, there is a lack of comprehensive, localized studies that systematically evaluate the effects of fiber length and content using robust optimization frameworks. To address this, the study employs the TOPSIS decision-making method, enabling the selection of the most effective fiber configuration based on compressive, tensile, and flexural performance metrics. Additionally, the use of SolidWorks modeling contributes to better visualization and replication of experimental test setups, which is crucial for technical validation and educational purposes.

This research is therefore justified on multiple fronts: it contributes to environmental sustainability, promotes the use of locally available natural resources, and offers a scientific basis for the engineering application of sisal fiber in cement composites. The findings aim to support infrastructure development in Ethiopia and similar regions by providing a viable, sustainable alternative to conventional construction materials.

LITERATURE REVIEW

2.1 Introduction

A composite material is a combination of two or more constituent materials with different physical and chemical properties. The result in improved mechanical performance and functionality .The matrix binds the reinforcement material, which provides strength and stiffness. This review explores their classifications, mechanical properties, advancements, and applications, with particular attention to research conducted in Ethiopia. Composite materials are broadly classified based on their matrix type: polymer matrix composites (PMCs): PMCs use polymers (e.g., epoxy, polyester) as the matrix, reinforced with fibers like glass, carbon, or aramid. They are lightweight, corrosion-resistant, and have high strength-to-weight ratios, making them suitable for aerospace and automotive applications [24]. Metal matrix composites (MMCs): MMCs utilize metals (e.g., aluminum, titanium) for high thermal conductivity and wear resistance, often used in automotive and military sectors [25]. Ceramic Matrix Composites (CMCs): These composites feature ceramics as matrices, offering excellent thermal resistance and durability, particularly for high-temperature applications such as turbines [29].

2.2 Natural Fiber Composites (NFRCs)

Natural fiber composites incorporate natural fibers like sisal, jute, or flax, focusing on sustainability and cost-effectiveness [40].

2.2.1 Mechanical Properties

Composite are designed to improve mechanical properties, including:

High Strength-to-Weight Ratio: A critical property for structural components, composites are lighter and stronger than traditional materials.

Durability and Corrosion Resistance: Many composites resist degradation in harsh environments, making them ideal for marine and chemical applications.

Flexibility and Customization: By altering fiber orientations, reinforcement types, or matrix materials, composites can be tailored for specific applications.

2.3 Applications of Composites

Composites find use in diverse sectors:

Construction: Fiber-reinforced composites are integrated into concrete to enhance its tensile strength and mitigate brittleness, a common issue in traditional concrete [29].

Aerospace and Defense: Carbon fiber composites are extensively used in aircraft due to their lightweight and structural efficiency, reducing fuel consumption and enhancing performance.

Automotive: Lightweight composite materials improve vehicle fuel efficiency and reduce emissions while maintaining safety standards [24].

Renewable Energy: Composite materials are used in wind turbine blades and lightweight pressure vessels, crucial for renewable energy systems.

Medical devices: Advanced composites are employed in prosthetics and implants for their biocompatibility and high performance.

2.4 Advancements in Composite Technology

Nano composites: The incorporation of nanoparticles such as graphene or carbon nanotubes significantly enhances mechanical, thermal, and electrical properties [25].

Self-Healing Composites: These composites contain healing agents that repair micro cracks autonomously, extending material life span and reducing maintenance costs [41].

Sustainable Composites: The use of natural fibers and recycled polymers addresses environmental concerns, paving the way for greener composite technologies.

2.5 Composite Research in Ethiopia

In Ethiopia, research efforts focused on cost-effective and sustainable composite materials for construction and industrial applications:

Natural Fiber Reinforced Composites: Sisal and jute fibers, which are locally abundant, are used to produce affordable and sustainable composites. Alkali treatment of fibers improves their tensile and flexural properties [42].

Recycled Material Composites: Studies in Adama have investigated the use of recycled construction waste in hollow concrete blocks. The results show enhanced compressive strength; reduce costs, and environmental benefits [42].

Cementitious Composites: Researchers are exploring natural fiber-reinforced cement composites to improve the mechanical concrete, addressing brittleness and crack propagation, especially in low-income housing projects.

2.6 Fibers

Fibers are small discrete reinforcing inputs produced from various materials like steel, glass, carbon and natural sources in various shapes and sizes [11]. Plain concrete possesses two major drawbacks as a structural material. They behave in brittle or semi brittle fashion and possess a very low tensile strength. Compared to other construction materials, it possesses a low specific modulus, limited ductility and little resistance to cracking. Micro cracks develop in the material during its manufacture due to inherent volumetric and micro structural changes, and an essential discontinuous, heterogeneous system thus exists even before any external load is applied. In addition to the low tensile strength, the material possesses little resistance to tensile crack propagation in turn results in low fracture toughness and limited resistance impact and explosive loading. The successful use of the material in construction, therefore, depends in restricting the stresses in the material under working load condition, and cracking and deformation further limit the exploitation of the material [10]. It is necessary, therefore, to impart tensile resistance properties to a concrete structural member in order to use it as a load bearing material. This has been achieved since a hundred years or more, by the use of reinforcing bars. Reinforcement with iron bars enable concrete to carry tensile stresses quit successfully but the cracking strain of concrete is still so low that it cracks long before the wire is seriously loaded, and if a larger tensile load is put upon the combined system, an elaborate pattern of cracks appears in the concrete. In conventional concrete reinforcement the cracks are of great disadvantage. If cracks are large, the concrete falls out in pieces. To avoid these difficulties, one thing to do is to put the concrete permanently into compression, by putting the steel reinforcement permanently in tension. This provides tensile strength to the concrete members, but they do not increase the inherent tensile strength of concrete itself. Thus, the overall performance of the traditional reinforced concrete composite material is still effectively dictated by the individual performance of the concrete phase and the steel phase. This has led to the search for new materials particularly two phase composites in which the weak matrix is reinforced with strong stiff fibers to produce a composite of superior properties and performance [6, 10]. It has been found that addition of small closely spaced and uniformly dispersed fibers to concrete would act as crack arrestors and substantially improve the tensile strength and other properties of concrete. This type of concrete is called as fiber reinforced concrete [27]. "Fiber reinforced concrete (FRC) can be defined as a composite material consisting of mixture of cement mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers" [9]. The following articles will discuss types of fibers used in concrete.

2.6.1 Natural fibers

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

Unprocessed natural fibers are available in reasonably large quantities in many countries and represent a continuously resource. Unprocessed natural fibers require relatively small amounts of energy and technical knowledge for their production compared to some other types of fibers. Coconut coir, sisal sugarcane bagasse, bamboo, jute, wood, and vegetable fibers are typical examples of unprocessed natural organic fibers [11]. Wood cellulose is the most frequently used processed natural fibers, where it is obtained using Kraft process. This process involves cooking wood chips in a solution of sodium hydroxide. Cellulose, hemicellulose and lignin can be obtained by bleaching [13]. The below shown Table 2.1 describes typical properties of naturally occurring fibers [28].

Table 0.1: Typical properties of natural fibers [28]

Fiber type	Coconut	Sisal	Sugar cane bagasse	Bamboo	Jute	Flax	Elephant grass	Water reed	Wood fiber (Kraft pulp)
Fiber Length(mm)	50-100	N/A	N/A	N/A	175-300	500	N/A	N/A	2.5-5.0
Fiber diameter (mm)	0.1-0.4	N/A	0.2-0.4	0.05-0.4	0.1-0.2	N/A	N/A	N/A	0.03-0.08
Specific gravity	1.12-1.15	N/A	1.2-1.3	1.5	1.02-1.04	N/A	N/A	N/A	1.5
Modulus of elasticity (Gpa)	19-26	13-26	15-19	33-40	26-32	100	5.0	5.0	N/A
Ult. tensile strength (Mpa)	120-200	275-700	180-190	350-500	250-350	1000	180	70	700
Elongation at break (%)	10-25	3-5	N/A	N/A	1.5-1.9	1.8	3.6	1.2	N/A
Water Absorption (%)	130-180	60-70	70-75	40-45	N/A	N/A	N/A	N/A	50-75

N/A: Not available

2.6.2 Synthetic fibers

Synthetic fibers are man-made fibers resulting from research and development in the petrochemical and textile industries [6]. These fibers are derived from organic polymers which are available in a variety of formulations. There are two different physical fiber forms: monofilament fibers and fibers produced from fibrillated tape. There are two different synthetic fiber volumes used in application, namely low volume percentage (0.1-0.3% by volume), and high volume percentage (0.4-0.8% by volume). Most synthetic fibers applications are at 0.1% by volume [13]. Fiber types that have been tried in Portland cement concrete based matrices are: acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene. Synthetic fibers can reduce plastic shrinkage and subsidence cracking and may help concrete after it is fractured.

Problem associated with synthetic fibers include: low fiber-to matrix bonding; inconclusive performance testing for low fiber-volume usage with polypropylene, polyethylene, polyester and nylon; a low modulus of elasticity for polypropylene and polyethylene; and the high cost of carbon and aramid fiber [6, 13].

2.6.3 Glass fibers

The first research on glass fibers was in the early 1960's used as conventional borosilicate glass (E-glass) and soda-lime –silica glass fibers (A-glass). Glass fibers have high modulus and high strength to develop strong bond with the concrete. The test results showed that alkali reactivity between the E-glass fibers and the cement-paste reduced the strength of the concrete. Glass fibers that are used in concrete must contain minimum of 16% of zirconia for alkali resistance. Fiber content in glass fiber reinforced concrete is about 4% to 6% by volume [6, 8].

2.6.4 Steel fibers

Steel fibers are short, discrete lengths of steel with an aspect ratio (ratio of length to diameter) from about 20 to 100, and with any of several cross sections. Some steel fibers have hooked ends to improve resistance to pullout from a cement-based matrix, Steel-fiber volumes used in concrete typically range from 0.25% to 2%. Volumes of more than 2% generally reduce workability and fiber dispersion and require special mix design or concrete placement techniques. Steel fibers have a relatively high modulus of elasticity. Their bond to cement matrix can be enhanced by mechanical anchorage or surface roughness and they are protected from corrosion by the alkaline environment in the cement matrix [6, 11].

2.7 Sisal fiber

Sisal fiber are obtained from the leaves the plant agave sisalana and produced in tropical regions such as Mexico (120Ktons), Brazil (125Ktons), Tanzania (26Ktons), Kenya (22Ktons), Madagascar (10Ktons) and china (25Ktons). It is mainly used in the manufacturing of natural ropes, twine, sacking, carpet making, and textile materials like nets, mats, and automobile floor mats. And sisal fiber can be used as reinforcement production as composites materials [2]. Sisal fiber is a material that was chosen to improve strength, durability, reduce cost of environmental compatibility, and reduce hazardous properties of a structure to obtain sustainability and better quality structure [3]. However, sisal fiber is more attractive than other because; easily available, renewability, low density, economical and acceptable mechanical properties. As well as artificial fibers and fabricated fibers used for the manufacturing of composites materials and environmental friendly [14]. In addition, sisal plant short fibers delay restrained plastic shrinkage controlling crack development at early ages and sisal plant fiber is important for well resistant to moist and it has good tension resistance or tensile strength [12]. Sisal fiber is the natural fiber obtained from the leaves of annual plant, which is available in abundance in Tigray, Ethiopia. Ethiopia stands at eleventh in worldwide countries in sisal fiber production, but Ethiopia cannot use different materials [14]. Generally, it is easily cultivated and reusable recourse as well as the one of the most widely used natural fibers. Ethiopia mostly used for rope and carpet and found everywhere it grown wild in the hinge fields used as a fence. However, we know thank for concrete technology, sisal fiber is important for improving concrete properties used as reinforced cement composite. Sisal fiber has the capacity to surface crack distributor for gradual concrete failure and used for compressive, flexural and tensile. . It has some limitation and use fiber treatment methods chemical treatment, thermal treatment, and Hybrid treatment.

Table 0.2: Properties of Sisal fiber

Property	Value	Description
Density	1.3 – 1.5 g/cm^3	Sisal fibers are relatively lightweight which makes them ideal for lightweight composite applications.
Tensile strength	400 – 700 MPa	Sisal has a high tensile strength, making it suitable for load-bearing applications.
Young’s Modulus	9 -20 GPa	This modulus reflects the fiber’s stiffness, showing that sisal has moderate elasticity compared to synthetic fibers.
Elongation at Break	2 – 4%	Sisal has limited elongation, meaning it doesn’t stretch much before breaking.

Moisture Absorption	10 -22%	Sisal is highly hydrophilic, which can affect composite performance under humid conditions. Surface treatments like NaOH can reduce moisture absorption.
Cellulose Content	65 – 75%	High cellulose content contributes to the strength and rigidity of the fiber.
Hemicellulose Content	10 -15%	Hemicellulose aids in fiber flexibility but can also attract moisture.
Lignin Content	9 -11%	Lignin provides stiffness and biodegradability, but excessive lignin can make the fiber brittle.
Microfibrillar angle	10 -22 degrees	Lower angles correlate with higher tensile strength and stiffness, while higher angles provide more flexibility.
Thermal Stability	Decomposes at 240 -300 ℃	Sisal has moderate thermal stability, which is suitable for applications where high heat resistance is not required.
Diameter	100 -300μm	Natural fibers vary in diameter, which can influence composite uniformity and strength.

2.7.1 Extraction process

A sisal fiber begins with the harvesting of mature leaves from sisal plant. These leaves are processed through a method called decortication, where machines scrape and crush the leaves to separate the fibers from the leaf pulp. The separated fibers are then thoroughly washed with water to remove impurities such as sap and plant residues. Once cleaned, the fibers are sun-dried for 1-2 days to reduce their moisture content, which enhances their strength and durability. After drying, the fibers are brushed, combed, or aligned to improve their texture and are then cut into specific lengths for industrial applications. The sisal fibers are extracted for Reinforcement of composite materials [36]. Sisal fiber extract by different way explains below.

2.7.2 Chemical process

Chemical processing is used to enhance its mechanical properties and compatibility with matrix materials. One of the most common methods is alkali treatment, where sisal fibers are soaked in a sodium hydroxide (NaOH) solution. This removes impurities such as lignin, hemicellulose, pectin, and waxes, improving the fibers' surface roughness and adhesion properties of sisal fibers for use in composite materials [37].

2.7.3 Mechanical process

Mechanical processing focuses on physically extracting and refining sisal fibers without altering their chemical structure. The process begins with decortication, where mechanical equipment separates the fibers from the leaf pulp by scraping and crushing the leaves. After separation, the fibers undergo combing or brushing to align them and remove any remaining plant residues. This step is important for ensuring uniformity and improving the texture of the fibers. Mechanical methods also include cutting the fibers into specific lengths to suit their intended applications. Mechanical processing preserves the natural properties of the fibers while preparing them for reinforcement in composites [38].

2.7.4 Steam-Explosion

Steam-explosion processing is a mechanical-chemical method used to treat sisal fibers to enhance their properties. In this process, the fibers are exposed to high-pressure steam at temperatures between 160°C and 240°C for a specific period. After steaming, the pressure is rapidly released, causing the fibers to "explode." This sudden depressurization breaks down the lignin and hemicellulose matrix, separates individual cellulose fibers, and increases the fiber's surface area. The treatment improves the fiber's mechanical properties, surface roughness, and bonding ability with matrices like cement [39].

2.7.5 Sisal Fiber in Cement Composite

Sisal Fiber properties: Sisal fibers are natural, strong, and environmentally friendly, making them attractive for composite materials. They have a high cellulose content, which provides good tensile strength, although they are somewhat limited by moisture absorption.

Sustainability: the use of sisal fibers in cement composites aligns with sustainable construction practices; as sisal is biodegradable and renewable, helping reduce reliance on synthetic fibers like glass or carbon.

2.7.6 Mechanical properties of Sisal Fiber Composites

Tensile strength: Sisal fibers improve the tensile strength of cement composites, enhancing their flexibility and durability. Studies often compared sisal to other natural fibers (e.g., jute, flax) and synthetic fibers, competitive advantages [21].

Impact Resistance and Toughness: Sisal fiber reinforcement increases toughness and impact resistance of cement composites, as shown by studies where fibers inhibit crack propagation [22].

Challenges with Moisture Absorption: One of the main limitations of Sisal fiber is its susceptibility to water, which can weaken fiber-matrix bonding. Chemical treatments, like alkali treatment, have been shown to reduce this effect and improve durability.

