ACCELERATED DURABILITY STUDY ON GLASS FIBER CONCRETE

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THEAWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY

IN

STRUCTURAL ENGINEERING

Submitted by:

Rafat Bano

(2K21/STE/23)

Under the supervision of

Dr. Awadhesh Kumar

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of
Engineering) Bawana Road,
Delhi-110042

May, 2023

M.Tech (Structural Engineering)

Rafat Bano

2023

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, **Rafat Bano**, Roll No. 2K21/STE/23, student of M. Tech (Structural Engineering), hereby declare that the project dissertation entitled "**Accelerated durability study on glass fiber concrete**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the awardof the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi **(RAFAT BANO)**

Date: May 31, 2023

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of
Engineering)Bawana Road, Delhi-
110042

CERTIFICATE

I hereby certify that the Project Dissertation entitled "**Accelerated durability study on glass fiber concrete**" which is submitted by **Rafat Bano**, Roll No. 2K21/STE/23, to Department of CivilEngineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by her under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
Date: May 31, 2023

(Dr. AWADHESH KUMAR)
PROFESSOR

SUPERVISOR
Department Of Civil Engineering

ACKNOWLEDGEMENT

I sincerely take this opportunity to acknowledge the debt of gratitude that I owe to my supervisor Dr. Awadhesh Kumar for his consistent guidance throughout the journey. He has helped me by means of his vast knowledge and expertise of the course content. He provided the desired impetus when things were not turning in the favor, which really helped me to achieve the anticipated goals within a given time frame. It is my fortune that, I got an opportunity to work under his guidance for my Major Projects. I wish that my learning under his guidance continues forever. At the last, I would like to extend a token of thanks to my parents, whose uninterrupted efforts have been a constant motivation throughout the journey.

ABSTRACT

Concrete has been a popular material choice for construction structures, including in cold regions and areas with high salt content. However, these environmental factors can have a significantly damaging impact on the properties of the concrete. As a results, this deterioration will shorten the life of the concrete construction in this climate. Durability is the concrete property that governs the lifespan and serviceability of a structure in relation to its intended use. The main criteria that determine the longevity and performance of concrete are the surrounding environment conditions. Analyzing the impact of chemical attacks may be critical for understanding the durability of concrete structures. Since sulphate attacks are the most common chemical attacks on concrete structures, their investigation can help to explain how they deteriorate and then fails. Sulphate attack has been frequently recognized to reduce the durability of concrete. In this study, glass fiber concrete exposed to accelerated effect in 10% sodium sulphate has been investigated. The changes in strength of concrete specimens were measured after a certain number of deterioration cycles to assess the level of sulphate attack. Concrete cubes, cylinders, and beams were tested for compressive strength, tensile strength, and flexural strength respectively. Compressive strength, flexural strength and tensile strength all were found to increase with increase in fiber content. Maximum strength was gained at a fiber content of 1%. Results obtained from durability test were compared to actual compressive, flexural, and tensile strength. Addition of glass fiber in concrete has been shown to improve resistance to sulphate attack.

Keywords: Durability, sodium sulphate, wetting-drying, compressive strength, tensile strength, flexural strength, sodium sulphate, and glass fiber.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is a widely utilized artificial material in civil engineering, with annual global production reaching 10,000 million tonnes. [1]. As concrete technology has developed, it has become a popular material choice for constructing structures that are exposed to extreme conditions such as cold regions and areas with high salt content. Concrete is among the most frequently utilized building material, with numerous advantageous features such as high compressive strength, durability, and stiffness under ordinary environmental conditions[2]. Concrete is famous for shatter easily under low-level tensile stress because of its intrinsic weakness in resisting tensile forces. The most valuable aspects of concrete are its strength and durability. Concrete considered to be one of the maximum long-lasting construction materials. Ordinary concrete has low tensile strength, ductility, and crack resistance. Several factors affect the aspects of concrete, including its strength, durability, and other characteristics. These factors include the types and amount of ingredients used, the proportions of the mixture, the compaction method employed, and controls utilized during the placement, compaction, and curing phases[3]. Beyond increasing tensile strength, the inclusion of fibers into concrete has several advantages. It also enhances fracture toughness, durability, and other critical qualities. Inspired by the traditional use of natural fiber techniques, artificial fibers are now routinely employed to upgrade the mechanical qualities of concrete. The introduction of vitreous, synthetic, steel, carbon, and glass fibers used in concrete have positive results in terms of improving the variety of concrete qualities. In general, including fibers into concrete mixes greatly improves tensile strength, flexural strength, fatigue resistance, wear resistance, deformation capability, load-bearing capacity after cracking, and toughness. The presence of fibers in the concrete matrix improves overall performance and durability by increasing its resistance to external forces and stresses. The fibers serve as reinforcements, assisting in the distribution and dissipation of stresses throughout the material, resulting in increased strength and resistance to cracking or failure. Furthermore, the presence of fibers could make concrete's ductility and energy absorption capacity, making it more resistant to dynamic loads and harsh weather conditions. Glass fiber is one among the most commonly utilized and popular fibers in both research and practice. Numerous works on experimental and empirical methods for measuring the strength characteristics of glass fiber reinforced concrete (GFRC) have been published in the last decades, taking into account concrete grades, concrete kinds, curing period, and aspect ratio. Moreover, it is now widely known that the introduction of glass fiber can significantly enhance the mechanical properties of concrete, particularly tensile strength and fracture toughness. Comparison to carbon fiber, glass fiber is less expensive. Additionally, all types of glass fibers possess certain unique characteristics such as being invisible on the finished surface.

GFRC is a kind of concrete that has glass fibers in its composition. The fibers are created by drawing glass strands into thin filaments and then weaving them together to produce a mesh-like structure. Glass fibers upgrade the strength, durability, and ductility of concrete when added to it. Glass fiber provides various advantages over typical reinforcement materials such as steel when used in concrete. Glass fiber is a non-corrosive substance, which means it is unlikely to rust or deteriorate as time passes, regardless of extreme conditions. As a result, it is an excellent solution for constructions subjected to high amounts of moisture or salt, such as bridges, tunnels, and coastal structures. Furthermore, glass fiber is much lighter than steel. It also allows for more design flexibility because the materials reduced weight enables for smaller sections and more complicated designs to be created. Glass fibers are created by drawing tiny strands of glass into thin filaments. The filaments are subsequently woven up to form a mesh-like structure that can be implemented as a reinforcing material in concrete along with insulation composites, and textiles. Glass fibers used in construction include alkali-resistant glass fibers, which are specially developed to resist deterioration in alkaline environments such as concrete. Various kinds of glass fibers may be better suited for usage in other applications.

Glass fibers have various characteristics that make them an appealing choice for use in building, in addition to their strength and durability. They are non-combustible, for example, which means they will not burn or contribute to the spread of flames in the event of a fire. They are also insect, rodent, and pest resistant, which can be an issue in some construction applications. Thus, glass fibers are versatile and long-lasting material that outperforms standard reinforcement materials such as steel. They are gaining popularity in the construction industry, particularly in applications requiring strength, endurance, and corrosion resistance. Concrete construction has to be exposed to the combined consequences of wetting-drying cycles and sulphate assault in certain conditions.

External sulphate attack on concrete is a complicated interaction among physical, chemical, and mechanical reactions that reduce concrete durability. When dynamical sulphate assaulting along with a wetting-drying cycle is applied to structural concrete instead of continually immersed in a sulphate solution, the damage to that structural concrete is greatly accelerated.