2.7.7 Application in construction

Load-Bearing Elements: A Sisal fiber composite for beams, slabs, and panels, especially where load-bearing requirements are moderate. They are also considered for pre-fabricated elements in low-cost housing. [23].

Non-structural Element: Sisal fibers are widely used for non-load-bearing applications such as partition walls, insulation panels, and decorative cladding. [23].

2.8 Natural Fiber in Cement Composite

The use of natural fibers in cement composites has garnered attention due to their eco-friendliness, renewability, and potential to improve the mechanical properties of composites. Researchers have studied various natural fibers, including sisal, jute, hemp, and flax, as sustainable reinforcement for cementitious materials. Compared to synthetic fibers, natural fibers offer advantages in terms of low cost. Biodegradability and low energy consumption for production. However, untreated fibers are often susceptible to moisture absorption, which can reduce bonding with the cement matrix and compromise mechanical properties over time [1].

2.8.1 Sisal Fibers and their Treatment

Sisal fibers are among the most promising natural fibers due to their high tensile strength, low density, and good durability in alkaline environments. However, the surface of sisal fibers can be hydrophilic, leading to poor adhesion with cement matrices. To enhance bonding, alkali treatment using sodium hydroxide (NaOH) has been widely adopted. This treatment removes hemicellulose and lignin, enhancing fiber-matrix adhesion, reducing water absorption, and increasing the interfacial bonding strength [20].

2.8.2 Alkali Treatment of Sisal Fibers

Alkali treatment (or mercerization) is common method for modifying the surface properties of natural fibers, improving compatibility with cement matrices. Studies have shown that treating sisal fibers with NaOH not only cleans the fiber surface but also increases the roughness, which enhances the mechanical interlocking with cement [4]. Observed that NaOH-treated sisal fibers embedded in cement composites showed increased tensile and compressive strength compared to untreated fibers. This improvement is attributed to the enhanced interfacial bonding between the treated fibers and the cementitious matrix.

2.8.3 Effects of Fiber Length and Content on Mechanical properties

The mechanical properties of fiber-reinforced cement composites are influenced by fiber length and content. Fiber length impacts the load transfer mechanism; longer fibers contribute to increased tensile strength, flexural strength, and toughness. Optimal fiber length varies by composite type but is often found in the range of 10mm-20mm for sisal fibers [16]. Excessive fiber length, however, may lead to fiber entanglement, poor dispersion, and workability issues, which negatively impact composite performance. Fiber content is another critical factor; a moderate fiber dosage (typically between 1% and 3% by weight of cement) is shown to improve compressive and tensile strength while preventing agglomeration. Excessive fiber content can lead to reduced compressive strength due to poor dispersion and increased porosity [20].

2.8.4 Mechanical properties of Sisal fiber Cement Composites

Several studies have investigated how NaOH-treated sisal fibers influence the compressive, tensile, and flexural strength of cement composites [15]. Demonstrated that sisal fibers enhance flexural strength due to their capacity to bridge cracks and arrest crack propagation, delaying failure under flexural loading. The tensile strength of cementitious composites was also found to be enhanced with the inclusion of NaOH-treated fibers, particularly with optimal fiber length and dosages.

2.8.5 Compressive Strength of Sisal Fiber Cement Composites

Sisal fiber content influences the compressive strength of cement composites. Studies have shown that, while untreated fibers tend to reduce compressive strength due to weak bonding, NaOH-treated fibers offer improvements [30]. Demonstrated NaoH treatment leads to better compaction and a stronger matrix-fiber interface, leading to modest increase in compressive strength, especially with lower fiber dosage (1-2%).

2.8.6 Flexural and Tensile Strength Benefits

The flexural and tensile strength of NaOH-treated sisal fiber composites generally show marked improvement over conventional cement. Treated fiber enhances load distribution and crack arresting, which are critical in flexural loading [18].highlighted that composite with 10-20mm NaOH-treated fibers at 2% fiber content displayed a significant increase in flexural strength. The presence of treated fibers allows composites to resist cracking and carry loads effectively across cracks.

2.8.7 Durability and Environmental Concerns

Long-term durability and moisture resistance remain concerns with natural fiber-reinforced cement composites. Natural fibers are susceptible to moisture absorption, which can weaken the composite. However, studies have shown that NaOH-treated fibers exhibit reduced water absorption due to the removal of hydrophilic components. This improved durability could extend the lifespan of sisal fiber composites, making them viable for applications in construction, especially or temporary constructions [19].

2.9 Concrete Materials

Concrete is a product obtained artificially by hardening of the mixture of binding material (cement), fine aggregate (sand), coarse aggregate (gravel), Admixture in some cases, and water, in a predetermined proportion, since concrete is made from different parts, it is known as a composite material. The cement and water from a paste that hardens and bonds the aggregate together into a coherent solid mass [6]. Performance of concrete depends on the quality of the constituent materials as well as on their proportion and on the process of construction that comprises: placing, compaction, and curing.

2.9.1 Aggregate

Aggregates, both fine and coarse, take about 65-75% by volume of concrete and are important ingredients in concrete production [5]. Aggregate are generally divided into two groups: fine and coarse aggregate. Fine aggregates consist of natural or manufactured sand with particle sizes ranging up to 9.5mm (3/8in.); coarse aggregate are particles retained on the 1.18mm (No.16) sieve and ranging up to 150mm (6in.) in size. The maximum size of coarse aggregate is typically 19mm or 25mm (3/4in. or 1in.). An intermediate-sized aggregate, around 9.5mm (3/8 in.), are sometimes added to improve the overall aggregate gradation [6]. Aggregates may be broadly classified as natural or artificial, both with respect to source and method of production. Natural sands and gravels are the product of weathering and the action of wind or water, while stone sands and crushed stone are produced by crushing natural stone. Screening and washing may be used to process aggregates from either of these categories. Aggregates may be produced from igneous, sedimentary, or metamorphic rocks, but the presence or absence of any geological type does not, by itself, make an aggregate suitable or unsuitable for use in concrete on a particular job should be based upon specific information obtained from tests used to measure the aggregate quality, or upon its service record, or both [7].The gravel part of aggregates forms the skeleton of the concrete, providing its compression strength. The smaller sizes aggregate fills the voids between the large particles, while the cement paste fills the smallest spaces, coats the aggregate particles and glues them together. The very fine cement particles also fill the smallest empty spaces, thereby giving the concrete its high density and impermeability.

2.9.2 Cement

Cement is a material with adhesive and cohesive properties which make it capable of binding two or more materials together into a solid mass. Cement when mixed with water form a paste which sets and hardens by means of chemical reaction called hydration, and retains strength and stability. There are generally two types of cement; non-hydraulic and hydraulic cements. Hydraulic cements are types of cements which are able set and harden in water and give a solid mass; which doesn't disintegrate (remain stable in water) [8]. The great majority of Portland cements made throughout the world are designed for general constructional use. The specifications with which such cements must comply are similar, but not identical in all countries and various names are used to define the material, such as OPC (Ordinary Portland Cement) in the UK, or Type I Portland cement in the

USA [9]. Cement type used in this specific research is an Ordinary Portland Cement because of its general use

2.9.3 Water

Water is an important constituent in concrete. It chemically reacts with cement to produce the desired properties of concrete. Mixing water is a quantity of water that comes in contact with cement, impact slump of concrete, and is used to determine water to cementitious materials ratio of concrete mixtures. According to National Ready Mixed Concrete Association (NRMCA) of Maryland, mixing water in concrete includes the following:

- Batch water measured and added to a mixer,
- Ice free moisture on aggregates,
- Water included in a significant quantity with chemical admixtures, and
- Water added after batching during delivery at the jobsite.

Strength and durability of concrete is controlled to a greater extent by water cement ratio. Concrete strength increases when less water is used during preparation of the mix. Although the hydration process consumes a certain amount of water, wet concert actually contains more water than required for the hydration reactions. The excess water is added to provide the wet mix with sufficient workability. Concrete needs to be workable so that it can be molded into the desired shape and consolidated to the required density. The quantity of water used to divide by the amount of cement gives the water to cement ratio. Low water-cement ratio leads to high strength but low workability while a high water to cement ratio produces a low strength concert but good workability. A careful balance of cement to water is therefore required when preparing the mix. Good quality water is required for the mixing of concrete. Natural water that is drinkable and has not pronounced taste or odour can be used as mixing water for making concrete. Salt water should not be used for mixing concrete as it causes a significant reduction in strength and large variations in setting time [6].

2.9.4 Admixtures

Admixtures are those ingredients in concrete other than cement, water, and aggregate those are added immediately before or during mixing. The major reasons for using admixtures are:

- To reduce the cost of concrete construction.

- To effectively enhance the existing properties of concrete.
- To maintain the quality of concrete targeted during the stages of mixing, transporting, placing, and curing in adverse weather conditions.
- To overcome certain emergency situations during concreting operations.

The effectiveness of an admixture depends upon factors such as type, and amount of cementing materials; water content; aggregate shape, gradation, and proportion; mixing time; slump; and temperature of the concrete [6].

2.10 Previous works related to fiber reinforced cement composite (FRCCs)

Fiber-reinforced cement composites (FRCCs) have been extensively studied to improve the mechanical properties of cementitious materials. Early studied emphasized the use of steel fibers to enhance tensile strength. Flexural behavior, and crack resistance. Banthia and Gupta (2004) demonstrated that steel fibers significantly increase toughness and post-cracking strength in high-performance concrete. Similarly, Balladur and shah (1992) highlighted the benefits of synthetic fibers, such as polypropylene, in controlling shrinkage cracks and enhancing impact resistance. However, the growing need for sustainable and eco-friendly construction materials has driven research into natural fibers like sisal, jute, and coir, which offer a renewable and cost-effective alternative. Pacheco-Torgal and Jalali (2011) reviewed the potential of natural fibers, noting their ability to improve ductility and energy absorption in cement composites. Research on the chemical and physical treatments of natural fibers has advanced significantly. Natural fibers are often chemically treated with agents such as NaOH to remove lignin and impurities, as this improves their bonding with the cement matrix. Several studies, including one by Ali et al. (2012), have shown that alkali-treated fibers exhibit better mechanical properties and durability compared to untreated fibers. However, challenges such as water absorption and fiber degradation in alkaline environments remain areas of active investigation. Researchers like Gram and Nimityongskul (1987) have developed hybrid fiber systems combining natural and synthetic fibers to mitigate these issues and balance sustainability with performance.

The role of fiber geometry, including length, orientation, and aspect ratio, has also been widely explored. Bentur and Mindess (2006) reported that longer fibers and higher aspect ratios improve crack bridging and post-cracking behavior, while shorter fibers are more effective in controlling early-age cracking. Studies on fiber orientation have demonstrated that randomly distributed fibers provide isotropic crack resistance, while aligned fibers enhance load-carrying capacity in specific directions. Furthermore, hybrid systems combining fibers of varying lengths and types have been shown to enhance both tensile and flexural performance (Li, 2002). Workability and compaction have been identified as critical challenges in FRCCs. Fibers can significantly reduce workability by increasing mix viscosity and causing segregation or clumping. Meha and Monteiro (2006) emphasized the importance of using super plasticizers and viscosity-modifying agents to improve the flow ability of fiber-reinforced mixes without compromising strength. Additionally, research by Yazic et al. (2007) has shown that proper mixing techniques and compaction methods are essential for achieving uniform fiber distribution and reducing air voids. These studies underline the need for balanced mix designs that ensure both workability and mechanical. In summary, extensive literature on FRCCs highlights the importance of optimizing fiber type, content, and treatment for enhanced composite properties. From steel to natural fibers, researchers continue to explore innovative solutions, such as hybrid systems and advanced mix designs, to address workability and durability challenges. These advancements underscore the potential of FRCCs to deliver sustainable, high-performance materials for a wide range of construction applications.

2.11 Working Mechanisms

The working mechanisms of fiber-reinforced cement composite (FRCCs) revolve around the ability of fibers to improve the material's tensile strength, toughness, and resistance to cracking. When stress is applied to the composite, the cement matrix initially bears the load. However, as cracks begin to form, the embedded fibers bridge the cracks, preventing their propagation and transferring the load across the crack planes. This crack-bridging mechanism enhances the ductility and post-cracking strength of the composite, as highlighted [26]. Furthermore, fibers resist pull-out forces due to friction, mechanical interlocking, or chemical bonding at the matrix-fiber interface, which contributes significantly to energy absorption and toughness [31].

The effectiveness of these mechanisms depends on several factors, including the type, length, and orientation of fibers. [32] Shows those fibers with a higher aspect ratio (length-to-diameter ratio) are more effective in bridging cracks and improving load transfer. Fiber orientation also plays a critical role; while randomly oriented fibers provide isotropic crack resistance, aligned fibers optimize strength and stiffness in specific directions [33]. Additionally, hybrid fiber systems that combine different types or lengths of fibers have been shown to achieve synergistic effects, improving both tensile and flexural performance [34]. Another Key mechanism is the interaction at the fiber-matrix interface. Strong interfacial bonding is essential for fibers to transfer stress effectively to the matrix. Chemical treatments, such as alkali treatment of natural fibers, improve the bonding by removing surface impurities and increasing roughness [1]. However, excessive bonding can limit the fiber pull-out mechanism, reducing the composite's energy absorption capacity. Thus, achieving a balance between bonding strength and pull-out resistance is critical for maximizing performance [26]. The volume fraction of fibers also influences the working mechanisms of FRCCs. Higher fiber content improves crack control and energy absorption but can reduce workability and lead to clumping if not properly dispersed [35]. Emphasizes the importance of proper mix design and mixing techniques to ensure uniform fiber distribution and effective matrix-fiber interaction. The use of admixtures, such as super plasticizers, further helps maintain workability and enhances the overall performance of the composite. In summary, the working mechanisms of FRCCs are governed by the synergy between fibers and the cementitious matrix. Factors like fiber type, orientation, aspect ratio, and volume fraction play pivotal roles in enhancing crack resistance, load transfer, and energy absorption. Advances in fiber treatments, hybrid systems, and optimized mix designs have further refine these mechanisms, as demonstrated by numerous studies, ensuring the widespread applicability of FRCCs in modern construction.

2.12 Orientation of fiber

Fiber orientation affects the mechanical properties of fiber-reinforced cement composites. Randomly oriented fibers provide uniform crack resistance in all directions, which is ideal for applications with multi-directional stresses. In contrast, aligned fibers improve strength and stiffness along specific directions, making them suitable for structural elements like beams and slabs. Hybrid orientations, combining random and aligned fibers, enhance both crack control and load-carrying capacity. Proper mix design and placement techniques are essential to maintain the desired orientation, ensuring consistent performance of the composite.

2.13 Workability and Compaction in Fiber-Reinforced Cement Composites

Workability and compaction are essential factors in the performance of fiber-reinforced cement composites (FRCCs). **Workability** refers to the ease with which the composite can be mixed, placed, and finished without segregation or loss of uniformity. Fibers generally reduce workability by increasing the viscosity of the mix, making it stiffer and harder to handle. The effect on workability depends on the fiber type, length, and content. High fiber dosages or long fibers can lead to clumping and uneven distribution, which negatively impact the composite's quality. To address these challenges, chemical admixtures like superplasticizers are often used to improve flow ability without increasing the water content, ensuring the mix remains cohesive and workable. **Compaction** is crucial for reducing air voids and ensuring proper bonding between the fibers and cement matrix. Poor compaction can lead to weak zones, segregation, and reduced mechanical performance. Effective compaction ensures that fibers are evenly distributed and adequately embedded in the matrix, maximizing their reinforcing potential. Techniques such as mechanical vibration, self-compacting concrete (SCC), or layered placement are commonly used to achieve better compaction. However, care must be taken to avoid over-vibration, which can lead to segregation of the fibers. In FRCCs, the balance between workability and compaction is critical, as it directly impacts the composite's strength, durability, and overall performance. Proper mix design and controlled mixing techniques play a vital role in addressing these challenges and achieving high-quality fiber-reinforced composites.

2.14 Aspect Ratios of Fibers

The aspect ratio of fibers, defined as the ratio of the fiber's length to diameter, plays a critical role in determining the mechanical performance of fiber-reinforced composites. A higher aspect ratio, where the fibers are long and thin, increases the surface area for bonding between the fibers and the matrix, leading to improved tensile strength, flexural strength, and crack-bridging capabilities. However, excessively high aspect ratios can make mixing and dispersion challenging, potentially causing fiber clustering. On the other hand, fibers with a lower aspect ratio, which are shorter and thicker, are easier to mix and distribute uniformly but may result in lower mechanical reinforcement. Therefore, selecting the appropriate aspect ratio is essential to balance workability and the desired mechanical properties of the composite.