1.2 HISTORY

Glass fibers were first used in the early 1930s when a researcher named Games Slayter discovered a method to make glass fibers in a laboratory setting. Although it was not until the 1950s that glass fibers were widely exploited in a wide range of applications. Glass fibers were largely used in the aerospace sector as a reinforcement material for composite materials throughout the 1950s, the reason for this was because of glass fiber's distinctive characteristics, such as its excellent strength, stiffness, and lightweight. Glass fibers were first employed in the construction industry as a reinforcing element for concrete in the 1960s. As a conclusion, GFRC was developed, which had numerous advantages over conventional concrete, such as enhanced strength and durability, improved crack resistance, and light weight. Glass fibers have since been employed in a range of applications, including insulation, filtration, and composite material reinforcing. Glass fiber technological advancements have also created in the of new types of glass fibers with improved feature such as high-temperature resistance and higher tensile strength. Glass fibers are now extensively used in a wide range of industries along with construction, aerospace, automotive, and marine. They are regarded as flexible and cost-effective materials with numerous advantages over traditional materials.

1.3 DIFFERENT TYPES OF FIBERS

Fibers can be roughly classified into several types, each of which is used for different applications.

1.3.1 Asbestos fiber

This fall based on a type of fiber made from a natural mineral. Asbestos fiber is highly resistant to heat, electricity, chemicals, and fire resistance. It has a moderate tensile strength. As a result, it gained popularity in the late 1800s. When asbestos fiber is blended with cement. Extra water is required due to the high absorption. However, asbestos was subsequently discovered to be carcinogenic, making it exceedingly harmful to human health. As a result, it was excluded entirely.

1.3.2 Carbon fiber

Carbon fiber has a high tensile strength and allows for more flexibility. They are constructed from oxidized polyacrylonitrile fibers. Following oxidation, thermal pyrolysis is performed, resulting in the creation of carbon fibers. They are very flexible and have a high tensile strength. This fiber is used to construct airplane rudders.

1.3.3 Natural fiber

Natural fibers include wood fibers such as bamboo, seed, fruit fiber, stem fibers such as jute, kenaf, san, flax, and leaf fibers such as henqueen, sisal, and energy-efficient manufacturing of this fiber is a natural benefit. However, they cannot be used in concrete because of their high water absorption, poor soluble base obstruction, susceptibility to creepy crawly and infectious assault.

1.3.4 Aramid fiber

The first prestressing tendons were made from aramid fibers in the 1980s, which were marketed under the name Kevlar and Tarpon. They are now produced by a small number of companies. Aramid fibers have high toughness and are not as brittle as carbon and glass fiber in their non-composite form, but they have other flaws. The fibers are less appealing for structural engineering because of their comparatively expensive price, limited compression, and shear strength, difficulty in manufacturing, and low resistance to ultraviolet light and moisture.

1.3.5 Steel fiber

Steel fibers are made from thin, flexible steel strand and offer excellent resistance to impact and fatigue. They are commonly used in industrial flooring, tunnel lining, and precast concrete products. These fibers come in various shapes and sizes, each with its unique benefits and limitations.

1.3.6 Glass fiber

Glass fiber has grown in favour as a replacement to asbestos since its identification as a carcinogen and subsequent removal from many items. However, worries about the safety of glass fiber have arisen, as research indicates that its composition may cause hazardous consequences akin to asbestos. Regardless, glass fiber has mechanical qualities that are equivalent to polymers and carbon fiber. While glass fiber is not as hard as carbon fiber, when utilised in composites, it is significantly less ductile. This property makes it a valuable material for applications requiring impact resistance. Because of their exceptional environmental resistance, better resistance to damage caused by impact loads, and high specific strength and stiffness, GFRC composites are frequently employed in industries such as maritime and plumbing. It should be noted that continuous study is being carried out to better understand the potential health hazards linked with glass fiber. To reduce potential health concerns, safety considerations, and correct handling practices should always be followed while working with potentially hazardous products, including glass fiber. Some of the properties of the fibers are given in the table 1.1.

Table 1.1: Typical properties of different fibers (source: Research paper)

Materials	**Tensile strength (MPa)**	**Modulus of Elasticity (MPa)**	**Density (Kg/m^3)**
Glass	3400-4800	70000-90000	2200-2800
Steel	280-1900	190000-210000	7900
Carbon	2200-5600	240000-830000	1800-2200
Aramid	2400-3600	130000-160000	1400-1500

1.4 ADVANTAGES OF GLASS FIBER CONCRETE

Glass fibers are a low-cost alternative to standard materials including concrete, steel, aluminum, and wood. Unlike these materials, which only have one basic strength, glass fiber has many advantages. As a result, glass fiber is perfect for future sustainable construction.

- Increased tensile strength: adding glass fibers to concrete increases its tensile strength making it less likely to break or fail under stress.
- Increased durability: GFRC is less susceptible to weathering, deterioration, and various kinds of degrading than conventional concrete, resulting in a great option for constructions in extremely difficult environments.
- Greater design flexibility: since GFRC can be molded in a wide range of forms and sizes, more elaborate designs and features can be included in architectural elements such as columns, cladding, and balustrades.
- Fire resistance: since glass fibers are non-combustible and do not contribute to the spread of flames, GFRC is an excellent option for use in constructions that require fire resistance.

1.5 DEMERITS OF GLASS FIBER CONCRETE

Since GFRC concrete has many advantages, there are certain disadvantages to consider. These are some examples:

- Fiber distribution: it can be difficult to ensure an even dispersion of glass fibers throughout the concrete, and insufficient distribution can contribute to decreased strength and durability.
- Appearance: when correlated to conventional concrete, concrete made with glass fibers might result in a different appearance, which may not be desired for some architectural purposes.
- Cost: because of the expense of the glass fibers and the additional manufacturing processes required, GFRC is often costlier than conventional concrete.

1.6 APPLICATIONS OF GLASS FIBER CONCRETE

Based on its unique qualities and benefits, glass fiber-reinforced concrete has a variety of uses in the building work. GFRC is commonly used in the following applications:

- Cladding: GFRC can be applied in building external cladding, offering an appealing and durable surface that could be moulded into a broad range of shapes and sizes.
- Precast element: when compared to standard precast materials, GFRC can be utilized to build precast architectural elements such as columns and cornices providing better design freedom and durability.
- Structural elements: GFRC can be used to reinforce structural elements such as beams, columns, and slabs increasing their strength and longevity.
- Artistic and decorative elements: GFRC may be utilized to build a wide range of artistic and decorative components such as sculptures and fountains, offering a lightweight and long-lasting alternative to traditional materials such as stone or metal.
- Restoration: GFRC can be utilized in the restoration of old structures and monuments, giving a durable and aesthetically beautiful material.

In general, the versatility and durability of GFRC make it an excellent solution for a wide range of construction.

1.7 OBJECTIVES

- To find the optimum percent of glass fiber in concrete with reference to compressive strength, split tensile strength, and flexural strength.
- To evaluate the strength after a sulphate attack on GFRC concretes (cubes for compressive strength, beams for flexural strength, and cylinders for tensile strength) after 50 cycles, 100 cycles, and 150 cycles.
- Comparing properties of concrete with various percentage of addition of glass fiber.

1.8 ORGANIZATION OF THESIS

Chapter 1 Gives a concise explanation of fiber-reinforced concrete and outlines, goals of the research.

Chapter 2 Provides a comprehensive literature review associated with fiber-reinforced concrete.

Chapter 3 Describe the methodology used and provides information on the experimental and theoretical procedures conducted.

Chapter 4 Explains the experimental work in detail.

Chapter 5 Results and discussion of the experimental work carried in the present study.

Chapter 6 Conclusions on the research work and scope for further research work.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

In this chapter, state-of-art on the use of glass fiber is presented. While various research on glass fiber-reinforced concrete (GFRC) has been undertaken, but experimental data are scarce about the selection of fiber design and their content for GFRC. To fill this void, a comprehensive experimental program was taken up to examine the impact of fiber content on the characteristics of GFRC. This program seeks to provide useful insights into the relationship among fiber content and GFRC characteristics. By systematically altering the fiber amount in concrete mixtures, researchers want to learn how it affects critical features of GFRC such as strength, durability, and other significant attributes. The results of this broad experimental program will add to the body of knowledge on GFRC and aid in the development of guidelines for the optimal selection of fiber design and content in GFRC applications. Finally, this research will help engineers and practitioners to make educated judgments about the use of glass fiber in concrete building projects.