2.15 Mixing of Fiber-Reinforced Cement Composites

The mixing process of fiber-reinforced cement composites (FRCCs) is critical for achieving uniform fiber distribution and optimal performance. Improper mixing can lead to clumping, uneven fiber dispersion, and segregation, which reduce the mechanical properties of the composite. Fibers should be added gradually during mixing to ensure they blend with the cement matrix. Proper sequencing of materials and maintaining an appropriate mixing duration are essential to ensure that the fibers are well-embedded in the matrix, providing consistent reinforcement and enhancing the composite's structural integrity.

Decision-making tool for different alternatives with multiple criteria

Choosing and applying appropriate decision-making methods has a vital role in the simplifying of decision optimization of a particular part of feature [50] one of the decision-making tools for solving problems with multiple criteria of alternatives from the given one is the TOPSIS(Technique for Ordering Preference by Similarity to Ideal Solution) method, which is a multi-criteria decision-making tool that shows the shortest distance from the ideal solution and the longest distance from negative ideal solution, the positive best alternative maximized the beneficial attribute and the negative best alternative minimized the cost attribute fitted the best solution [51], [52]. It has numerous advantages, easy to use, fast, and relative simple, and a systematic procedure.

The TOPSIS method is used to solve problems with multiple objective optimization problems in ranking composite materials by considering different variables which help to choose the best alternatives from a set of alternatives [53]. TOPSIS solves the positive and negative best alternative which used as references for the optimal.

2.16 The use of Solid work in Cement Composite Research

Solid Works, computer-aided design (CAD) software, has been increasingly adopted in civil engineering research for visualizing and analyzing cement composite materials. According to Sharma et al. (2021), 3D modeling tools like Solid Work play a vital role in illustrating specimen geometries, and alignment in natural fiber-reinforced cement composites. In their study Solid Works was used to model composite beams and simulate various fiber lengths and orientations, which helped predict structural behavior before physical testing. Ali and Zhang (2019) applied

Solid Works to create virtual models of flexural and compression test setups for natural fiber cementitious beams. Their research demonstrated that the use of Solid Works improves the clarity of test process, especially when analyzing crack propagation, failure zones, and stress concentration areas. Similarly, Patel et al. (2020) highlighted that Solid Works modeling can assist in the optimization of mix designs by helping researchers understanding the relationship between fiber content and mechanical performance**.**

The application of Solid Works in sisal fiber research specifically supports visualization of the internal distribution of fibers, alignment effects, and mechanical load conditions, making it valuable tool in the development and characterization of fiber-reinforced composites.

2.17 Summary of Literature Review

Fiber-reinforced cement composites (FRCCs) have gained significant attention in the construction industry due to their enhanced mechanical properties and durability. Researchers have explored a variety of fibers, including synthetic, steel, and natural fibers like sisal, to improve the performance of cementitious materials. Studies highlight that fibers enhance tensile, flexural, impact strength by bridging cracks and resisting deformation under stress. The reinforcement effect depends on flier type, content, length, and orientation, with natural fibers offering eco-friendly and sustainable alternatives to synthetic and steel counterparts.

The chemical properties of natural fibers like sisal, primarily composed of cellulose, hemicellulose, and lignin, contribute to their mechanical performance in composites. However, untreated natural fibers may exhibit high water absorption and weak interfacial bonding with the cement matrix. Alkali treatments, such as NaOH, are commonly used to enhance fiber properties by removing lignin and impurities, improving the matrix-fiber bond. Studies show that treated sisal fibers exhibit better tensile strength and durability, making them more suitable for cement composites.

Previous research on FRCCs has focused on optimizing fiber content and aspect ratios to maximize mechanical performance. Fibers with high aspect ratios (length-to-diameter ratio) enhance crack bridging and load transfer but may reduce workability if not properly mixed. Researchers also emphasize the role of fiber orientation in determining composite behavior. Random fiber orientation provides isotropic crack resistance, while unidirectional and multi-directional alignments are preferred for structural applications under specific load conditions.

The workability and compaction of FRCCs are critical to ensuring uniform fiber distribution and achieving the desired performance. High fiber dosages and lengths tend to reduce workability, leading to clumping and uneven distribution. Admixtures like super plasticizers and viscosity-modifying agents are essential to maintain workability without compromising strength. Proper mixing techniques, such as gradual fiber addition and mechanical mixing, are also crucial to prevent segregation and ensure effective fiber-matrix bonding.

In conclusion, the literature underscores the importance of optimizing fiber type, length, orientation, and content to achieve tailored mechanical properties in FRCCs. Advances in natural fiber treatment and mix design have expanded the applicability of FRCCs in sustainable construction. However, challenges such as maintaining workability at high fiber dosages and ensuring uniform distribution remain critical areas for further research. The integration of innovative admixtures and manufacturing techniques offers promising avenues for improving the performance of fiber-reinforced composites.

MATERIALS AND METHODS

3.1 Introduction

Concrete is a composite material composed of cement, sand as fine aggregate, crushed rock as coarse aggregate, water and admixture. It's obvious that, concrete can be produced through mixing of concrete ingredients, but the important point to bear in mind is producing acceptable concrete quality with a reasonable economy. To produce acceptable quality, it's important to make physical characteristic tests on concrete making materials before any concrete experiments are carried out. So, this chapter elaborates concrete making materials used for the research and their physical test results conducted from the experiment, mix design and proportioning, and concrete production process.

3.2 Materials Used for Experiment

3.2.1 Cement

Cement from different sources may have different properties which in turn will influence properties of concrete mix. Ordinary Portland cement (OPC) is designed for a general use of construction work throughout the world. From locally produced cements Messebo Ordinary Portland Cement has been used in specific research. Based on this locally available cement which was bought from Mekelle market, produced by Messebo Cement Factory at Mekelle, Ethiopia is used for this study.

3.2.2 Fine Aggregate

Clean, well-graded Sand passing through a 4.75 mm sieve was used as the fine aggregate. The physical properties of fine aggregates like specific gravity and absorption capacity (ASTM C 128), fineness modulus (ASTM C 136), silt content and moisture content (ASTM C 566) are determined.

3.2.3 Coarse Aggregate

The maximum aggregate size of coarse aggregate is 19 mm. Physical properties of coarse aggregate ; like specific gravity and absorption capacity (ASTM C 127), moisture content (ASTM C 566) and sieve analysis (ASTM C 136) are determined.

3.2.4 Water

Water is an important constituent in concrete. It chemically reacts with cement to produce the desired properties of concrete. Mixing water is an amount of water that falls in contact with cement. Impacts concrete slump, and is used to assess the ratio of concrete mixtures to water to cement materials.

3.2.5 Sisal Fiber

Sisal Plant was collected from Tigray region, Mekelle Zone, a place called Choma. Sisal fiber was extracted by hand and knife (manually).

3.2.6 NaOH (Sodium hydroxide)

To treat the Sisal fibers, a solution of 5% sodium hydroxide (NaOH) was used. The freshly extracted fibers were fully immersed in the solution and left to soak for 24 hours at room temperature. This alkali treatment aimed to remove impurities such as lignin, hemicellulose, and surface waxes, enhancing the fiber's surface roughness and bonding potential with cement matrix. After the treatment, the fibers were thoroughly rinsed with distilled water until the rinse water reached a neutral PH, ensuring the removal of any residual alkali. Finally, the treated fibers were dried in an oven at 60°C until a constant weight was achieved.

3.3 Methods

3.3.1 Material Preparation

Ordinary Portland Cement (OPC) supplied from Messebo cement factory has been used for this specific research throughout the whole experiment. The cement produced as per **CEM –I- 42.5** grades.

Aggregate samples have been prepared in accordance with the test requirements; and hence mined river sand samples were collected from suppliers; basaltic crushed stone samples were also collected from manufactures. It is very important to obtain the right type and quality of aggregates on site. They should be clean, hard, strong, and durable and graded in size to achieve utmost economy from the paste. Therefore, to judge the quality and physical characteristics of the aggregates, physical tests were conducted for both fine and coarse ingredients.

Sisal fibers were prepared from the raw sisal plants were harvested and manually processed to extract fibers. As shown in **Figure 1**, the raw sisal fibers were separated from the plant, retaining their natural impurities such as waxes and lignin. And the Sisal fibers were treated by 5% of sodium hydroxide (NaOH). The freshly extracted fibers were fully immersed in the solution and left to soak for 24hourse at room temperature. This alkali treatment aimed to remove impurities such as lignin, hemicellulose, and surface waxes, enhancing the fiber's surface roughness and bonding potential with cement matrix. After the treatment, the fibers were thoroughly rinsed with distilled water until the rinse water reached a neutral pH, ensuring the removal of any residual alkali. Finally, the treated fibers were dried in an oven at **60**℃ until a constant weight was achieved as shown in **Figure 2**. The fibers were carefully cut into predetermined length of **10 mm, 15 mm, and 20 mm** using precision cutting tools (scissor, Ruler) to ensure uniformity as required for the experimental setup as shown in **Figure 3**. Finally, the sisal fibers were mixed with content of **1%, 2%,** and **3%** by weight of cement.

Figure 0.1.1: Sisal plant and extract process

Figure 0.1.2: The treated sisal fiber dried in an oven at 60°C

Figure 0.1.3: Treated fiber cutting by length

3.3.2 Testing constituent materials

3.3.2.1 Tests for coarse aggregate

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

Sieve analysis is a procedure for the determination of the particle size distribution of aggregates using a series of square or round openings sieves starting with the largest opening at the top. According to the Ethiopian standard coarse aggregates are those between 75 and 4.75 mm in size. Sample were prepared for particle size distribution in such a way that crushed basaltic stones with 19 mm nominal maximum sizes were blended to keep graduation requirement within the range specified on Ethiopian Standard for grading coarse aggregates. The fineness modulus for this coarse aggregate sample was found to be2.02%.

Figure 4 below shows gradation curve for coarse aggregate used in the research in comparison to minimum quantities of coarse aggregates on each series of sieves specified in the Ethiopian Standard (ES C.D 3.201). The detail gradation tests for coarse aggregates are given in Appendix C (C1) of this paper.

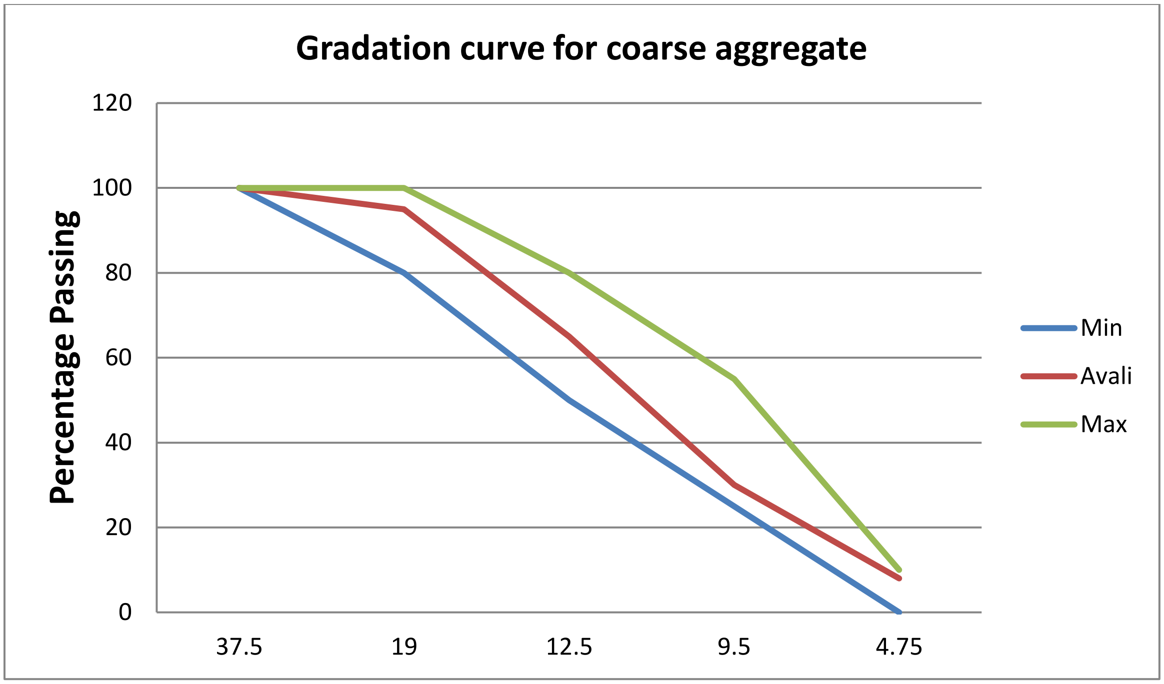


Figure3.4: Gradation curve for coarse aggregate

Specific gravity is the ratio of the density of a substance to the density of a reference substance usually water; equivalently, it is the ratio of the mass of a substance to the mass of water for the same given volume. Absorption is the process by which water is drawn into and tends to fill the permeable pores in a porous solid body.

An approximate coarse aggregate sample of 5 Kg was acquired by using quartering from the mass sample. All aggregate materials passing No.4 (4.75 mm) sieve were rejected.

Measured quantities:	where:
A= 4936 g	A= weight of oven-dry sample in air,[g]
B=5027 g	B= weight of saturated-surface-dry sample in air, [g]
C=3230 g	C= weight of saturated sample in water, [g]

Table 3 shown below, summarizes the results for bulk specific gravity, bulk specific gravity (SSD basis), apparent specific gravity and absorption capacity of coarse aggregates.

Table 0.1: Specific Gravities and Absorption Capacity of Coarse Aggregate

	Bulk Specific gravity	Bulk Specific gravity (SSD basis)	Apparent Specific gravity	Absorption Capacity
Calculation	$\frac{A}{B-C}$	$\frac{B}{B-C}$	$\frac{A}{A-C}$	$\frac{B-A}{A} \times 100$
Results	2.76	2.80	2.89	1.84%

Moisture content of coarse aggregate samples has to be determined as it affects workability and water-cement ratio in the mix design. A design water-cement ratio is usually specified based on the assumption that aggregates are inert (neither absorbs nor gives water to the mixture) and hence aggregates from different sources do not comply with this assumption of water-cement ratio.

To determine moisture content, 2kg coarse aggregate sample was weighed and oven dried for about 24hrs at a temperature of 105℃–110℃. The sample was then removed from oven and placed on a desiccator for about an hour to cool without absorbing water from the atmosphere. The sample was then weighed (oven dry weight). Moisture content of the coarse aggregate in this case was calculated to be 2.04%. Detailed Moisture content determinations for coarse aggregates are discussed in Appendix c (C1) of this paper

The unit weight measures the volume that the graded aggregate will occupy in concrete and includes both solid aggregate particles and the voids between them. The unit weight is simply measured by filling a container of known volume and weighing it. Oven-dried coarse aggregate samples were used in this specific test.

In determining unit weight of coarse aggregate, applicable to the aggregates of 40mm maximum size [43].Normal Crushed rocks and gravels have bulk unit weight 1520–1680kg/m^3 and produce normal weight concrete. Table 3.2 below shows dry rodded unit weight Calculation of coarse aggregate used in this specific research.

Table 0.2: Unit weight determination for coarse aggregate

	Weight of container(kg)	Weight of sample &Measure (kg)	Inside diameter of measure (mm)	Inside height of measure (mm)	Volume of measure (m^3)	Unit weight of coarse aggregate(kg/ m^3)
Calc.	–	–	–	–	V=$\frac{\pi D^2 h}{4}$	$\frac{28054-4841}{0.01382}$
Results	4841	28054	253	275	0.01382	1679.67

3.3.2.2 Tests for fine aggregates

1. Silt Content

The distinction between silt & clay can't be based on particle size because both are microscopic having sizes finer than No.200 (0.075mm) sieve and hence the significant physical properties of the two materials are related only indirectly to the size of particles. The objective of this test is to determine these fine particle contents from the mass sand sample.

Test results: where

A=10ml — A= amount of silt deposited above the sand

B=290ml — B = amount of clean sand

Silt content (%) =$A/B * 100$

Silt content (%) =$10/290 \times 100$=3.45% <6%⋯ ⋯ok!

According to the Ethiopia Standard the silt content of the sand is more than 6%. It is recommended either to wash or reject the sand. The sand samples in specific research were used without washing since silt content is less than 6%.

2. Sieve analysis

According to the Ethiopia Standard, fine aggregates are those between 9.5mm and μm in size. Sample were prepared for particle size distribution in such a way that river sand with 4.75mm nominal maximum sizes was prepared in accordance with the gradation requirement specified in the Ethiopian Standard for the grading of fine aggregates. Fineness modulus for this fine aggregate sample came to be 2.4%. The sand sample used in this specific research was tested to have a particle size distribution within the range of the Ethiopian Standard for the grading of fine aggregate. Thus, it satisfies the graduation requirement.

A detailed gradation test results for fine aggregates in comparison with the requirements set in the Ethiopian Standard for grading of fine aggregate (ES C.D3.201) using ranges of percentage passing through each sieve opening were presented by Appendix C (C2) of this paper. Figure 3.5 below shows gradation curve for fine aggregate used in the minimum and maximum quantities of fine aggregates on series of sieves specified in the Ethiopian Standard.

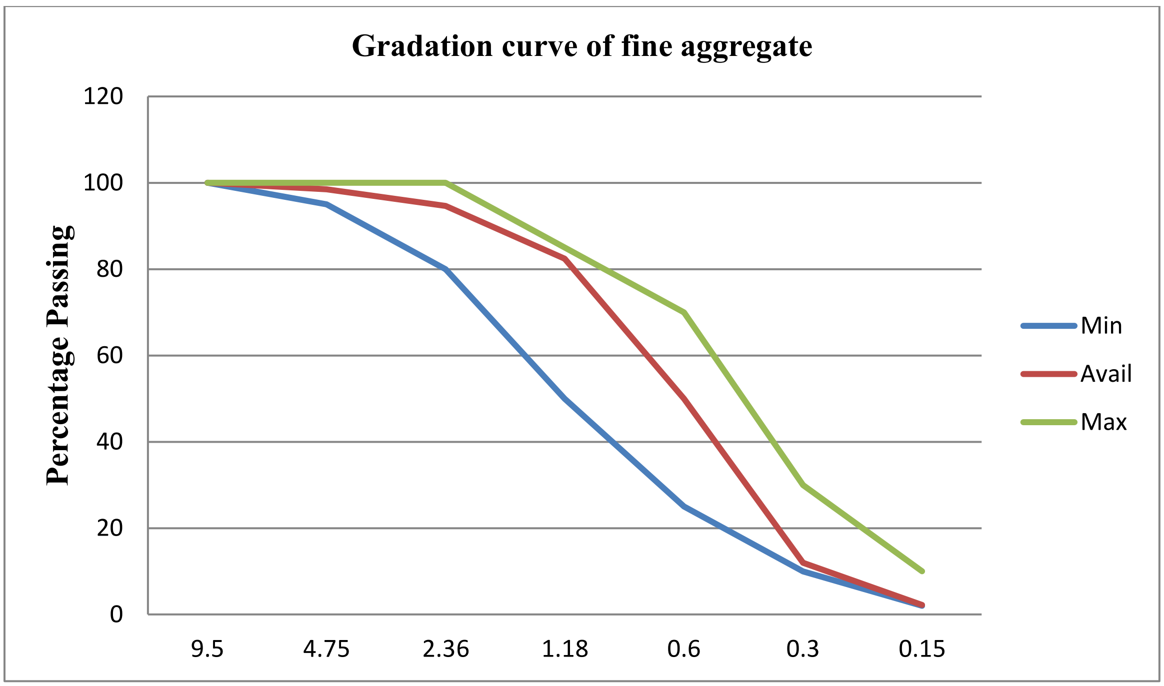


Figure 3.5: Gradation curve for fine aggregate

3. Specific gravity and absorption capacity

The objective of this test is to determine bulk and apparent specific gravity and absorption capacity of the fine aggregate approximately 500g of fine aggregate sample from availed mass of the total was taken by using a method of sample splitter. Sample test was prepared and procedures were followed in accordance with the guide of Construction Materials Laboratory Manual by Abebe Dinku.

Weight of the sample 500g

Measured quantities: where

W=320g W= weight of pycnometer, gm.

V=975.39mm V=volume of flask/ container

Va =769.80ml Va=volume of water added to pycnometer $[cm^3]$

A=475g A=weight of oven dry sample in air [g]

Calculation: **where**

C=0.9976Va +500+W C=weight of pycnometer filled with sample plus water,[gm]

=0.9976∗(769.80)+500+320

=1587.95g

B=0.9976V+W B=weight of flask filled with water,[gm]

=0.9976∗(975.39)+320 =1293.05g

Tables 5 shown below summarize the test results for bulk specific gravity, bulk specific gravity (SSD basis), apparent specific gravity and absorption capacity of fine aggregates.

Table 0.3: Specific gravities and absorption capacity of fine aggregate

	Bulk specific gravity	Bulk specific gravity(SSD basis)	Apparent specific gravity	Absorption capacity
Calculation	$\frac{A}{B+500-c}$	$\frac{500}{B+500-c}$	$\frac{A}{B+A-C}$	$\frac{500-A}{A}\times 100$
Results	2.32	2.44	2.64	5.26%

4. Moisture content

To determine the moisture content, 500g fine aggregate sample was weighed and oven dried for about 24hrs to remove from the oven and placed on a desiccator for about an hour to cool without absorbing water from the atmosphere. The sample was then weighed (oven dry weight). Moisture content of fine aggregate in this specific research was calculated to be 3.10%. A detailed moisture content determination for fine aggregates is discussed in Appendix C (C2) 0f this paper.

3.3.3 Mix Proportion

The objective of concrete mix proportion is to determine the most economical and practical combination of readily available materials that will satisfy the performance requirement under a particular condition of use. In this specific research mix design of sisal fiber reinforced cement composites with determined ratio of cement, sand, water, coarse aggregate and sisal fiber were proportioned for C-25 concrete based ACI 211.1-9. The completed mix design procedure is in shown in Appendix A of this paper.

This study investigates the effects of NaOH-treated sisal fibers on the compressive, flexural, and tensile strength of cement composites. The mix proportions were designed to evaluate fiber length (10mm, 15mm, and 20mm) and fiber content (1%, 2%, and3% by weight of cement). Concrete specimens were prepared using molds of different dimensions: Compressive strength $10\times 10 \times 10cm$ cubes, flexural strength $50\times 10 \times 10cm$ beams, and Tensile strength cylindrical molds with of radius 5cm and height of 20cm. A water-to-cement ratio of 0.56 was maintained across all tests, and adjustments for mold size were made using a density of 2300kg/m^3

Table 0.4: Quantities for concrete are scaled for each mold size and adjusted for 20% wastage factor (1.2) based on density of 2300 kg/m^3shows

Material	Base weight (kg/$m^{3)}$	Mold Size		
		Cube (compressive test)	Flexural	Split tensile
		$10\times 10 \times 10cm$	$50\times 10 \times 10cm$	Cylindrical mold $\pi 5^2 \times 20cm$
Cement	363.48	0.4362	2.181	0.685
Water	205.835	0.247	1.235	0.388
Fine Aggregate	735.454	0.8286	4.4128	1.386

Coarse Aggregate	1027.808	1.2334	6.1668	1.936

1. Fiber content was added based on the weight of cement after accounting for wastage.

Table 0.5: Fiber quantities for each mold size.

Table Mold	Cement weight (kg)	Content		
		1% Fiber (kg)	2% Fiber (kg)	3% Fiber (kg)
$10\times 10 \times 10cm$	0.4362	0.0044	0.0087	0.0131
$50\times 10 \times 10cm$	2.181	0.0218	0.0436	0.0654
Cylindrical mold $\pi 5^2 \times 20cm$	0.685	0.00685	0.0137	0.02055

Table 0.6: Quantities of materials for each mix in kg for $1m^3$ concrete based weight of cement

Mix code	Sisal fiber (%)	Sisal fiber length (mm)	W/C ratio	For $1m^3$ of concrete based weight of cement				
				Cement (kg)	Water (kg)	Fine aggregate(kg)	Coarse aggregate (kg)	Sisal fiber (kg)
M_0	0	0mm	0.56	363.48	205.835	735.454	1027.808	0
M_1	1	10	0.56	363.48	205.835	735.454	1027.808	0.03305
M_2	2	10	0.56	363.48	205.835	735.454	1027.808	0.0661
M_3	3	10	0.56	363.48	205.835	735.454	1027.808	0.09915
M_4	1	15	0.56	363.48	205.835	735.454	1027.808	0.03305
M_5	2	15	0.56	363.48	205.835	735.454	1027.808	0.0661
M_6	3	15	0.56	363.48	205.835	735.454	1027.808	0.09915

M_7	1	20	0.56	363.48	205.835	735.454	1027.808	0.03305
M_8	2	20	0.56	363.48	205.835	735.454	1027.808	0.0661
M_9	3	20	0.56	363.48	205.835	735.454	1027.808	0.09915

3.3.4 Mixing and Casting

The mixing and casting of the cement composite were carried out systematically to ensure uniformity and consistency in the prepared specimens. The mix proportions used were as follows: cement (363.48kg/m^3), water (205.808kg/m^3), fine aggregate (735.454kg/m^3), and coarse aggregate (1027.835kg/m^3). The water-cement (w/c) ratio was maintained at 0.56 to achieve the desired workability and strength. An additional 20% of material was included to account for mold size and material wastage. Sisal fibers with lengths of 10mm, 15mm, and 20mm were incorporated into the mix at weight fractions of 1%, 2%, and 3% relative to the weight of cement. These fibers were pretreated with a 5% NaOH solution for 24 hours to improve their bonding with the cement matrix, thoroughly washed with water to remove excess alkali, and dried under ambient conditions.

The mixing process began with dry-mixing the cement, fine aggregate, and coarse aggregate for two minutes to achieve a uniform blend. Water, combined with a super plasticizer to improve workability, was gradually added during mixing, which continued for three minutes. The pretreated sisal fibers were then introduced incrementally into the wet mixture and blended for two additional minutes to ensure even distribution throughout the matrix.

The fresh composite was poured into molds prepared for different mechanical tests, for compressive strength tests, cube molds 100mm$\times$ $10mm \times 10mm$ were used, for flexural strength testes, prism molds of 100mm$\times$ $100mm \times 500mm$ ware cast, for tensile strength tests cylindrical molds 100mm diameter and 200mm height were used based to ASTM C192. Mechanical vibration was applied during casting to remove air voids and ensure proper compaction. The top surfaces of the specimens were leveled using a trowel, and the molds were left undisturbed for 24 hours at room temperature.

Three samples of compressive strength casted based on fiber length (10 mm, 15 mm, and 20 mm) and content (1 %, 2 %, and 3 % by weight of cement); 60 cubes in total for 7^{th} and 28^{th}days.

Three samples of tensile strength casted base on fiber length (10 mm, 15 mm, and 20 mm) and content (1 %, 2 %, and 3 % by weight of cement); 60 cylinders in total for 7^{th} and 28^{th} days.

Three samples of flexural strength casted based on fiber length (10 mm, 15 mm, and 20 mm) and content (1 %, 2 %, and 3 % by weight of cement); 60 beams in total for 7^{th} and 28^{th} days. Figure 3.6 below shows cube samples, cylindrical samples and prismatic samples casted for testing.

Figure 3.6: Figure of cube casting test

3.3.5 Curing

After demolding, the specimens were submerged in water tanks maintained at 27℃ ± 2℃ and cured for 7 days and 28 days. This curing process ensured proper hydration of cement and optimal bonding between the fibers and compost matrix. At the end of 7 days and 28 days curing period, the specimens were tested for their compressive, flexural, and tensile strengths.

A test is systematic experimental procedure carried out to assess the mechanical properties of materials. In this study, tests were conducted to evaluate the compressive strength, tensile strength, and flexural strength of cement composites reinforced with NaOH-treated sisal fibers of varying lengths (10mm, 15 mm, and 20mm) and contents (1%, 2%, and 3%). These tests are critical to understanding the influence of fiber treatment, length, and content on the overall performance of the composite materials.

Figure 3.7: The curing specimens for 28 days

3.4: Application of the TOPSIS method

In this study, ten different mixes of sisal fiber reinforced cement composites were prepared by varying fiber content and fiber length, and their mechanical performance was evaluated through Compressive, tensile, flexural strength tests. While each strength test provides valuable information independently, selecting the optimal mix design requires a multi – criteria decision – making approach. Therefore, the **Technique for Order Preference by Similarity to ideal Solution (TOPSIS)** method was applied to determine the most effective mix. TOPSIS is a systematic and widely used method in engineering research suitable for ranking alternative when multiple conflicting performance indicators exist. In this thesis, TOPSIS was employed to identify the mix that demonstrated the best overall mechanical performance, considering weighted contributions from each test result.

TOPSIS method involve some step; these are as followed [44], [45], [46]

Step1: Construct the Decision Matrix

In this step, all alternatives (e.g., mix designs) and criteria (e.g., compressive, tensile, and flexural strength) are organized in a table 4.7 below showing the performance of each alternative against each criterion.

Table 3.7: list all mix designs and their performance in each criterion.

Mix - Code	CS (Mpa)	TS (Mpa)	FS (MPa)
M_0	25.06	2.6	3.8
M_1	26	2.9	4.1
M_2	28.6	3.3	4.6
M_3	27.4	3.11	4.4
M_4	29.11	3.5	4.9
M_5	31.6	4.1	5.4
M_6	30.01	3.8	5.01
M_7	27.02	3.2	4.5
M_8	28.9	3.6	4.8
M_9	27.81	3.41	4.8

Step2: Normalize the Decision Matrix

Each performance value was normalized using the formula

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij}^2}}$$

Table 3.8 Normalize the Decision Matrix

Criteria	Mix - Code									
	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
CS	0.28	0.26	0.32	0.31	0.33	0.35	0.34	0.30	0.32	0.31
TS	0.18	0.29	0.23	0.22	0.25	0.29	0.27	0.23	0.25	0.24
FS	0.26	0.28	0.31	0.30	0.33	0.37	0.34	0.31	0.33	0.31

Step3: Construct the Weighted Normalized Matrix

Normalized values were multiplied by the assigned weights for each criterion. In this study, the following weights were used based on the significance of the mechanical properties:

Table3.9 Relative Importance weight

Description	Criteria		
	CS	TS	FS
Importance in Application	3	3	4
Weight = 1	0.25	0.35	0.4

Using the formula: $v_{ij} = r_{ij} \times w_{ij}$

Table3.10 weighted Normalized Matrix

Mix - Code	Normalize weight			Weighted value		
	CS	TS	FC	CS	TS	FC
M_0	0.28	0.18	0.26	0.112	0.054	0.078
M_1	0.29	0.20	0.28	0.116	0.06	0.084
M_2	0.32	0.23	0.31	0.128	0.069	0.093

$\mathbf{M_3}$	0.31	0.22	0.30	0.124	0.066	0.09
$\mathbf{M_4}$	0.33	0.25	0.33	0.132	0.075	0.099
$\mathbf{M_5}$	0.35	0.29	0.37	0.14	0.087	0.111
$\mathbf{M_6}$	0.34	0.27	0.34	0.136	0.081	0.102
$\mathbf{M_7}$	0.30	0.23	0.31	0.12	0.069	0.093
$\mathbf{M_8}$	0.32	0.25	0.33	0.128	0.075	0.099
$\mathbf{M_9}$	0.31	0.24	0.31	0.124	0.072	0.093

Step4: Determine the Ideal Best (A^+) and Ideal Worst (A^-) Solution

- **A^+** Consists of the maximum value for each criterion (best performance).
- **A^-** Consists of the minimum value for each criterion (worst performance).

Table3.11 Ideal the best and Ideal the worst

Criteria	**A^+ (Max)**	**A^-(Min)**
CS	0.136	0.112
TS	0.087	0.054
FS	0.111	0.078

Step5: Calculate the Separation Measure

Using Euclidean distance, the separation from ideal best (S_i^+) and from ideal worst (S_i^-) was computed.

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2}\ , \qquad S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2}$$

Where i = 1, 2, 3.......