Chandramouli K et al. (2010) used alkali-resistant glass fibers to investigate the strength qualities of glass fiber concrete. The study looked at how these fibers the compressive, flexural, and split tensile strength of concrete in different grades, notably M20, M30, M40, and M50. One important observation was noted that including glass fibers in the concrete mixtures reduced leaking. Furthermore, the percentage enhanced in compressive and flexural strength of several types of glass fiber concrete mixtures over the strength of the mixtures at 28 days ranged from 20% to 25% and 15% to 20%, respectively. These findings show that glass fibers have a favorable consequences on the strength qualities of concrete, with considerable improvements reported in both compressive and flexural strength across different grades of concrete mixes[4].

Avinash Gornale (2012) focused his study on the strength properties of GFRC investigated in this research paper. The study involved performing compression, split tensile, and tensile tests on three different concrete grades (M20, M30, & M40). The results discovered that the incorporation of glass fiber decreases the workability of the concrete. Additionally, there was a substantial strength gain for the compression and flexural strength of GFRC when analyzed to plain concrete[5].

Komal Chawla (2013) study focused on composites of concrete that were reinforced with glass fiber. Test were conducted to evalvate compressive strength, flexure strength, and toughness. % increase in compressive strength was observed different kinds of concrete mixes which contained a varying quantity of glass fiber, compared to compressive and flexural strength of plain concrete at 28 days[6].

Durga Chaitanya Kumar Jagarapu (2016) performed experiments to investigate concrete reinforced with glass fibers. The study involved conducting tests on the concrete samples to measure their compressive strength, tensile strength, and flexural strength. The results showed that at a 1% glass fiber content, the concrete's workability improved. Furthermore, the increase in compressive, tensile, and flexural was demonstrated to be more pronounced at 1% glass fiber content[3].

K.I.M. Ibrahim (2016) focused on the mechanical properties of glass fiber-reinforced concrete (GFRC). The study indicated that glass fibers have a favorable impact on the mechanical strength of concrete. Significant improvements in compression, splitting, and flexural properties of the specimens at 7 and 28 days were noted when the findings of GFRC were compared to those of plain concrete.

It is found that incorporating 0.5% glass fibers into the concrete increased compressive strength by 22.3%. When correlate to normal concrete, the flexural strength of GFRC at 0.5% increased by 58.8%. Furthermore, the tensile strength of GFRC increased significantly by around 94.8% at 0.5%. These findings clearly show that glass fibers upgrade the mechanical features of concrete. The addition of glass fibers resulted in significant improvements in GFRC specimens for

compression, flexural, and tensile strength, demonstrating the potential benefits of using glass fiber-reinforced concrete in diverse building applications[7].
The experimental investigation focused on comparing the strength and durability properties of glass fiber-reinforced concrete to that of conventional concrete.

S.Hemalatha et al. (2016) conducted experimental investigation on comparing the strength and durability characteristics of glass fiber reinforced concrete to that of conventional concrete. The results of the research consistently indicate that adding glass fiber to ordinary concrete enhanced strength attributes across multiple metrics, including compressive strength, flexural strength, and split tensile strength. However, it was discovered that after a certain amount of glass fiber addition, the strength benefits began to steadily reduce. Furthermore, the addition of glass fibers to the concrete indicated in a progressive improvement in its durability. This shows that the addition of glass fibers upgrade the long-term performance and resistance of the concrete to numerous environmental variables, hence increasing its overall longevity. Overall, the study shows that incorporating glass fibers into concrete can improve strength and durability up to a particular amount of fiber addition. These findings help us understand the advantages and disadvantages of employing glass fiber-reinforced concrete in construction applications[8].

Tarun Kumar (2016) conducted research on glass fiber reinforced concrete: design & analysis. The compression, flexural, and split tensile strength of concrete of grades M20, M30 & M40 were investigated in this study. When compared to 28 days strength, the increase in compression strength, flexural strength, and split tensile strength for M-20, M-30, and M-40 grade of concrete at 3, 7, and 28 days are 20% to 30%, 25% to 30% and 25% to30% respectively[9].

Ajmal Paktiawal et.al. (2016) looked into the durability properties of alkali-resistant glass fiber high-strength concrete (GFRC). They investigated the workability of the concrete along with the compressive and tensile strengths, non-destructive testing (NDT), percentage of voids, and sorptivity on hardened concrete specimens[10]. According to their findings, raising the fiber percentage to 1.6% resulted in a 17.31% increase in the tensile strength of the GFRC. The increase in split tensile strength became less pronounced when the fiber content exceeded 1.6%. As a result, a fiber content greater than 1.6% does not produce as significant advantage in split tensile strength.

Sanghamitra Patel et.al. (2017) used glass and steel fibers in an experimental investigation on the characteristics of concrete. The goal of this study was to add steel fibers and glass fiber to the concrete and to investigate the strength properties of concrete as fiber content varies. The inclusion of fibers enhanced all mechanical parameters, including compressive strength, flexure strength, splitting strength, and shear strength, regardless of the fiber type or w/c ratio[11].

Hanuma Kasagani et.al. (2018) studied the influence of graded fibers on the stress-strain behavior of glass fiber reinforced concrete in tension. The effect of fiber efficiency features such as fiber length, fiber dispersion, and fiber orientation on GFRC tensile strength was studied. It was discovered that specimens with short fiber lengths (3mm and 6mm) have higher tensile strength than specimens with long fiber lengths (12mm and 20mm). Strain hardening effect increased as fiber volume content and fiber length increased[12].

K. B Sankeerthan Reddy et al. (2019) looked at the durability and physical qualities of glass fiber-reinforced concrete (GFRC) when exposed to high temperatures. A carbonation test was carried out to determine the durability of GFRC. Furthermore, the compressive strength, split tensile strength, and flexural strength of GFRC were investigated and correlated to regular concrete at elevated temperatures of 300°C, 500°C, 700°C, and 1000°C. When correlated to plain concrete, the 28-day strength of GFRC was much higher, roughly 49%. Furthermore, when interacting with a temperature of 1000°C, plain concrete lost 80.3% of its original strength. These findings point to GFRC's higher performance and tolerance to high temperatures in terms of maintaining strength qualities when compared to regular concrete[13].

Prasad Bishetti (2019) conducted experimental study on concrete that was reinforced with glass fiber. The research focused on three types of strengths (compressive strength, flexural, and tensile strengths). The results of the study showed that when 0.1% GFRC was used in correlation to the control mix, there was an increment of 20.22% in compressive strength, 12.09% in flexural strength, and 31.32% in tensile strength[14].

Jaison Joy Memadam et.al. (2019) used the calcium chloride integral curing technique to examine the strength features of glass fiber reinforced concrete (GFRC). The goal was to compare the results of GFRC cured with calcium chloride integral to those of GFRC cured with conventional curing for (M30 concrete) for 7, 14, and 28 days. When correlate to the standard curing process, the results demonstrated a marginal improvement in the compressive strength of the GFRC. Furthermore, the tensile strength of the GFRC increased by 22.37% during the calcium chloride integral curing procedure[15].

Ghanshyam Bhoi et.al. (2022) aimed to study on the effect of glass fiber reinforced concrete and concrete tiles reinforced concrete, with short discrete fibers (M20). In the absence of additives, inserting short discrete glass fibers in the range of 0.1 to 0.3% by weight of concrete did not produce any notable changes in the compressive strength of concrete. However, the addition of glass fibers improved the split-tensile strength of the concrete. Furthermore, when the fiber content of concrete increased, it also increased its flexural strength[16].

Anteneh Tibebu, et.al. (2022) performed experiment to investigate the compression and characteristics of chopped glass fiber-reinforced concrete. The study involved comparing the GFRC to control concrete and monitoring their progress after 28 days of curing. The results of the investigation indicated that when the glass fiber-reinforced concrete (GFRC) had 0.1% glass fiber content, the strength of the concrete increased as the proportion of glass fibers in the mixture increased. Although, the workability of concrete was found to decrease with the increase in glass fiber quantity[2].

2.2 RESEARCH GAP

- There is a gap in the literature review regarding the effect of sodium sulphate study on glass fiber concrete.
- The environmental conditions are the main criteria determining the service life and outcome of concrete. To understand the durability of concrete structures, it can be important to analyze the effect of chemical attacks. Since sulphate attacks are the primary chemical attacks on concrete structures, their study helps to explain them when they degrade and then fail.

CHAPTER 3

EXPERIMENTAL INVESTIGATION

3.1 METHODOLOGY

In this chapter, we will look at the attributes of the various materials used in this study. These materials are carefully chosen to meet the major goals of investigation. To fulfill these goals, the following tasks were completed, which is shown in fig 3.1.

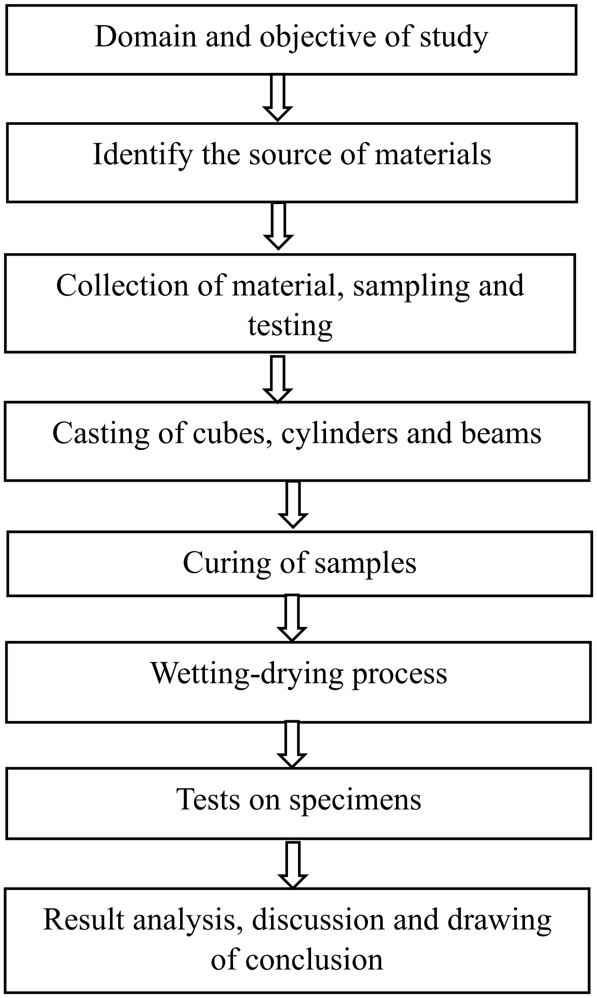

Fig 3.1 Flow chat of methodology

3.2 MATERIALS

This study conducted on two types of concrete: regular concrete and fiber-reinforced concrete. The materials used to make these concretes, as well as the properties of each material, are as follows:

3.2.1 Cement

The key material in the project is cement, which serves as a binding agent due to its adhesive and cohesive properties. Ordinary Portland Cement (OPC 43) has been used for this experimental work shown in the fig 3.2. The cement utilized in the research was evaluated for various objectives as per IS: 4031-1998[17] and found to conform to several outlines of IS:1489-1991[17], which is shown in table 3.1. A specific gravity of 3.15 was found in the cement, as shown in table 3.2.

Fig 3.2: Cement

Table 3.1: Setting time of cement

Sample test	Setting time (min)	Requirement IS: 269-2015 (min)	remark
Initial setting time	60	≥30	Acceptable
Final setting time	450	≥600	Acceptable

Table 3.2: Properties of cement

SNO	Properties	Results	Requirement as per IS:269-2020
1	Normal consistency	31%	25%-35%
2	Specific gravity	3.15	-
3	Fineness	3.3%	<10%

3.2.2 Coarse Aggregate

Table 3.3: Coarse aggregate properties as per sieve analysis performed

S.No	IS Sieve size (mm)	Weight retained	Cum. Weight retained	Cum. % of weight retained	Cum. % of weight passing
1	20	145	145	14.5	85.5
2	12.5	468	613	61.3	38.9
3	10	235	848	84.8	15.2
4	4.75	134	982	9802	1.8
5	Pan	18	1000	-	-
	Total	1000			
	Fineness modulus	2.588			

Coarse aggregate is a type of aggregate with size of more than 4.75 mm and is an important material in concrete which is shown in fig 3.3. The specific gravity of the material had been found 2.67, and fineness modulus 2.588, shown in table 3.3. The characteristics of concrete are closely depends upon to those of its components, and therefore the aggregate utilized in a concrete mixture must possess qualities such as hardness, strength, density, and durability[16].

Fig 3.3: Coarse Aggregate

3.2.3 Fine Aggregate

Sand produced from river was employed as the fine aggregate in the concrete mixture, shown in fig 3.4 with specific gravity and fineness modulus of 2.55 and 2.924 respectively[18] shown in table 3.4. The role of the fine aggregate is just to enhance the density of concrete by occupying the voids within the coarse aggregate, minimizing cement shrinkage, and producing a cost-effective mix.

Fig 3.4: Fine Aggregate

Table 3.4: Fine aggregate properties as per sieve analysis performed

S.No	**Weight retained (g)**	**Cum. Weight retained (g)**	**Cum % of weight retained**	**% Passing**	**Recommended values by IS code for zone II**
10mm	0	0	0	100	100
4.75mm	0	0	0	100	90-100
2.36mm	110	110	10.14	89.86	75-100
1.18mm	175	285	26.27	73.37	55-90
600	265	550	50.69	49.31	35-59
300	140	690	63.59	29.30	8-30
150	170	860	79.26	20.73	0-10/20

3.2.4 Water

Although water is a crucial element of cement paste and influences its strength and other properties, the quality of mixing and curing water sometimes leads to distress, disintegration, and reduces lifespan of the structure. The water utilized in concrete should be free from substances that could compromise concrete’s strength as well as durability as per IS 456- 2000[19]. So ordinary tap water available in the laboratory was used in preparing mix and curing.

3.2.5 Admixture

In this research work SikaPlast-5061 NS2 has been used as a superplasticizer. Admixtures are substances that can be mixed into concrete to change its properties and features. These additives provide a variety of advantages and can improve many elements of concrete performance. Table 3.5 shows the details of admixture.

Table 3.5: Details of SikaPlast-5061NS2 (source: supplier)

Properties	**Superplasticizer**
Type of chemical	Modified polycarboxylate
Conforming standard	IS103, ASTM C4904
Form	Viscous liquid
Colour	Reddies brown
Relative density	1.08kg/l
Ph	<6
Specific gravity	1.08

3.2.6 Glass fiber

The glass fiber of filament diameter of 14 microns and a length of 12mm were used as shown in fig 3.6.

Table 3.6: Properties of Glass fiber

Fiber type	**AR glass fiber**
Density (g/cm^3)	2.7
Elastic Modulus (MPa)	7200
Tensile Strength (MPa)	1700
Length (mm)	12
Diameter (micron)	14

The aspect ratio of glass fiber is 857.1, tensile strength 2500N/mm^2, elongation breaks 3.6%, modulus of elasticity 72 GPa, density 2700 kg/m^{3,} and white color glass fibers were utilised for this research work[20]. The properties of the fibers were provided by the supplier, which is shown in table 3.6.