Table 3.12 Euclidean Distance

Ideal Solution	Mix - Code									
	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
S^+	0.059	0.048	0.031	0.037	0.021	0	0.014	0.034	0.022	0.031
S^-	0	0.010	0.028	0.022	0.038	0.059	0.046	0.026	0.037	0.066

Step6: Calculate the Relative Closeness to the Ideal Solution

The Closeness Coefficient (C_i^*) was calculated as: $C_I^* = \frac{S_i^-}{S_i^+ + S_i^-}$

Higher values of C_i^* indicate better alternatives

Table3.13 Relative Closeness

Mix	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
CC	0	0.1724	0.4746	0.3729	0.6441	1	0.7667	0.4333	0.6271	0.6804

Step7: Rank the Alternatives

Finally, all alternatives are ranked based on their C_i^*values, from highest to lowest. The Top – ranked alternative is the most preferred.

Table 3.14 Alternative Rank

Mix –code	Closeness Coefficient	Rank
M_5	1	1
M_6	0.7667	2
M_9	0.6804	3
M_4	0.6441	4
M_8	0.6271	5

$\mathbf{M_2}$	0.4746	6
$\mathbf{M_7}$	0.4333	7
$\mathbf{M_3}$	0.3729	8
$\mathbf{M_1}$	0.1724	9

Based on the TOPSIS ranking, the mix with highest performance is mixing $\mathbf{M_5}$ (2 % fiber content and 15 mm length.

TEST RESULTS AND DISCUSSIONS

4.1 Mechanical Test Results

This chapter present and discusses the experimental results obtained from testing sisal fiber-reinforced cement composites. The mechanical properties evaluated include compressive strength, split tensile strength, and flexural strength. Each test was conducted at 7 and 28 days 0f curing for all combinations of fiber lengths (10 mm, 15 mm, and 20 mm) and fiber contents (1 %, 2 %, and 3 % by weight of cement). The primary objective of this analysis is to evaluate how fiber length and content influence mechanical performance and identify the optimal configuration for wall construction applications.

4.1.1 Split tensile strength test

The split tensile strength results indicate that fiber reinforcement improves tensile behavior compared to the control mix. The highest strength was recorded for the mix containing 15 mm fiber length at 2 % content, yielding 4.10 Mpa at 28 days. This improvement is attributed to better fiber distribution, efficient crack bridging, and strong interfacial bonding due to NaOH treatment. However, tensile strength declined slightly at higher fiber contents (3 %) due to poor workability and fiber clumping. Three cylindrical samples were tested for each length and content addition of sisal fiber. Typical failure loads and tensile strength of $7^{th} and 28^{th}$ day SFRCCs under tensile loading were presented in Tables 4.1 and 4.2 and illustrated a detailed test result of split tensile strength at the age of 7^{th} and 28^{th} day for SFRCCs is presented in Appendix C2 at the end this document.

Table 0.1: 7 day Spilt tensile strength test result

Mix-code	Sample no.	Failure load (kN)	Splitting Tensile Strength (Mpa)
M_0	1	61.030	1.94
	2	60.140	1.91
	3	59.500	1.89
	Mean		1.92
$\mathbf{M_1}$	1	70.12	2.23
	2	60.16	1.98

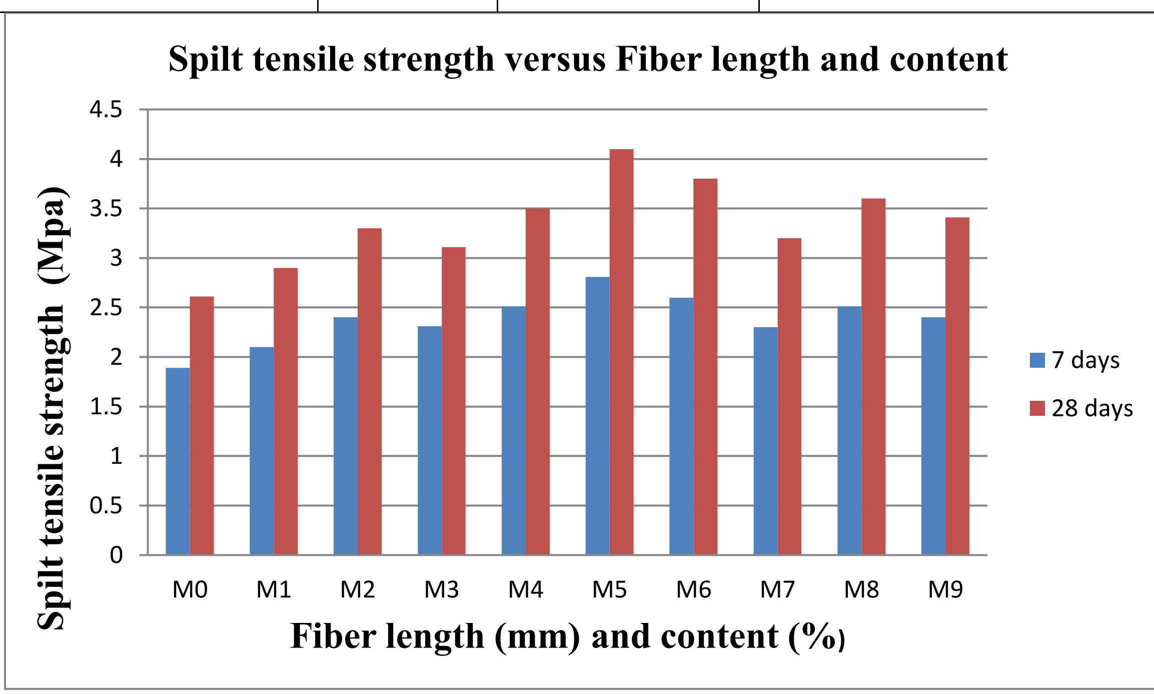
	3	65.53	2.09
	Mean		2.10
$\mathbf{M_2}$	1	73.95	2.35
	2	76.07	2.42
	3	75.76	2.41
	Mean		2.40
$\mathbf{M_3}$	1	74.02	2.36
	2	73.17	2.33
	3	70.23	2.24
	Mean		2.31
$\mathbf{M_4}$	1	79.06	2.52
	2	80.12	2.55
	3	77.24	2.46
	Mean		2.51
$\mathbf{M_5}$	1	92.10	2.93
	2	87.74	2.79
	3	84.71	2.70
	Mean		2.81
$\mathbf{M_6}$	1	83.50	2.66
	2	80.82	2.57
	3	80.42	2.56
	Mean		2.60
$\mathbf{M_7}$	1	74.50	2.37
	2	69.78	2.22
	3	72.61	2.31
	Mean		2.30
$\mathbf{M_8}$	1	80.120	2.55
	2	79.780	2.54
	3	76.230	2.43
	Mean		2.51

$\mathbf{M_9}$	1	74.23	2.36
	2	75.34	2.40
	3	76.54	2.44
	Mean		2.40

Table 0.2: 28-day spilt tensile strength test result

Mix-code	Sample no.	Failure load (kN)	Splitting Tensile Strength (Mpa)
$\mathbf{M_0}$	1	83.75	2.67
	2	82.48	2.63
	3	79.97	2.55
	Mean		2.61
$\mathbf{M_1}$	1	92.06	2.93
	2	89.87	2.86
	3	91.24	2.90
	Mean		2.90
$\mathbf{M_2}$	1	109.42	3.48
	2	97.41	3.10
	3	103.79	3.30
	Mean		3.30
$\mathbf{M_3}$	1	100.51	3.20
	2	98.27	3.13
	3	94.75	3.02
	Mean		3.11
$\mathbf{M_4}$	1	109.97	3.50
	2	110.40	3.51
	3	109.34	3.48
	Mean		3.50
$\mathbf{M_5}$	1	132.87	4.23
	2	124.76	3.97
	3	128.77	4.10

	Mean		4.10
$\mathbf{M_6}$	1	129.56	4.12
	2	107.65	3.43
	3	120.50	3.84
	Mean		3.80
$\mathbf{M_7}$	1	103.53	3.30
	2	99.87	3.18
	3	98.25	3.13
	Mean		3.20
$\boldsymbol{M_8}$	1	115.430	3.60
	2	114.560	3.65
	3	109.760	3.49
	Mean		3.60
M_9	1	103.57	3.30
	2	108.57	3.46
	3	109.44	3.48
	Mean		3.41



4. 1: Spilt tensile strength variance with fiber length and content

4.1.2 Flexural strength test

Flexural strength tests were conducted using third-point loading as per ASTM C 78. Result show significant enhancement in flexural performance with fiber addition. The optimal result was observed for 15 mm fiber length at 2 % content, with 5.4 Mpa at 28 days. This increase is due to improved energy absorption and crack resistance. At higher contents, fiber dispersion becomes non-uniform, leading to reduced strength. For the sake of testing presented in the Table 4.3 and 4.4 and illustrated in figure 4.1 as shown below. A detailed test result of flexural strength at the age of 7^{th} and28^{th} day for SFRCCs are presented in appendix C2 at the end this document.

Table 0.3: 7-day flexural strength test results

Mix-code	Sample no.	Failure load (kN)	flexural Strength (Mpa)
$\mathbf{M_0}$	1	4.9	2.83
	2	4.14	2.79
	3	4.165	2.81
	Mean		2.81
$\mathbf{M_1}$	1	5.01	3.38
	2	4.65	3.14
	3	4.60	3.11
	Mean		3.21
$\mathbf{M_2}$	1	5.22	3.52
	2	5.67	3.83
	3	5.09	3.44
	Mean		3.60
M_3	1	5.12	3.46
	2	5.07	3.42
	3	4.97	3.35
	Mean		3.41
$\mathbf{M_4}$	1	5.93	4.00
	2	5.77	3.89
	3	5.66	3.82

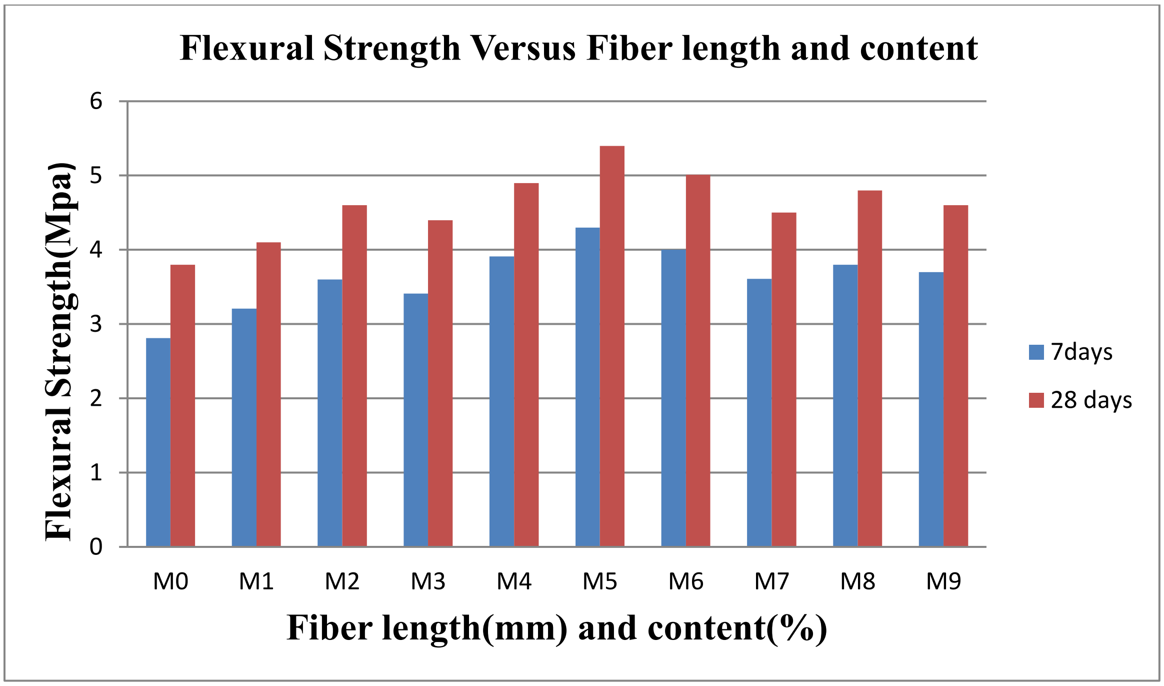
	Mean		3.91
M_5	1	6.41	4.33
	2	6.72	4.54
	3	5.97	4.03
	Mean		4.30
M_6	1	5.87	3.52
	2	5.98	4.04
	3	5.93	4.00
	Mean		4.00
M_7	1	5.21	3.52
	2	5.82	3.93
	3	5.02	3.39
	Mean		3.61
M_8	1	5.91	3.99
	2	5.48	3.70
	3	5.51	3.72
	Mean		3.80
M_9	1	5.33	3.60
	2	6.01	4.06
	3	5.12	3.46
	Mean		3.70

Table 0.4: 28-day flexural strength test results

Mix-Code	Sample no.	Flexural load (KN)	Flexural strength (Mpa)
M_0	1	5.08	4.10
	2	5.19	3.50
	3	5.635	3.80
	Mean		3.80
M_1	1	6.17	4.16
	2	6.08	4.10
	3	5.99	4.04

	Mean		4.10
M_2	1	6.87	4.64
	2	7.02	4.74
	3	6.55	4.42
	Mean		4.60
M_3	1	6.79	4.58
	2	6.54	4.41
	3	6.24	4.21
	Mean		4.40
M_4	1	7.54	5.09
	2	7.12	4.81
	3	7.13	4.81
	Mean		4.90
M_5	1	8.02	5.41
	2	8.12	5.48
	3	7.88	5.32
	Mean		5.40
M_6	1	7.07	4.77
	2	7.80	5.27
	3	7.40	5.00
	Mean		5.01
M_7	1	6.61	4.46
	2	7.12	4.81
	3	6.29	4.25
	Mean		4.50
M_8	1	7.22	4.87
	2	6.98	4.71
	3	7.12	4.81
	Mean		4.80
	1	6.68	4.51

M_9	2	7.25	4.89
	3	6.51	4.39
	Mean		4.60



4. 2: Variation of flexural strength with fiber length and content

4.1.3 Compressive strength test

Compressive strength improved moderately with fiber addition, with the highest value being 31.6 Mpa at 28 days for the 15 mm, 2 % mix. This is primarily due to the increased resistance to internal micro cracks. However, excessive fiber content led to increased porosity and reduced compaction, thus decreasing strength at 3 % content. Overall, the compressive strength results confirm that optimized fiber parameters can enhance performance without significantly compromising structural integrity. And were presented in the Table 4.5 and 4.6 and illustrated in figure 4.2 as shown below. A detailed test result of spilt tensile strength at the age of 7^{th} and28^{th} day for SFRCCs is presented in appendix C3 at the end this document.