Fig 3.5: Glass fiber

3.3 SPECIMENS DETAILS

The experimental program was planned to determine mechanical properties of Glass Fiber Reinforced Concrete (GFRC) with varied fiber content. The experiment involves casting M30-strength concrete specimens with varying fiber levels of 0%, 0.5%, 1.0%, and 1.5%.

Cubic specimens with dimensions of 150mm x 150mm x 150mm were prepared specifically for compressive strength testing. Beams with dimensions of 500mm x 100mm x 100mm were also prepared to determine flexural strength. While for the tensile test, cylindrical with diameters of 150mm and lengths of 300mm were prepared, taking into account the various fiber compositions shown in table 3.7. The purpose of the experiment was to see how different percentages of glass fibers affect the mechanical properties of GFRC, specifically compressive strength, tensile strength, and flexural strength.

Table 3.7: Details on the number of specimens cast, cured and tested

Sno	Fiber content	Compressive strength					Tensile strength					Flexural strength					Total
		7d	28d	50c	100c	150c	7d	28d	50c	100c	150c	7d	28d	50c	100c	150c	
1	0%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	45
2	0.5%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	45
3	1%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	45
4	1.5%	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	

3.4 MIX PROPORTION

Conforming to IS:10262-2009, M30 grade of concrete mix along with superplasticizer, and w/c ratio 0.43 table 3.8 shows the mix proportion.

Table 3.8: Mix proportion of sample

Materials	**Quality (kg/m^3)**
Cement	367.44
Fine aggregate	675.79
Coarse aggregate	1233.75
Superplasticizer	3.4
Water	158

3.5 CASTING OF SPECIMENS

The cubes of size 150mm x150mm x150mm, cylinder of size 150mm in diameter and 300 length, and beams of size 500mm x100mm x100mm as shown in fig 3.6,3.7, and 3.8 were prepared and cured for 28 days in water. After curing specimens were tested for compressive strength, tensile strength, and flexural strength respectively.

Fig 3.6: Cubes

Fig 3.7: Cylinders

Fig 3.8 Beams

3.6 DEMOULDING

After leveling the fresh concrete in the moulds, it was permitted to be set for 24 hours. The concrete went through the initial hardening process during this time. A permanent marker was used to make different marks on each concrete sample to ensure accurate identification. The specimens were then gently took away from the moulds. This procedure ensured that the concrete specimens were labeled correctly and distinguished for subsequent testing at specified age and analysis.

3.7 CURING

Curing is essential for minimizing moisture loss from the concrete sample and ensuring that the specimens could achieve the required strength. All concrete specimens in this investigation were cured for 28-days shown in fig 3.9.

3.8 WORKABILITY

The workability of all the concrete mixes used in the work was determined by performing a slump cone test. The results of the slump values are listed below in

Table 3.9. As the percentage of glass fiber in the concrete mix increases, the slump value started decreasing

Fig 3.9: Curing Tank

Table 3.9 Workability Test on Fresh Concrete

S.NO	Glass fiber content	Workability(mm)
1	0%	100
2	0.5%	94
3	1.0%	85
4	1.5%	77

3.9 TESTS ON HARDENED CONCRETE

3.9.1 Compressive Strength Test

- The compressive strength of the concrete was evaluated after 7days and 28 days curing on specimen measuring 150mm x 150mm x150mm[15].

- Once the specimens have been left to cures for 7days and 28 days, take them out of the water and eliminate any surplus water from their surface by wiping them off.
- For testing, specimens are placed between the bearing surface. It is essential to prevent the presence of any loose material or dust particles on the metal plates of the machine.
- Gradually and consistently apply the load till the specimens fail.

Fig 3.10: Compressive strength test

- Note down the maximum load when the specimens fail. The average is used to calculate its maximum load at failure as shown in fig 3.10.
- The calculation was done using the,

  Compressive strength (N/mm^2) = Ultimate load/Cross-section area

3.9.2 Tensile Strength Test

- Concrete specimen measuring 300mm in length and 150mm in diameter were tested for tensile strength after 7 days and 28 days of curing.
- Once the specimens have been left to cure for 7 days and 28 days, take them out of the water and eliminate any surplus water from their surface by wiping them off.
- Testing specimens are placed between the bearing surface.
- It is essential to prevent the presence of any loose material or dust particles on the metal plates of the machine. There after gradually and consistently apply the load till the specimens fail as shown in fig 3.11.

Fig 3.11: Tensile strength test

- Note down the maximum load when the specimens fail.
- The average is used to calculate its maximum load at the time of specimen failure.
- The calculation was done using the,

Tensile strength (N/mm^2) $=2P/\pi dl$

P= Maximum load (N)

l= 300mm, d= 150mm

3.9.3 Flexural Strength Test

- The flexure strength of the concrete was determined after 28 days of curing using specimens measuring, 500mm x 100mm x100mm.
- Once the specimens have been left to cure for 7days and 28 days, take them out of the water and eliminate any surplus water from their surface by wiping them off[21].
- The connected components of the supporting and loading rollers must be cleaned, and any loose sand or other substance should be excluded from the surfaces of the sample they will make contact with the rollers.

Fig 3.12: Flexural strength test

- Bring the applied load into contact with the specimen's surface only at the loading points as shown in fig 3.12. Gradually and consistently apply the load till the specimens fail.
- Note down the maximum load when the specimens fail.
- The average is used to calculate its maximum load at failure.
- The calculation was done using the,

  Flexural strength (N/mm^2) = Pl/bd^2

  Where,

  P= Maximum load (N)

  l= 500mm

  b= 100mm

  d= 100mm

3.10 WETTING-DRYING CYCLES

- To acquire the experimental physical sulphate attack results in a shorter period, the artificially accelerated sulphate attack was created as simultaneous wetting and dying in a 10% sodium sulphate solution.
- The wetting-drying cycles were set to finalized as 16-hour wetting and 8-hour drying period. Other investigators have discovered this wetting-drying cycle to be very intense. And hence, full wetting of the specimens by submerging them in the solution and maximum sun drying of the specimens were obtained by leaving them in the open environment for the duration specified.
- After the initial 28 days of water curing, the samples were subjected to a 10% sodium sulphate solution for wetting-drying cycles, as shown in fig 3.13 and fig 3.14 to be replicated at ambient temperature. Such specimens were tested for three important concrete strengths, compressive strength, flexural strength, and tensile strength after 50, 100, and, 150 cycles respectively.

(a)

(b)

Fig 3.13 (a), (b): Specimens fully submerged in 10% sodium sulphate solution

(a)

(b)

Fig 3.14 (a), (b): Drying process of specimens

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GENERAL

In this chapter, a comprehensive examination and explanations of the mechanical properties and durability effect on glass fiber concrete has been done.

4.2 COMPRESSIVE STRENGTH OF GLASS FIBER CONCRETE

The compressive strength of glass fiber concrete was determined using the parameters outlined in IS:516-1959[23]. The results of compressive strength testing on 150mmx150mmx150mm specimens with different fiber content are shown in Table 4.1. Each mixture, which contained varying quantities of glass fibers, was tested to assess its compressive strength. Initially, as the number of glass fibers increased, the strength of the material showed a growth. However, at 1.5% fiber content, the strength began to deteriorate. Figure 4.1 depicts the relationship between compressive strength and glass fiber. At 1%, the highest compressive strength was found.

The compressive strength tests were then performed on the specimens which had gone through 50 cycles of wetting and drying process. The compressive strength of each mixture with varying amounts of glass fiber was determined. Initially, increase in the glass fiber content improved the strength, but at 1.5% fiber level, the strength declined. When the strength after 50 cycles was compared to the strength after 28 days, a reduction was noted.

Another round of compressive strength testing was performed after 100 cycles of the wetting-drying process. Similarly to prior cycles, increase in the glass fiber content initially boosted the strength, but at 1.5% fiber concentration, the strength decreased. When the strength after 100 cycles was compared to the strength after 50 cycles, a reduction was noted.

Finally, the compressive strength tests were done on the specimens which had gone through 150 cycles of wetting and drying process. As before, larger glass fiber content initially boosted strength, but at 1.5% fiber level, strength declined. When the strength after 150 cycles was compared to the strength after 100 cycles, a drop was registered.

Table 4.1: Compressive strength of cubes

SNO	Glass fiber	0 cycles	50 cycles	100 cycles	150 cycles
1	0%	44.24	43.8	42.5	39.3
2	0.5%	47.59	46.7	45.6	43.4
3	1.0%	51.5	51.1	49.3	48.1
4	1.5%	46.9	45.2	44.1	42.4

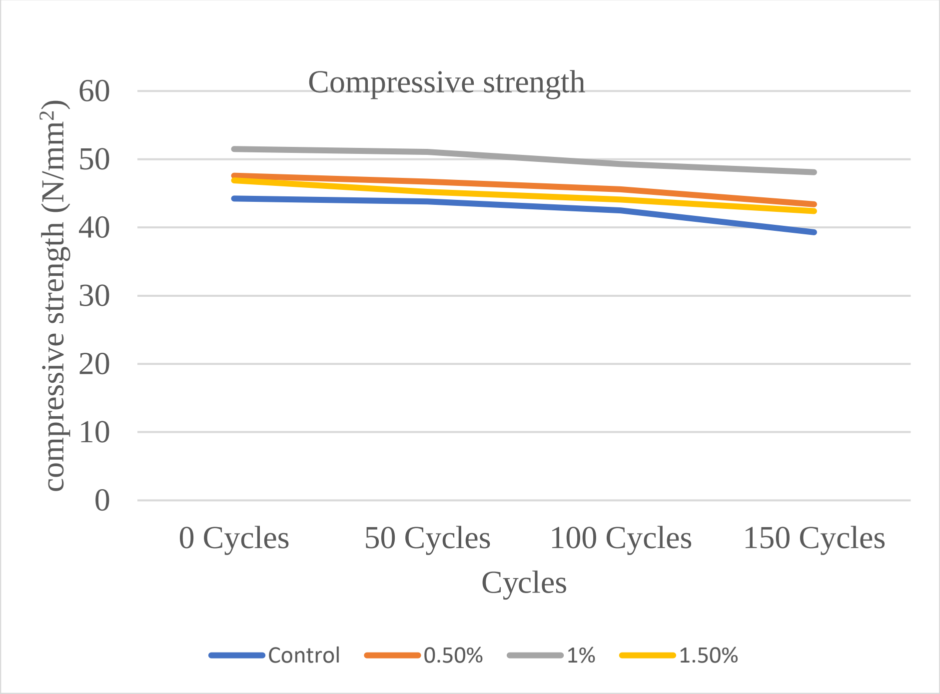

Fig 4.1: Compressive strength of cubes for various % of fiber content

Figure 4.1 depicts the compressive strength fluctuation of concrete cubes subjected to alternating wetting and drying cycles with a 10% sodium sulphate solution. The graph shows a progressive decline in compressive strength over the course of the cycles.

The fraction of compressive strength loss increases in direct proportion to the number of cycles. This suggests that the concrete becomes less resistant to the deterioration effects of the sodium sulphate solution after repeated soaking and drying cycles. The persistent fall in compressive strength indicates the possibility of concrete deterioration owing to chemical exposure.

To determine the concrete's vulnerability to sodium sulphate assault, the percentage loss in compressive strength has been monitored and evaluated throughout the wetting-drying cycles. This examination sheds light on the concrete's durability and capacity to function well in extreme weather situations.

The compressive strength of the concrete gradually decreases during the wetting and drying cycles. When examining the percentage loss in compressive strength, the control concrete indicates an increasing trend as the number of cycles increases, but the glass fiber concrete exhibits loss at a slower rate of loss. Among the glass fiber mixes, the 1% glass fiber mix has the best performance against sulphate attack, with a total loss of just 7.06% after 150 cycles, compared to 12.56% loss for the conventional concrete. This suggests that adding glass fiber to the concrete mixture improves its resistance to sulphate attack and minimises the level of compressive strength loss over time.

4.3 TENSILE STRENGTH OF GLASS FIBER CONCRETE

The tensile strength of glass fiber concrete was determined using the parameters specified in IS:516-1959[23]. Table 4.2 shows the tensile strength measurements on cylindrical specimens of diameter 150mm and 300mm length with different fiber content. Each mixture, which had varying percentages of glass fibers, was tested to assess its tensile strength. Initially, increase in the number of glass fibers resulted in an increase in strength. However, at 1.5% fiber content, the strength began to deteriorate. Figure 4.2 depicts the relationship between tensile strength and glass fiber. The highest tensile strength was obtained at 1% fiber content.

After subjecting the specimens to 50 cycles of wetting and drying, the tensile strength tests were carried out. Each mixture's tensile strength with varied glass fiber content was measured. Initially, increase in the glass fiber content resulted in an increase in strength, but at 1.5% fiber concentration, the strength decreased. When the strength after 50 cycles was compared to the strength after 28 days, a drop in strength was registered.

The tensile strength tests were then performed after 100 cycles of the wetting-drying process. Similar to prior cycles, increasing glass fiber content resulted in an initial increase in strength, but at 1.5% fiber concentration, the strength decreased. When the strength after 100 cycles was compared to the strength after 50 cycles, it was shown to be lower.

Finally, the tensile strength tests were done on the specimens which had gone through 150 cycles of wetting and drying. As in prior cycles, increase in fiber content initially boosted strength, but at 1.5% fiber concentration, strength decreased. When the strength after 150 cycles was compared to the strength after 100 cycles, a decrease in strength was noted.

Table 4.2: Tensile strength of cylinders

SNO	Glass fiber	0 cycles	50 cycles	100 cycles	150 cycles
1	0%	3.9	3.82	3.6	3.43
2	0.5%	4.0	3.9	3.75	3.5
3	1.0%	4.1	4.0	3.8	3.7
4	1.5%	3.7	3.62	3.45	3.0

The fluctuation in split tensile strength of concrete cylinders after subjected to alternating wetting and drying cycles with a 10% sodium sulphate solution is shown in Figure 4.2. The graph depicts a progressive loss in tensile strength over time. There is an increase in the proportion of tensile strength loss as the number of cycles increases.

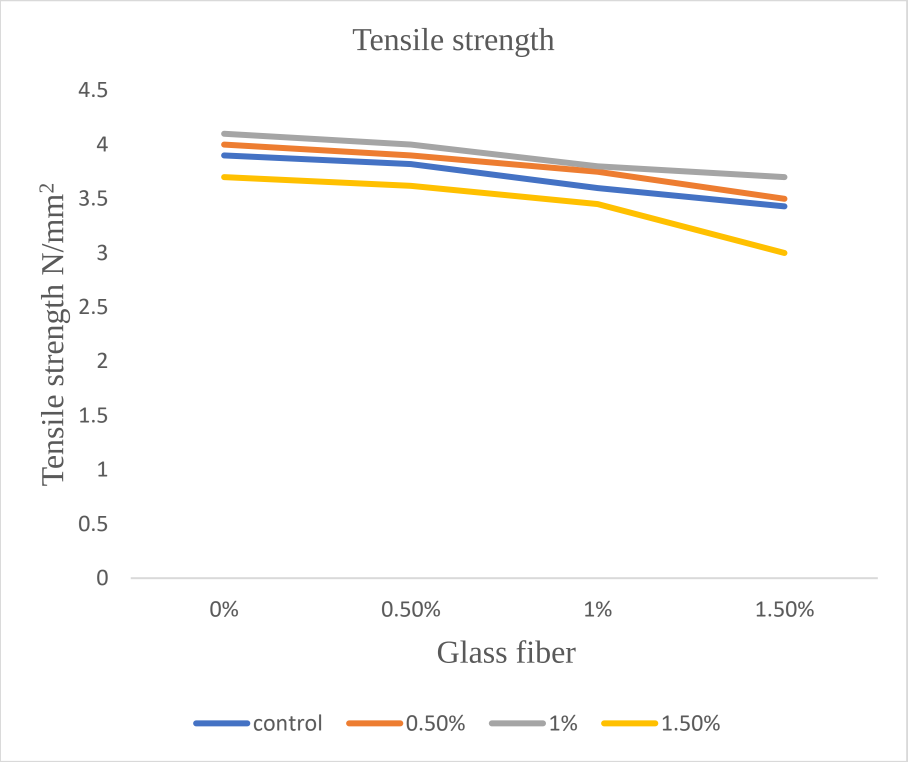

Fig 4.2: Tensile strength of cylinders for various % of fiber content

This suggests that as the soaking and drying cycles are repeated, the concrete's ability to resist the deterioration effects of the sodium sulphate solution decreases. The continuous decline in tensile strength shows that the concrete may deteriorate as a result of aggressive exposure.