Table 0 5: 7-day compressive strength test results

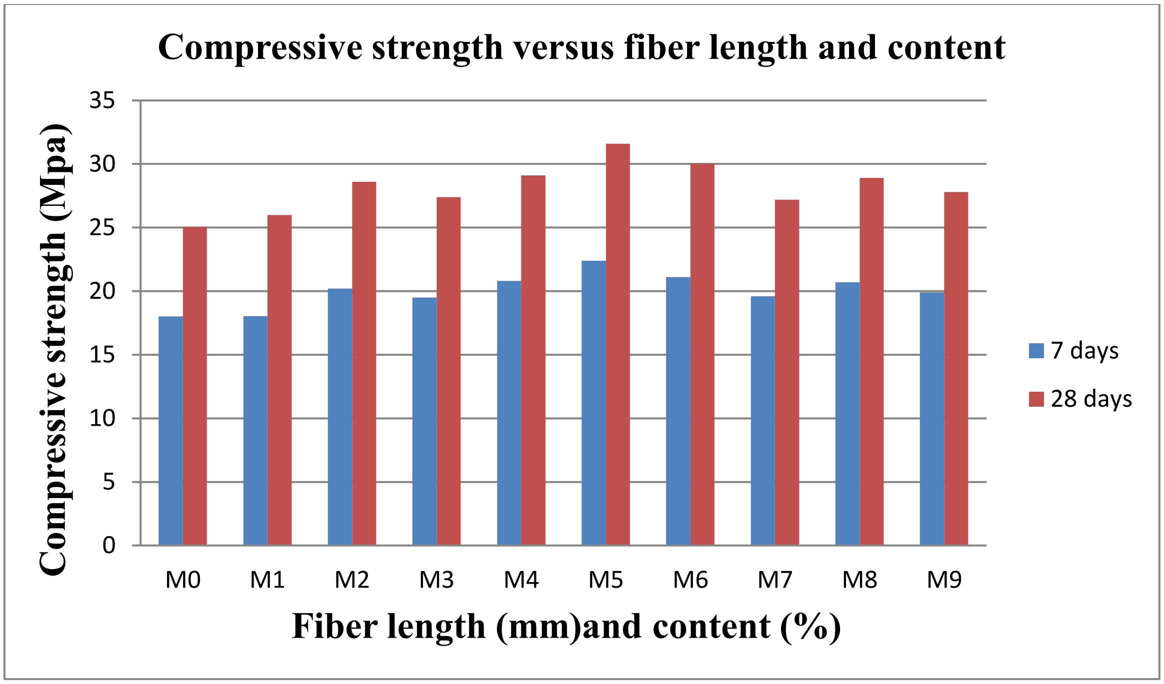
Mix-code	Sample no.	Failure load (kN)	Compressive strength (Mpa)
M_0	1	180.02	18.00
	2	179.11	17.91
	3	181.02	18.10
	Mean		18.01
M_1	1	175.70	17.57
	2	184.07	18.41
	3	181.61	18.16
	Mean		32.53
M_2	1	198.98	19.90
	2	199.06	19.91
	3	208.20	20.82
	Mean		20.21
M_3	1	200.00	20.00
	2	189.78	18.98
	3	195.36	19.54
	Mean		19.50
M_4	1	214.22	21.42
	2	198.97	19.90
	3	210.84	21.08
	Mean		20.80
M_5	1	220.05	22.01
	2	210.43	21.04
	3	241.50	24.15
	Mean		22.40
M_6	1	211.880	21.19
	2	200.850	20.09
	3	220.180	22.02
	Mean		21.10

M_7	1	193.53	19.35
	2	200.01	20.00
	3	194.75	19.48
	Mean		19.61
M_8	1	199.65	19.97
	2	203.6	20.36
	3	218.19	21.82
	Mean		20.71
M_9	1	198.95	19.90
	2	201.8	20.18
	3	196.54	19.65
	Mean		19.91

Table 0.6: 28-day compressive strength test results

Mix-code	Sample no.	Failure load (kN)	Compressive Strength (Mpa)
M_0	1	250.3	25.03
	2	247.6	24.76
	3	254.01	25.40
	Mean		25.06
M_1	1	256.02	25.60
	2	263.02	26.30
	3	261.00	26.10
	Mean		26.00
M_2	1	287.98	28.80
	2	281.08	28.11
	3	288.99	28.90
	Mean		28.60
M_3	1	281.21	28.12
	2	268.94	26.89
	3	271.95	27.20

	Mean		27.40
$\mathbf{M_4}$	1	294.99	29.50
	2	287.43	28.74
	3	290.87	29.09
	Mean		29.11
$\mathbf{M_5}$	1	308.74	30.87
	2	313.98	31.40
	3	325.2	32.52
	Mean		31.60
$\mathbf{M_6}$	1	294.340	29.43
	2	304.130	30.41
	3	301.770	30.18
	Mean		30.01
$\mathbf{M_7}$	1	270.15	27.02
	2	276.87	27.69
	3	269.11	26.91
	Mean		27.20
$\mathbf{M_8}$	1	273.11	27.31
	2	290.01	29.00
	3	304.2	30.42
	Mean		28.91
$\mathbf{M_9}$	1	271.74	27.17
	2	299.43	29.94
	3	263.23	26.32
	Mean		27.81



4. 3 Variation of compressive strength with fiber length and content

4.1.4 Fresh Concrete Properties

Workability, measured by slump test, showed a decreased trend with increasing fiber content. The addition due to the lower specific gravity of sisal compared to cement matrix. These effects are critical for casting and compaction and must be managed through proper mix design. Table 4.4 below shows slump and fresh concrete densities for each mix.

Table 0.1.1: Slump and fresh concrete density test results

Mix - code	Slump (mm)	Fresh concrete density (kg/m^3)
$\mathbf{M_0}$	78	2473.3
$\mathbf{M_1}$	70	2383.33
$\mathbf{M_2}$	61	2370
$\mathbf{M_3}$	37	2288.33
$\mathbf{M_4}$	74	2354
$\mathbf{M_5}$	40	2330
$\mathbf{M_6}$	34	2276.67
$\mathbf{M_7}$	42	2336.67
$\mathbf{M_8}$	31	2310

M_9	20	2253.3

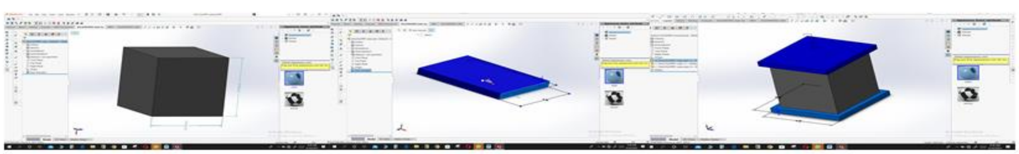
4 .2Solid Works Model of test Setups

To improve understanding and replication of the testing conditions, SolidWorks software was used to create detailed 3D models of all test setups (compression, split tensile, and flexural). These models clearly illustrate specimen geometry, load application points, and support conditions. Although not intended for simulation, these models provide clarity on test configurations and enhance reproducibility. Dimensions and loading directions are aligned with ASTM standards, offering a visual complement to experimental documentation.

4.2.1 Compression Test Setup

A 3D model of the cube specimen under compression was developed, showing the loading plates and the direction of applied force. Figure 4.2.1 below shows the model of the compression test specimen.

4. 4 model of the compression test specimen

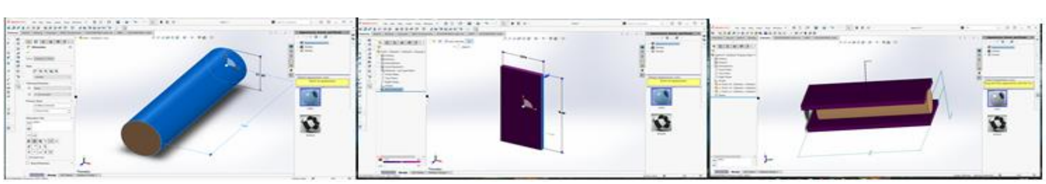


a, Cube Specimen b, Steel Plate c, Assembly of compression test setup

4.2.2 Spilt Tensile Test Setup

A cylinder specimen under spilt tensile loading was modeled to demonstrate line loading with wooden strip along the diameter. Show below Figure 3.8

4. 5 model of the spilt tensile specimen

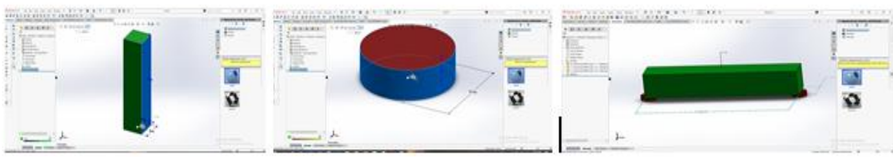


a, Cylinder Specimen b, Steel Plate c, Model of Split tensile setup

4.2.3 Flexural Test Setup

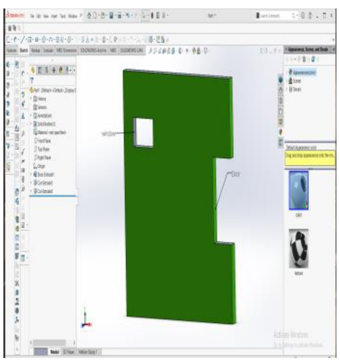
A beam under third-point loading was modeled to reflect the actual flexural test condition using a two-point loading system. Show figure 3.9

4. 6 model of flexural setup



a, Beam Specimen   b, Roller steel   c , Model of flexural Setup

4. 7 model of Wall (include door and window)



4.3 Discussions

The results clearly show that sisal fiber enhances mechanical properties of cement composites, with optimal improvements at 2 % fiber content and 15 mm length. The improvement is most significant in tensile and flexural strength due to crack-bridging mechanisms and enhanced bonding from NaOH treatment. At higher fiber contents, performance declines due to poor workability, fiber balling, and void formation.

Compressive strength gains were modest, suggesting that fiber reinforcement primarily contributes to ductility and crack control rather than axial load capacity. The decline at 3 % fiber content supports previous findings that excess fibers reduce packing density and hinder compaction.

The TOPSIS method was applied to rank mixes based on mechanical performance, assigning the highest weight to flexural strength (0.4), followed by tensile (0.35), and compressive (0.25). This prioritization reflects the intended application in wall panels, where flexural behavior is critical. The optimal mix (15 mm, 2 %) consistently ranked highest.

The use of NaOH –treated fibers significantly improved interfacial bonding, enhancing load transfer across the matrix. However, no SEM or FTIR analysis was performed; future work should include such tests to confirm chemical surface modification.

SolidWorks modeling contributed to visualizing loading configurations, which is important for academic instruction and ensuring experimental reproducibility. Future studies may include finite element analysis (FEA) to predict stress distribution.

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study investigated development and characterization of sisal fiber-reinforced cement composites for wall applications. The experimental program examined the effects of varying sisal fiber lengths (10 mm, 15 mm, and 20 mm) and contents (1 %, 2 %, and 3 % by weight of cement) on mechanical properties, including compressive, split tensile and flexural strengths. Sodium hydroxide (NaOH) treatment was applied to enhance fiber –matrix bonding, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was used for mix optimization. SolidWorks software was employed to visualize the test setups.

Key findings from the study are as follows:

- The incorporation of NaOH-treated sisal fibers significantly improved tensile and flexural strengths due to enhanced fiber-matrix interfavial bonding and effective crack-bridging behavior.
- Optimal performance was achieved with 15 mm fiber length at 2 % content, yielding 28-day strengths of 4.10 Mpa (tensile), 5.40 Mpa (flexural), and 31.6 Mpa (compressive).
- Compressive strength increased moderately with fiber addition, primarily due to resistance to internal micro cracks. However, excessive fiber content (3 %) negatively affected workability and strength.
- Workability decreased with higher fiber contents due to increased internal friction, which may require the use of super plasticizers or adjusted mix designs in practical applications.
- TOPSIS analysis confirmed the optimal mix (15 mm, 2 %) when flexural strength was weighted highest, aligning with the target wall application.
- SolidWorks modeling improved understanding of experimental setups and provided a visual reference for replication and teaching purposes.

Overall, the study confirms that NaOH-treated sisal fibers can serve as an effective and sustainable reinforcement in cement composites, particularly for non-load-bearing and moderately load-bearing wall structures. The research contributes to localized material innovation, sustainability, and the practical use of natural fibers in civil engineering.

5.2 Recommendations

Based on the experimental results, modeling analysis, and multi-criteria decision-making evaluation using the TOPSIS method, the following recommendations are made:

- Future research should include durability testing (e.g., water absorption, freeze-thaw resistance, and thermal behavior) to evaluate long-term performance under various environmental conditions.
- Microstructural analyses such as SEM (Scanning Electron Microscopy) and FTIR (Fourier Transform infrared Spectroscopy) are recommended to better understand fiber-matrix bonding and the effects of NaOH treatment.
- Investigate the effect of hybrid natural fibers (e.g., sisal combined with jute or hemp) to further improve mechanical properties and balance cost, strength, and ductility.
- Encourage the use of modeling tools like SolidWorks and finite element analysis (FEA) in construction material research to simulate stress distribution and optimize component design.
- Promote the practical application of sisal fiber composites in low-cost housing, particularly in regions where sisal is locally available, to reduce reliance on synthetic materials.
- Incorporate sustainability assessment tools (e.g., life cycle analysis or embodied carbon studies) in future studies to validate the environmental benefits of natural fiber composites.
- Support local industries and small-scale fiber processing as part of community-based sustainable construction programs in Ethiopia.

These conclusion and recommendations provide a foundation for continued research and practical application of sisal fiber-reinforced cement composites in environmentally conscious construction practices.

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APPENDIX

Appendix A: Mix Design of Concrete Using ACI Method

A.1 Introduction

This appendix presents the detailed mix design procedure for concrete based on the ACI 211.1- 19 method. The mix was designed to achieve the required compressive strength while incorporating NaOH-treated sisal fibers at varying lengths (10mm, 15mm, and 20mm) and contents (1%, 2%, and 3%) to evaluate their effects on mechanical properties.

A.2 Design Parameters

The mix design was carried out considering the following parameters:

Target Compressive Strength (f'-c):

7- day strength: 22.40 Mpa

28- Day strength: 31.61 Mpa

Water-Cement Ratio (W/c): 0.56

Cement Content : 363.48 kg/m^3

Water Content : 205.835 kg/m^3

Fine Aggregate: 735.454 kg/m^3

Coarse Aggregate: 1027.808 kg/m^3

Maximum Aggregate Size: 20 mm

Slump Range: 75-100 mm

Sisal Fiber Content : 1 %, 2 %, 3 % by volume of cement

Exposure Conditions: Moderate

A.3 Mix Design Procedure

Step 1: Selection of Water –Cement ratio of 0.56 was chosen based on ACI guidelines to balance workability and strength.

Step 2: Selection of Water Content Based on ACI 211.1 tables, the required water content for a slump range of 75- 100 mm and a maximum aggregate size of 20 mm is 205.835 kg/m^3

Step 3: Calculation of Cement Content

The cement content was determined using the selected water-cement ratio:

Cement Content= $\frac{Water\ Content}{W/C \quad Ratio} = \frac{205.835}{0.56}$ = 363.48 kg/m^3

This ensures adequate strength and durability.

Step 4: Selection of Coarse Aggregate

According to ACI guidelines, the coarse aggregate content was determined as 1027.808 kg/m^3 for a maximum aggregate size of 20 mm.

Step 5: Calculation of Fine Aggregate Content

The fine aggregate content was determined using the following equation:

Fine Aggregate = 1− (Cement Volume + Coarse Aggregate Volume + Water Volume +Air Content) × 1000

Substituting the Known Values:

Fine Aggregate = 1− ($\frac{363.48}{3150} + \frac{1027.808}{2700} + \frac{205.835}{1000}$ + 0.02) × 1000

Fine Aggregate = 1 – (0.1154 + 0.3807 +0.2058 + 0.02) × 1000

Fine Aggregate = 1 – (0.722) × 1000

Fine Aggregate = 735.454 kg $/m^3$

Thus, the computed fine aggregate Content is 735.454 kg$/m^3$

Step 6: Addition of Sisal fibers

Sisal fibers were incorporated at 1 %, 2 %, and 3 % by volume of cement. the fiber content was adjusted carefully to prevent segregation and maintain workability.

Step 7: Adjustment for Moisture Content

Moisture content in the aggregates was considered, and appropriate adjustments were made to the water and aggregate content.

Step 8: Trial Mix and Adjustments

A laboratory trial mix was conducted, and minor adjustments were made to optimize workability, strength, and durability.

A.4 Final Mix Proportions (per 1m^3 of concrete)

Material	**Quantity (kg/m^3)**
Cement	363.48
Water	205.835
Coarse Aggregate	1027.808
Fine Aggregate	735.454
W/ C Ratio	0.56
Sisal Fiber	1 %, 2 %, 3 % by volume of cement

A.5 Conclusion

This mix design follows the ACI 211.1 method while incorporating sisal fibers to analyze their effect on compressive, tensile, and flexural strength. Laboratory validation confirms that the mix meets the required workability and strength criteria for structural applications.