To determine the concrete's vulnerability to sodium sulphate assault, the percentage loss in tensile strength has been carefully monitored and evaluated throughout the wetting-drying cycles. This information will be useful in determining the concrete's durability and capacity to operate well under adverse weather conditions.

Figure 4.2 after 150 cycles, the combination with 1% glass fiber has the lowest total loss in tensile strength, around 10.81%. This is around 4% less loss than that is seen in the control mixture. These results indicate that incorporating glass fiber in the concrete mixture helps to reduce tensile strength loss and maintain a higher residual strength even after numerous wetting and drying cycles.

4.4 FLEXURAL STRENGTH OF GLASS FIBER CONCRETE

The flexural strength tests on glass fiber concrete were carried out in accordance with IS:516-1959[23]. The 28-day flexural strength test results on specimens measuring 500mm x 100mm x 100mm with variable fiber content are shown in Table 4.3. The flexural strength of each mixture in varying amounts of glass fibers was determined. Initially, increase in the number of glass fibers resulted in an increase in strength. The strength, however, decreased at 1.5% fiber content.

The flexural strength of each mixture with different glass fiber content was determined after 28 days. Initially, increasing the glass fiber content resulted in an increase in strength, but at 1.5% fiber concentration, the strength declined.

After 50 cycles of wetting and drying, the samples were tested for flexural strength. Flexural strength was determined for each mixture with varied glass fiber percentages. The strength initially increased as the glass fiber level grew, but at 1.5% fiber content, the strength declined. When the strength after 50 cycles was compared to the strength after 28 days, a drop in strength was seen.

The flexural strength test was then performed after 100 cycles of the wetting-drying process. Similarly to prior cycles, increasing glass fiber content resulted in an initial rise in strength, but at 1.5% fiber concentration, the strength decreased. When the strength after 100 cycles was compared to the strength after 50 cycles, it was shown to be lower.

Finally, the samples were subjected to 150 cycles of wetting-drying before determining the flexural strength. As in prior cycles, larger glass fiber content initially boosted strength, but at 1.5% fiber concentration, strength decreased. When the strength after 150 cycles was compared to the strength after 100 cycles, a decrease in strength was noted.

Table 4.3: Flexural strength of prism

S.NO	Glass fiber	0 cycles	50 cycles	100 cycles	150 cycles
1	0%	6.0	5.96	5.7	5.3
2	0.5%	6.9	6.75	6.25	6.0
3	1.0%	7.33	7.1	6.9	6.7
4	1.5%	5.23	5.12	4.9	4.6

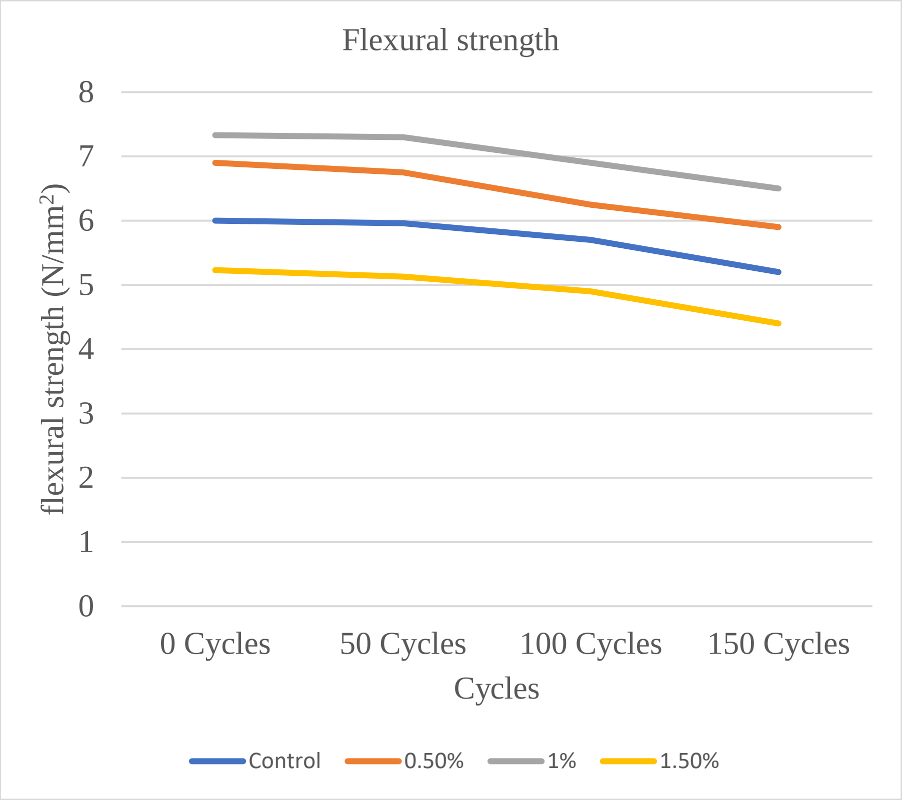

Fig 4.3: Flexural strength of prism for various % of fiber content

Figure 4.3 depicts the flexural strength fluctuation of concrete prisms after subjected them to alternating wetting and drying cycles with a 10% sodium sulphate solution. Figure 4.3 depicts the continuous loss of flexural strength over time.

The percentage of flexural strength loss increases as the number of cycles increases.

This demonstrates that the resistance of the concrete to the damaging effects of the sodium sulphate solution decreases with repeated soaking and drying. The continuous loss in flexural strength shows that the concrete may be deteriorating owing to aggressive exposure. It is critical to monitor the percentage loss in flexural strength throughout the wetting-drying cycles to assess the concrete's susceptibility to sodium sulphate assault. This data may provide insights into the concrete's durability and long-term performance under harsh climatic conditions.

Figure 4.3 displays the overall flexural strength reduction in various concrete mixes. The results show that all mixes lose about 15% of their flexural strength. The lowest loss of all is roughly 9.40% for 1% glass fiber mix, compared to a control mix loss of 15%. This implies that including glass fiber into the concrete mixture improves its resistance to flexural strength loss, resulting in greater residual strength values even after wetting and drying cycles.

CHAPTER 5

CONCLUSION

5.1 GENERAL

The aim of this study was to look into the usefulness of glass fiber concrete or to improve its resistance under sulphate attack. Through alternate wetting and drying cycles in a sodium sulphate solution, the specimens were subjected to accelerated sulphate assault. The following are the findings of this study:

1. Compressive strength, tensile strength, as well as flexural strength, increases with an increase in fiber upto 1%. Compressive strength, tensile strength, as well as flexural strength, are maximum at 1% fiber content.
2. Adding 1.5% fiber was making lumps (observed at the time to mixing) in the concrete during the time of mixing due to which proper bonding of fiber could not take place which cause a reduction of strengths at 1.5% fiber content.
3. Glass fiber concrete has shown to be efficient in increasing sulphate resistance across all wetting-drying cycles. The study reveals that adding glass fiber to concrete increased durability and protection against the damaging effects of sulphate exposure. This was beneficial in reducing effects of sulphate assault and can be considered a useful method for improving the resistance of concrete structures in such demanding conditions.
4. The study found that glass fiber concretes had a lower rate of strength loss as the number of cycles rose. This suggests that the utilization of glass fiber in concrete has the ability to increase the service life of structures. Glass fiber concrete showed improved resistance to sulphate attack, which may help to enhance long-term durability and performance of concrete constructions.