Appendix B: Test Results

B1: Tensile Strength tests

Mix code: M_0(fiber length 0 mm & fiber content 0 %)

Table B1: 7^{th} & 28^{th} day Tensile Strength test results 0 mm & 0 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
		L	D			$\sigma = {}^{2p}/_{\pi LD}$
7	1	20	10	1570.8	61.030	1.94
	2	20	10	1570.8	60.140	1.91
	3	20	10	1570.8	59.500	1.89
Mean						1.92
28	1	20	10	1570.8	83.75	2.67
	2	20	10	1570.8	82.48	2.63
	3	20	10	1570.8	79.97	2.55
Mean						2.61

Mix code: M_1(Sisal fiber length 10 mm & fiber content 1 %)

Table B2: 7^{th} & 28^{th} day Tensile Strength test results for 10 mm & 1 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
		L	D			$\sigma = {}^{2p}/_{\pi LD}$
7	1	20	10	1570.8	70.12	2.23
	2	20	10	1570.8	60.16	1.98
	3	20	10	1570.8	65.53	2.09
Mean						2.10
	1	20	10	1570.8	92.06	2.93

28	2	20	10	1570.8	89.87	2.86
	3	20	10	1570.8	91.24	2.90
Mean						2.90

Mix code: M_2(Sisal fiber length 10 mm & fiber content 2 %)

Table B3: 7^{th} & 28^{th} day Tensile Strength test results for 10 mm & 2 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
						$\sigma = {}^{2p}/_{\pi LD}$
		L	D			
7	1	20	10	1570.8	73.95	2.35
	2	20	10	1570.8	76.07	2.42
	3	20	10	1570.8	75.76	2.41
Mean						2.40
28	1	20	10	1570.8	109.42	3.48
	2	20	10	1570.8	97.41	3.10
	3	20	10	1570.8	103.79	3.30
Mean						3.30

Mix code: M_3(Sisal fiber length 10 mm & fiber content 3 %)

Table B4: 7^{th} & 28^{th} day Tensile Strength test results for 10 mm & 3 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
						$\sigma = {}^{2p}/_{\pi LD}$
		L	D			
7	1	20	10	1570.8	74.02	2.36
	2	20	10	1570.8	73.17	2.33
	3	20	10	1570.8	70.23	2.24
Mean						2.31

28	1	20	10	1570.8	100.51	3.20
	2	20	10	1570.8	98.27	3.13
	3	20	10	1570.8	94.75	3.02
Mean						3.11

Mix code: M_4(Sisal fiber length 15 mm & fiber content 1 %)

Table B5: 7^{th} & 28^{th} day Tensile Strength test results for 15 mm & 1 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
		L	D			$\sigma = {2p}/{\pi LD}$
7	1	20	10	1570.8	79.06	2.52
	2	20	10	1570.8	82.12	2.55
	3	20	10	1570.8	77.24	2.46
Mean						2.51
28	1	20	10	1570.8	109.97	3.50
	2	20	10	1570.8	110.40	3.51
	3	20	10	1570.8	109.34	3.48
Mean						3.50

Mix code: M_5(Sisal fiber length 15 mm & fiber content 2 %)

Table B6: 7^{th} & 28^{th} day Tensile Strength test results for 15 mm & 2 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
		L	D			$\sigma = {2p}/{\pi LD}$
7	1	20	10	1570.8	92.10	2.93
	2	20	10	1570.8	87.74	2.79
	3	20	10	1570.8	84.71	2.70

Mean						2.81
28	1	20	10	1570.8	132.87	4.23
	2	20	10	1570.8	124.76	3.79
	3	20	10	1570.8	128.77	4.10
Mean						4.10

Mix code: M_6(Sisal fiber length 15 mm & fiber content 3 %)

Table B7: 7^{th}& 28^{th} day Tensile Strength test results for 15 mm & 3 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
		L	D			$\sigma = {2p}/{\pi LD}$
7	1	20	10	1570.8	83.50	2.66
	2	20	10	1570.8	80.82	2.57
	3	20	10	1570.8	80.42	2.56
Mean						2.60
28	1	20	10	1570.8	129.56	4.12
	2	20	10	1570.8	107.65	3.43
	3	20	10	1570.8	120.50	3.84
Mean						3.80

Mix code: M_7(Sisal fiber length 20 mm & fiber content 1 %)

Table B8: 7^{th}& 28^{th} day Tensile Strength test results for 20 mm & 1 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
		L	D			$\sigma = {2p}/{\pi LD}$
7	1	20	10	1570.8	74.50	2.37
	2	20	10	1570.8	69.78	2.22

	3	20	10	1570.8	72.61	2.31
Mean						2.30
28	1	20	10	1570.8	103.53	3.30
	2	20	10	1570.8	99.87	3.18
	3	20	10	1570.8	98.25	3.13
Mean						3.20

Mix code: M_8(Sisal fiber length 20 mm & fiber content 2 %)

Table B9: 7^{th} & 28^{th} day Tensile Strength test results for 20 mm & 2 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
		L	D			$\sigma = {2p}/{\pi LD}$
7	1	20	10	1570.8	80.120	2.55
	2	20	10	1570.8	79.780	2.54
	3	20	10	1570.8	76.230	2.43
Mean						2.51
28	1	20	10	1570.8	115.430	3.67
	2	20	10	1570.8	114.560	3.65
	3	20	10	1570.8	109.760	3.49
Mean						3.60

Mix code: M_9(Sisal fiber length 20 mm & fiber content 3 %)

Table B10: 7^{th} & 28^{th} day Tensile Strength test results for 20 mm & 3 %

Test age	Sample no.	Length (cm)	Diameter (cm)	Volume (cm^3)	Failure load (kN)	Splitting tensile strength (Mpa)
		L	D			$\sigma = {2p}/{\pi LD}$
	1	20	10	1570.8	74.23	2.36

7	2	20	10	1570.8	75.34	2.40
	3	20	10	1570.8	76.54	2.44
Mean						2.40
28	1	20	10	1570.8	103.57	3.30
	2	20	10	1570.8	108.57	3.46
	3	20	10	1570.8	109.44	3.48
Mean						3.41

B 2: Flexural strength Taste

Mix Code: M_0(fiber length 0 mm and fiber content 0 %)

Table B11.1: 7^{th} &28^{th} day's Flexural Strength test results for 0 mm and 0 %.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$^{PL}/_4$	I=$^{bd^3}/_{12}$	C=$^D/_2$	$\sigma = \frac{Mc}{I}$
7	1	50	10	10	4.19	0.52375	833.33	5	3.1425
	2	50	10	*10*	4.14	0.5175	833.33	5	3.105
	3	50	10	10	4.165	0.520625	833.33	5	3.12387
	Mean								3.124
28	1	50	10	10	5.08	0.635	833.33	5	3.81
	2	50	10	10	5.19	0.64875	833.33	5	3.8925
	3	50	10	10	5.635	0.704375	833.33	5	4.226267
	Mean								3.976

Mix Code: M_1(Sisal fiber length 10 mm and fiber content 1 %)

Table B12: 7^{th} &28^{th} day's Flexural Strength test results for 10 mm and 1 %.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$^{PL}/_4$	I=$^{bd^3}/_{12}$	C=$^{D}/_2$	$\sigma = \frac{Mc}{I}$
7	1	50	10	10	5.01	0.62625	833.33	5	3.7575
	2	50	10	10	4.65	0.58125	833.33	5	3.4875
	3	50	10	10	4.6	0.575	833.33	5	3.45
	Mean								3.565
28	1	50	10	10	6.17	0.77125	833.33	5	4.6275
	2	50	10	10	6.08	0.76	833.33	5	4.56
	3	50	10	10	5.99	0.74875	833.33	5	4.4925
	Mean								3.05

Mix Code: M_2(Sisal fiber length 10 mm and fiber content 2 %)

Table B13: 7^{th} &28^{th} day's Flexural Strength test results for 10 mm and 2 %.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$^{PL}/_4$	I=$^{bd^3}/_{12}$	C=$^{D}/_2$	$\sigma = \frac{Mc}{I}$
7	1	50	10	10	5.22	0.6525	833.33	5	3.915
	2	50	10	10	5.67	0.70875	833.33	5	4.2525
	3	50	10	10	5.09	0.63625	833.33	5	3.8175
	Mean								3.995
28	1	50	10	10	6.87	0.85875	833.33	5	5.1525
	2	50	10	10	7.02	0.8775	833.33	5	5.2650
	3	50	10	10	6.55	0.81875	833.33	5	4.9125
	Mean								5.11

Mix Code: M_3(Sisal fiber length 10 mm and fiber content 3 %)

Table B14: 7^{th} &28^{th} day's Flexural Strength test results for 10 mm and 3%.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$PL/4$	I=$bd^3/12$	C=$D/2$	$\sigma = \frac{Mc}{I}$
7		50	10	10	5.12	0.64	833.33	5	3.84
		50	10	10	5.07	0.63375	833.33	5	3.8025
		50	10	10	4.97	0.62125	833.33	5	3.7275
	Mean								3.79
28		50	10	10	6.79	0.84875	833.33	5	5.0925
		50	10	10	6.54	0.8175	833.33	5	4.9050
		50	10	10	6.24	0.78	833.33	5	4.68
	Mean								4.8925

Mix Code: M_4(Sisal fiber length 15 mm and fiber content 1 %)

Table B15: 7^{th} &28^{th} day's Flexural Strength test results for 15 mm and 1 %.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$PL/4$	I=$bd^3/12$	C=$D/2$	$\sigma = \frac{Mc}{I}$
7	1	50	10	10	5.93	0.74125	833.33	5	4.4475
	2	50	10	10	5.77	0.72125	833.33	5	4.3275
	3	50	10	10	5.66	0.7075	833.33	5	4.2450
	Mean								4.34
	1	50	10	10	7.54	0.9425	833.33	5	5.6550

28	2	50	10	10	7.12	0.89	833.33	5	5.34
	3	50	10	10	7.13	0.89125	833.33	5	5.3475
	Mean								5.4475

Mix Code: M_5(Sisal fiber length 15 mm and fiber content 2 %)

Table B16: 7^{th} &28^{th} day's Flexural Strength test results for 15 mm and 2 %.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$PL/4$	I=$bd^3/12$	C=$D/2$	$\sigma = \frac{Mc}{I}$
7	1	50	10	10	6.41	0.80125	833.33	5	4.8075
	2	50	10	10	6.72	0.84	833.33	5	5.04
	3	50	10	10	5.97	0.74625	833.33	5	4.4775
	Mean								4.775
28	1	50	10	10	8.02	1.0025	833.33	5	6.015
	2	50	10	10	8.12	1.015	833.33	5	6.09
	3	50	10	10	7.88	0.985	833.33	5	5.91
	Mean								6.005

Mix Code: M_6(Sisal fiber length 15 mm and fiber content 3 %)

Table B17: 7^{th} &28^{th} day's Flexural Strength test results for 15 mm and 3 %.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$PL/4$	I=$bd^3/12$	C=$D/2$	$\sigma = \frac{Mc}{I}$
	1	50	10	10	5.87	0.73375	833.33	5	4.4025

7	2	50	10	10	5.98	0.7475	833.33	5	4.4850
	3	50	10	10	5.93	0.74125	833.33	5	4.4475
	Mean								4.445
28	1	50	10	10	7.07	0.88375	833.33	5	5.3025
	2	50	10	10	7.80	0.975	833.33	5	5.85
	3	50	10	10	7.40	0.925	833.33	5	5.55
	Mean								5.5675

Mix Code: M_7(Sisal fiber length 20 mm and fiber content 1 %)

Table B18: 7^{th} &28^{th} day's Flexural Strength test results for 20 mm and 1 %.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$^{PL}/_4$	I=$^{bd^3}/_{12}$	C=$^{D}/_2$	$\sigma = \frac{Mc}{I}$
7	1	50	10	10	5.21	0.65125	833.33	5	3.9075
	2	50	10	10	5.82	0.7275	833.33	5	4.3650
	3	50	10	10	5.02	0.6275	833.33	5	3.765
	Mean								4.01
28	1	50	10	10	6.61	0.8275	833.33	5	4.9650
	2	50	10	10	7.12	0.89	833.33	5	5.34
	3	50	10	10	6.29	0.78625	833.33	5	4.7175
	Mean								5.00

Mix Code: M_8(Sisal fiber length 20 mm and fiber content 2 %)

Table B19: 7^{th} &28^{th} day's Flexural Strength test results for 20 mm and 2 %.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$PL/4$	I=$bd^3/12$	C=$D/2$	$\sigma = \frac{Mc}{I}$
7	1	50	10	10	5.91	0.73875	833.33	5	4.4325
	2	50	10	10	5.48	0.685	833.33	5	4.11
	3	50	10	10	5.51	0.68875	833.33	5	4.1325
	Mean								4.225
28	1	50	10	10	7.22	0.9025	833.33	5	5.415
	2	50	10	10	6.98	0.8725	833.33	5	5.235
	3	50	10	10	7.12	0.89	833.33	5	5.34
	Mean								5.33

Mix Code: M_9(Sisal fiber length 20 mm and fiber content 3 %)

Table B20: 7^{th} &28^{th} day's Flexural Strength test results for 20 mm and 3 %.

Test age (days)	Sample no.	Dimensions (cm)			Failure load (kN)	Max moment (kNm)	Moment of Inertia (cm^4)	Centroidal depth (cm)	Bending Strength (Mpa)
		L	B	D	P	M=$PL/4$	I=$bd^3/12$	C=$D/2$	$\sigma = \frac{Mc}{I}$
7	1	50	10	10	5.33	0.66625	833.33	5	3.9975
	2	50	10	10	6.01	0.75125	833.33	5	4.5075
	3	50	10	10	5.12	0.64	833.33	5	3.84
	Mean								4.115
28	1	50	10	10	6.68	0.835	833.33	5	5.01
	2	50	10	10	7.25	0.90625	833.33	5	5.4375
	3	50	10	10	6.51	0.81375	833.33	5	4.8825
	Mean								5.11

B3: Compressive Strength Testes

Mix Code: M_0(Sisal fiber length 0 mm and fiber content 0 %)

Table B21: 7^{th} &28^{th} day's Compressive strength test results for 0 mm and 0 %.

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
7	1	10	10	10	1000	180.02	18.0	18.79
	2	10	10	10	1000	179.11	17.91	16.80
	3	10	10	10	1000	181.02	18.10	20.00
	Mean						18.01	18.54
28	1	10	10	10	1000	250.3	25.03	25.85
	2	10	10	10	1000	247.6	24.76	25.81
	3	10	10	10	1000	254.01	25.40	25.79
	Mean						25.06	26.01

Mix Code: M_1(Sisal fiber length10 mm and fiber content 1 %)

Table B22: 7^{th} &28^{th} day's Compressive strength test results for10 mm and 1 %.

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
7	1	10	10	10	1000	175.70	17.57	25.01
	2	10	10	10	1000	184.07	18.41	25.86
	3	10	10	10	1000	181.61	18.16	29.58
	Mean						18.05	26.82
	1	10	10	10	1000	256.02	25.60	32.25

28	2	10	10	10	1000	263.02	26.30	32.53
	3	10	10	10	1000	261.00	26.10	29.78
						Mean	26.00	31.52

Mix Code: M_2(Sisal fiber length10 mm and fiber content 2 %)

Table B23: 7^{th} &28^{th} day's Compressive strength test results for10 mm and 2 %.

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
7	1	10	10	10	1000	198.98	19.90	31.41
	2	10	10	10	1000	199.06	19.91	30.05
	3	10	10	10	1000	208.20	20.82	29.33
						Mean	20.21	30.26
28	1	10	10	10	1000	287.98	28.80	32.51
	2	10	10	10	1000	281.08	28.11	32.29
	3	10	10	10	1000	288.99	28.90	28.65
						Mean	28.60	31.17

Mix Code: M_3(Sisal fiber length10 mm and fiber content 3 %)

Table B24: 7^{th} &28^{th} day's Compressive strength test results for10 mm and 3 %.

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
7	1	10	10	10	1000	200.00	20.00	26.72
	2	10	10	10	1000	189.78	18.98	24.96
	3	10	10	10	1000	195.36	19.54	29.72
						Mean	19.50	27.13

28	1	10	10	10	1000	281.21	28.12	31.88
	2	10	10	10	1000	268.94	26.89	25.81
	3	10	10	10	1000	271.95	27.20	35.69
	Mean						27.40	31.13

Mix Code: M_4(Sisal fiber length15 mm and fiber content 1 %)

Table B25: 7^{th} &28^{th} day's Compressive strength test results for15 mm and 1 %.

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
7	1	10	10	10	1000	214.22	21.42	17.37
	2	10	10	10	1000	198.97	19.90	16.33
	3	10	10	10	1000	210.84	21.08	17.65
	Mean						20.80	17.12
28	1	10	10	10	1000	294.99	29.50	24.59
	2	10	10	10	1000	287.43	28.74	20.34
	3	10	10	10	1000	290.87	29.09	24.06
	Mean						29.11	22.69

Mix Code: M_5(Sisal fiber length15 mm and fiber content 2 %)

Table B26: 7^{th} &28^{th} day's Compressive strength test results for15 mm and 2 %.