5.2 RECOMMENDATIONS FOR FUTURE STUDY

More research is needed to be enhance for understanding on the influence of glass fiber on concrete. Some of the areas for further research are given below:

1. Examine the durability features of glass fiber concrete, such as its resistance to chemical assaults, alkali-silica interactions, and freeze-thaw cycles.
2. Consider the effects of numerous elements on the dispersion and bonding of glass fibers inside the concrete matrix, including mix design, mixing techniques, and fiber surface treatments. Examine the interfacial bonding between the cementitious matrix and the glass fibers.
3. Analyse the effectiveness of glass fibers in concrete structure reinforcing. Compare the load-bearing capacity, crack resistance, and overall structural behaviour of glass fiber reinforced concrete (GFRC) to conventional steel reinforced concrete.
4. Examine the degree to which other building components, such as steel reinforcement, epoxy adhesives, or overlays, are bonded to glass fiber concrete. Also look at things like adhesive qualities, interface roughness, and surface preparation that affect bond strength.

REFERENCES

[1] F. Ming, Y. S. Deng, and D. Q. Li, “Mechanical and Durability Evaluation of Concrete with Sulfate Solution Corrosion,” *Adv. Mater. Sci. Eng.*, vol. 2016, 2016, doi: 10.1155/2016/6523878.

[2] A. Tibebu, E. Mekonnen, L. Kumar, J. Chimdi, H. Hailu, and N. Fikadu, “Compression and workability behavior of chopped glass fiber reinforced concrete,” *Mater. Today Proc.*, vol. 62, no. xxxx, pp. 5087–5094, 2022, doi: 10.1016/j.matpr.2022.02.427.

[3] J. D. Chaitanya, G. V. S. Abhilash, P. K. Khan, G. Manikanta, and V. Taraka, “Experimental Studies on Glass Fiber Concrete American Journal of Engineering Research (AJER),” *Am. J. Eng. Res.*, vol. 5, no. 5, pp. 100–104, 2016, [Online]. Available: www.ajer.org

[4] Chandramouli K., S. S. Rao, Pannirselvam N, S. T. Sekhar, and Sravana P, “Strength Properties of Glass Fibre Concrete,” *J. Eng. Appl. Sci.*, vol. 5, no. 4, pp. 1–6, 2010.

[5] A. Gornale, S. Ibrahim Quadri, S. Mehmood Quadri, S. Md Akram Ali, and S. Shamsuddin Hussaini, “Strength Aspects of Glass Fibre Reinforced Concrete,” *Int. J. Sci. Eng. Res.*, vol. 3, no. 7, pp. 3–7, 2012.

[6] K. Chawla, “Studies of Glass Fiber Reinforced,” *Int. J. Struct. Civ. Engg. Res.*, vol. 2, no. 3, pp. 3–9, 2013.

[7] K. I. M. Ibrahim, “Mechanical Properties of Glass Fiber Reinforced Concrete (GFRC),” *IOSR J. Mech. Civ. Eng.*, vol. 13, no. 04, pp. 47–50, 2016, doi: 10.9790/1684-1304054750.

[8] M. Nazeer and L. Gouri Mohan, “An experimental study on hybrid fibre reinforced concrete,” *Int. J. Earth Sci. Eng.*, vol. 7, no. 3, pp. 1171–1177, 2014.

[9] T. Kumar, “Glass Fibre Reinforced Concrete : Design & Analysis Gian Jyoti Group of Institutions-Shambhukalan,” *J. Mech. Civ. Eng.*, no. 5, pp. 35–41, 2016.

[10] A. Paktiawal and M. Alam, “Alkali-resistant glass fiber high strength concrete and its durability parameters,” *Mater. Today Proc.*, vol. 47, pp. 4758–4766, 2021, doi: 10.1016/j.matpr.2021.05.668.

[11] A. Thankachan and G. kumari, “Experimental Study on Properties of Concrete by

Using Ceramic Materials," *Int. J. Eng. Trends Technol.*, vol. 43, no. 7, pp. 404–408, 2017, doi: 10.14445/22315381/ijett-v43p269.

[12] H. Kasagani and C. B. K. Rao, "Effect of graded fibers on stress strain behaviour of Glass Fiber Reinforced Concrete in tension," *Constr. Build. Mater.*, vol. 183, pp. 592–604, 2018, doi: 10.1016/j.conbuildmat.2018.06.193.

[13] K. B Sankeerthan Reddy, J. S. R. Prasad, and V. Malagavelli, "Durability and physical properties of glass fiber reinforced concrete subjected to elevated temperatures," *Int. J. Innov. Technol. Explor. Eng.*, vol. 8, no. 11, pp. 3845–3848, 2019, doi: 10.35940/ijitee.K2296.0981119.

[14] P. Bishetti, "Glass Fiber Reinforced Concrete," *Int. J. Civ. Eng.*, vol. 6, no. 6, pp. 23–26, 2019, doi: 10.14445/23488352/ijce-v6i6p105.

[15] J. J. Memadam and T. V. S. Vara Lakshmi, "Strength characteristics of glass fiber reinforced concrete (Gfrc) using calcium chloride integral curing method," *Int. J. Recent Technol. Eng.*, vol. 8, no. 2 Special Issue 11, pp. 3040–3044, 2019, doi: 10.35940/ijrte.B1392.0982S1119.

[16] G. Bhoi, V. Pate, and M. R. Patel, "Study on the Effect of Glass Fibre Reinforced Concrete and Concrete Tiles Reinforced Concrete," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 10, no. 5, pp. 2564–2569, 2022, doi: 10.22214/ijraset.2022.42753.

[17] K. Kumar Poloju, C. Rahul, and V. Anil, "Glass fiber reinforced concrete (GFRC) - strength and stress strain behavior for different grades of concrete," *Int. J. Eng. Technol.*, vol. 7, no. 4.5, p. 707, 2018, doi: 10.14419/ijet.v7i4.5.25064.

[18] S. L. Hake, S. S. Shinde, P. K. Bhandari, P. R. Awasarmal, and B. D. Kanawade, "Effect of Glass Fibers on Self Compacting Concrete," *E3S Web Conf.*, vol. 170, pp. 1–6, 2020, doi: 10.1051/e3sconf/202017006018.

[19] R. SINGH Turkiya, M. Bishnoi, R. Singh, M. Tech Scholar, and A. Professor, "an Experimental Investigation of Concrete Properties M30 Due To Incorporation of Glass Fibers," *Int. J. Technol. Res. Eng.*, vol. 4, no. 10, pp. 2228–2232, 2017, [Online]. Available: www.ijtre.com

[20] A. Kimbonguila, L. Matos, J. Petit, J. Scher, and J.-M. Nzikou, "Effect of Physical Treatment on the Physicochemical, Rheological and Functional Properties of Yam Meal of the Cultivar 'Ngumvu' From Dioscorea Alata L. of Congo," *Int. J. Recent Sci.*

Res., vol. 10, no. ii, pp. 30693–30695, 2019, doi: 10.24327/IJRSR.

[21] T. S. Ahuja and A. Panwar, “Glass Fibre Reinforcements in Concrete,” *Int. J. Sci. Res.*, vol. 5, no. 4, pp. 2051–2055, 2016, doi: 10.21275/v5i4.nov163090.