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
7	1	10	10	10	1000	220.05	22.01	25.23
	2	10	10	10	1000	210.43	21.04	26.41
	3	10	10	10	1000	241.50	24.15	23.26

						Mean	22.40	24.97
28	1	10	10	10	1000	308.74	30.87	30.46
	2	10	10	10	1000	313.98	31.40	34.29
	3	10	10	10	1000	325.2	32.52	32.92
						Mean	31.60	32.56

Mix Code: M_6(Sisal fiber length15 mm and fiber content 3 %)

Table B27: 7^{th} &28^{th} day's Compressive strength test results for15 mm and 3 %.

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
7	1	10	10	10	1000	211.880	21.19	27.69
	2	10	10	10	1000	200.850	20.09	22.25
	3	10	10	10	1000	220.180	22.02	26.51
						Mean	21.10	25.45
28	1	10	10	10	1000	294.340	29.43	34.41
	2	10	10	10	1000	304.130	30.41	25.62
	3	10	10	10	1000	301.770	30.18	34.75
						Mean	30.01	31.49

Mix Code: M_7(Sisal fiber length20 mm and fiber content 1 %)

Table B28: 7^{th} &28^{th} day's Compressive strength test results for20 mm and 1 %.

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
7	1	10	10	10	1000	193.53	19.35	19.25
	2	10	10	10	1000	200.01	20.00	17.23

	3	10	10	10	1000	194.75	19.48	20.85
						Mean	19.61	19.11
28	1	10	10	10	1000	270.15	27.02	27.71
	2	10	10	10	1000	276.87	27.69	27.83
	3	10	10	10	1000	269.11	26.91	25.06
						Mean	27.20	26.87

Mix Code: M_8(Sisal fiber length20 mm and fiber content 2%)

Table B29: 7^{th} &28^{th} day's Compressive strength test results for20 mm and 2 %

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
7	1	10	10	10	1000	199.65	19.97	19.63
	2	10	10	10	1000	203.6	20.36	17.06
	3	10	10	10	1000	218.19	21.82	18.30
						Mean	20.71	18.34
28	1	10	10	10	1000	273.11	27.31	25.29
	2	10	10	10	1000	290.01	29.00	26.79
	3	10	10	10	1000	304.2	30.42	25.11
						Mean	28.91	25.79

Mix Code: M_9(Sisal fiber length20 mm and fiber content 3 %)

Table B30: 7^{th} &28^{th} day's Compressive strength test results for20 mm and 3 %.

Test age days	Sample No.	Dimensions (cm)			Volume (cm^3)	Failure Load (kN)	100cube Compressive strength (Mpa)	150 cube Compressive strength (Mpa)
		L	B	D				
	1	10	10	10	1000	198.95	19.90	16.83

7	2	10	10	10	1000	201.8	20.18	17.25
	3	10	10	10	1000	196.54	19.65	17.67
	Mean						19.91	17.24
28	1	10	10	10	1000	271.74	27.17	24.80
	2	10	10	10	1000	299.43	29.94	26.32
	3	10	10	10	1000	263.23	26.32	25.52
	Mean						27.81	25.51

Appendix C: Tests for Constituent Materials

Aggregate needs to be standardized because concrete strength and quality depends on physical properties, mechanical properties and chemical composition of the parent aggregate making materials. All physical tests conducted for both fine & coarse aggregate were discussed by the following session:

i, Sieve Analysis

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

Test Results:

Table C. 1: Particle size distribution for coarse aggregate

Sieve size (mm)	Weight of sieve (gm)	Wt. of sieve and retained (gm)	Weight Retained (gm)	Percentage Retained (%)	Cumulative coarse (%)	Cumulative Passing (%)
37.5			0	0	0	100
19	1389	1439	100	5	5	95
12.5	1166	1766	600	30	35	65
9.5	1173	1873	700	35	70	30
4.75	1175	1615	440	22	92	80

Pan	735	95	180	8	−	−
				Total	202	

Calculation:

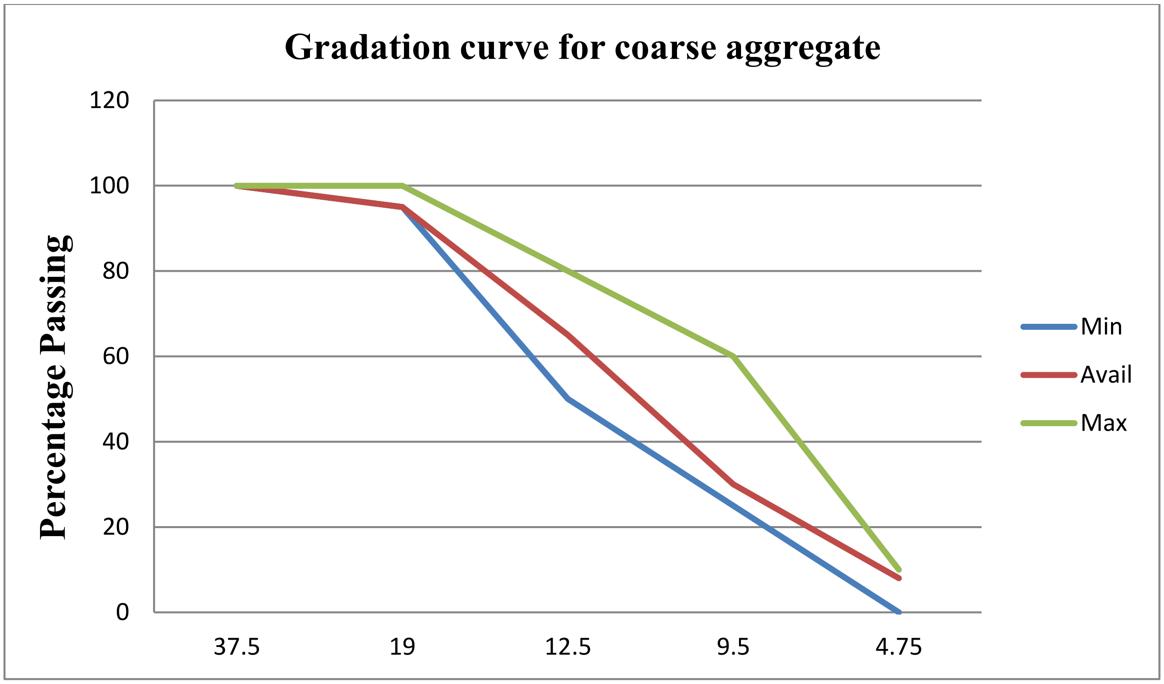
$$F.M = \frac{\sum cummulativ\ coarse\ (\%)}{100} = \frac{202}{100} = 2.02\%$$

Where: F.M =the Fineness Modulus of the aggregate

A requirement from the Ethiopian Standard for grading coarse aggregate regarding ranges of percentage passing through each sieves are presented in Table C.2 shown below.

Table C.2: Ethiopian Standard for grading of coarse aggregate (ESC.D3.201)

Normal of aggregate, mm	Percentage passing through test sieves having square opening						
	75mm	63mm	37.5mm	19mm	13.2mm	9.5mm	4.75mm
38 − 5	100	−	95− 100	30 − 70	−	10 − 35	0 − 5
19 − 5	−	−	100	95 − 100	−	25 − 55	0 − 5
13 − 5	−	−	−	100	90 − 100	40 − 85	0 − 10



FigureC.1 Gradation curve for coarse aggregate

Comment

All the coarse aggregate samples were blended to keep gradation requirement within the range and hence it is basic to prepare good quality concrete.

Specific gravity and water absorption

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

An approximate aggregate sample of 5kg was required by using quartering from the mass sample. All aggregate materials passing No. 4(4.75mm) sieve were rejected.

Test Results: where:

A= 4939g A= weight of oven dry sample in air, [g]

B=5027g B= weight of saturated- surface-dry sample in air, [g]

C=3230g C=weight of saturated sample in water, [g] Calculation:

Bulk Specific Gravity

$$\text{Bulk sp gr} = \frac{A}{B-C}$$

$$\text{Bulk sp gr} = \frac{4936}{5027-3230} = 2.75$$

Bulk Specific Gravity (Saturated-Surface Dry basis):

$$\text{Bulk Sp gr (SSD basis)} = \frac{B}{B-C}$$

$$\text{Bulk sp gr (SSD basis)} = \frac{5027}{5027-3230} = 2.80$$

Apparent Specific Gravity:

$$\text{Apparent sp gr} = \frac{A}{A-C}$$

$$\text{Apparent sp gr} = \frac{4936}{4936-3230} = 2.89$$

Absorption Capacity:

$$\text{Absorption Capacity (\%)} = \frac{B-A}{A} * 100$$

$$\text{Absorption Capacity (\%)} = \frac{5027-4936}{4936} \times 100 = 1.84\%$$

Moisture Content of coarse aggregate:

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

Test Results:	Where
A=2000g	A= weight of original sample [g]
B=1960g	B= weight of oven dry sample [g]
	W = Moisture content (%)

Calculation

W (%) =$\frac{A-B}{B}$ *100

W (%) = $\frac{2000-1960}{1960}$ ×100 =2.04%

Comment:

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

Unit weight of aggregates

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

Test Results:

Weight of the Measuring apparatus =4841gm.

Weight of sample + Measuring apparatus = 28054gm.

Calculation:

Dimension of the measuring apparatus:

Inside diameter =253mm

Inside height of the measure = 275mm

Volume of the measuring apparatus:

$$V = \frac{\pi h D^2}{4} = \frac{3.14 \times 0.275 \times 0.253^2}{4} = 0.01382 m^3$$

Unit weight of CA $\frac{28054-4841}{0.01382}$= 1679.67Kg/$m^3$

C 2: Tests for Fine Aggregates

Silt Content

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

Test Results: Where

A= 10ml A= amount of silt deposited above the sand.

B= 290ml B= amount of clean sand.

Calculation:

Silt Content (%) $= \frac{A}{B} * 100$

Silt Content (%) $= \frac{10}{290} \times 100 = 3.45 < 6 \ldots\ldots Ok!$

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

Sieve Analysis

The objective of the test is to determine the particle size distribution of fine aggregates. Table C.3 and C.4 below summarize the particle size distribution as per the Ethiopian Standard for the grading fine aggregate.

Test Results

Table C.3: particle size distribution for fine aggregate

Sieve size	Weight of sieve (gm)	Weight sieve and retained(gm)	Weight of retained (gm)	Percentage retained (%)	Cumulative retained (%)	Cumulative passing (%)
9.5	585	585	0	0	0	100
4.75	426	434	8	1.6	1.6	98.4
2.36	388	407	19	3.8	5.4	94.6

1.18	372	432	60	12	17.4	82.4
0.6	325	486	161	32.2	49.6	50.4
0.3	301	493	192	38.4	88	12.0
0.15	272	321	49	9.8	97.8	2.2
Pan	243	254	11	2.2	–	–
Total					259.8	

Fineness modulus F.M= $\frac{\sum cumulative\ retained\ (\%)}{100}$

$$F.M = \frac{259.8(\%)}{100} = 2.58 \sim 2.6\%$$

Table C.4 the Ethiopian Standard for grading of fines aggregate (ESC.D3.201)

Sieve size	9.50mm	4.75mm	2.36mm	1.18mm	0.6mm	0.3mm	0.15mm
Percentage passing	100	95 – 100	80 – 100	50 -85	25 – 60	10 – 30	2 – 10

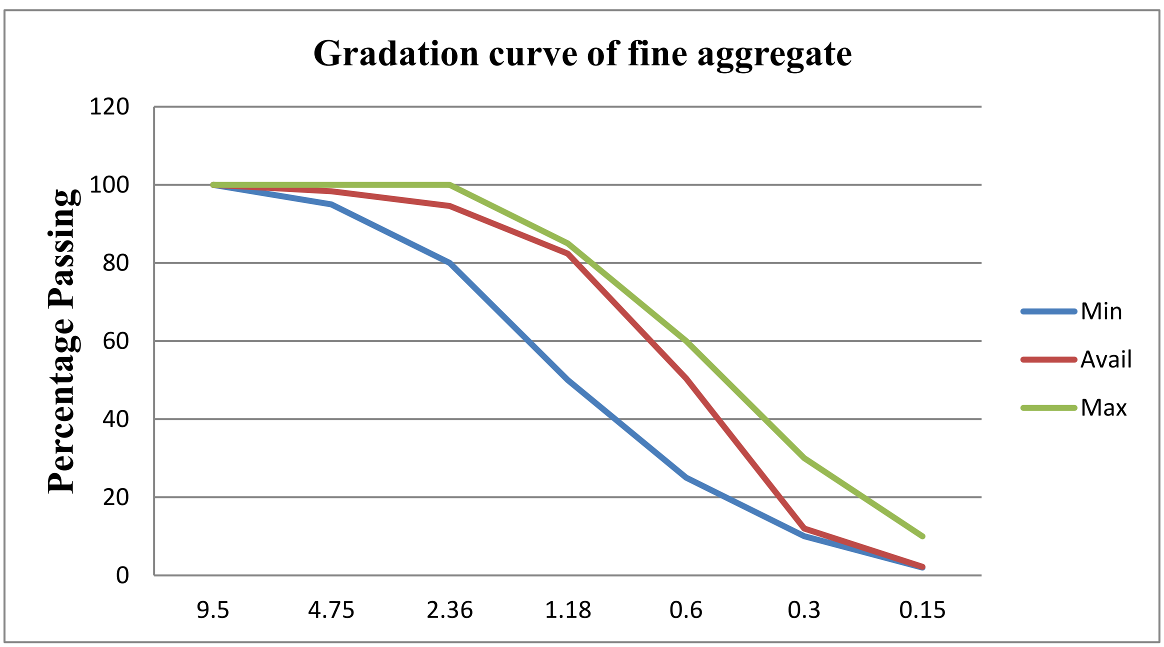


Figure C.2: Gradation curve for fine aggregate

Comment:

The Sand sample purchased was tested to check if the material has a particle size distribution within the range of the Ethiopian Standard for the grading of the fine aggregate. Thus it satisfies the gradation requirement.

Specific gravity and absorption capacity

The objective of this test is to determine bulk and apparent specific gravity, and absorption capacity of the fine aggregates.

Sample tests were prepared and the procedures for the setup followed in accordance with the guide of Construction Materials Laboratory Manual by Abebe Dinku. Tests results were presented as shown below.

Test Results:

Weight of sample = 500g

Test results for the computation of specific gravity & absorption fine aggregate

Where

W= 320g — W = weight of pycnometer .gm.

V= 975.39ml — V = Volume of flask/ container

Va = 769.80ml — Va =Volume of water added to pycnometer [cm^3]

A = 475g — A = weight of oven dry sample in air, [g]

Calculation: — where

C = 0.9976Va +500+w — C = weight of pycnometer filled with sample plus water,[g]

= 0.9975(769.80)+500+320 — B = weight of flask filled with water, [g]

=1587.95g

B =0.9976V+W

=0.9976(975.39)+320 = 1,293.05g

Bulk Specific gravity

Bulk Sp gr = $\frac{A}{B+500-c}$

Bulk Sp gr = $\frac{475}{1293.05+500-1587.95} = 2.32$

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

Bulk Sp gr (SSD basis) = $\frac{500}{B+500-C}$

Bulk Sp gr (SSD basis) = $\frac{500}{1293.05+500-1587.95}$ = 2.44

Apparent Specific gravity:

Apparent Sp gr = $\frac{A}{B+500-C}$

Apparent Sp gr = $\frac{475}{1293.05+475-1587.95}$ = 2.64

NB: In the computation of quantities for concrete mixes it is the specific gravity of Saturated – Surface –Dry (SSD) aggregates.

Absorption:

Absorption Capacity (%) = $\frac{500-A}{A} * 100$

Absorption Capacity (%) = $\frac{500-475}{475} \times 100$ = 5.26%

Moisture Content

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

Test Results

A= 500g

B = 485g

Where:

A = weight of original sample [g]

B= weight of oven dry sample [g]

Calculation

Where

$W(\%) = \frac{A-B}{B} * 100$ W = Moisture Content

$W(\%) = \frac{500-485}{485} \times 100 = 3.1\%$

Appendix D: Sample Photo gallery taken during the Research

Photo: Cement used the mix

Photo: Mechanical mixer

Photo: Flexural testing machine

Photo: Compression testing machine

Photo: Spilt tensile testing machine

Photo: Workability test using Slump

Photo: coarse aggregate

Photo: Fine aggregate