

FLEXURAL BEHAVIOUR OF FERROCK GEOPOLYMER CONCRETE BEAMS WITH GFRP BARS.

Submitted in partial fulfilment of the requirements of the award of
Master of Engineering Degree in Structural Engineering

By

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafied work of **ASHFAAQ A (41380002)** who carried out the project entitled "**FLEXURAL BEHAVIOUR OF FERROCK GEOPOLYMER CONCRETE BEAMS WITH GFRP BARS**" under my supervision from December 2022 to May 2023.

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DECLARATION

I **ASHFAAQ A (41380002)** here by declare that the Project Report entitled **“FLEXURAL BEHAVIOUR OF FERROCK GEOPOLYMER CONCRETE BEAMS WITH GFRP BARS”** done by me under the guidance of **Dr. R. Padmapriya M.E, Ph.D** at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** is submitted in partial fulfillment of the requirements for the award of Master of Engineering Degree in Structural Engineering.

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ABSTRACT

Concrete, a prominent material in the construction industry, heavily relies on cement as a binding component. Despite its importance, cement emits carbon dioxide, prompting the search for alternatives. One such alternative is Ferrock, an iron-based binding compound that not only provides a versatile building material but also presents a carbon-negative option. Ferrock is composed of iron oxide powder, fly ash, lime powder, metakaolin, and oxalic acid, the latter of which acts as a catalyst. During the hardening process, iron oxide reacts with carbon dioxide and water to produce iron carbonate, effectively reducing the emission of greenhouse gases. Ferrock also minimizes water usage by using carbon dioxide instead of traditional water curing. The construction industry is constantly evolving, leading to the development of new materials. For instance, the conventional steel bars used in reinforced concrete construction are gradually being replaced by glass fiber reinforced polymer (GFRP) bars due to their high strength-to-weight ratio, corrosion resistance, durability, and better stiffness. However, GFRP bars have a linear stress-strain behavior and are prone to sudden, brittle failure, making the use of reinforcing fibers necessary to ensure structural safety.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is a widely used building material for infrastructure, with approximately one ton produced each year per person on average. However, due to its global extensive use, it is crucial to properly evaluate its environmental impact, particularly its effect on greenhouse gas emissions and climate change. To address this, various "Green concrete" concepts have been developed over the years, which focus on partially replacing cement with other materials to reduce the highest CO₂ emissions from concrete production. The cement industry alone is responsible for 5-7% of all anthropogenic CO₂ generated, contributing to around 3% of total greenhouse gas emissions from human activities. Thus, a transition to sustainable materials is necessary for the construction industry, requiring the development of innovative and alternative materials that reduce the consumption of natural resources and energy while minimizing pollution.

Ferrock, a patented concrete technology based on iron carbonate and incorporating largely recycled materials, is showing promising signs as an alternative to traditional concrete. It is stronger, more flexible, less expensive, and carbon negative, absorbing CO₂ instead of emitting it. Thus, a transition to sustainable materials is necessary for the construction industry, requiring the development of innovative and alternative materials that reduce the consumption of natural resources and energy while minimizing pollution. Additional information on using recycled materials as substitutes for binding material production can be found in the Environmental Protection Agency's essay "Creating a Carbon-Negative Building Material from Recycled Glass, Steel Dust, and Carbon Dioxide." Information on the environmental impact of various components of concrete, such as fly ash and silica fume, can be found in scientific reports and studies, including "Sustainability of Construction Materials" and "Limestone Material Fact Sheet." More information on Ferrock and traditional concrete can be found in the review section.

Ferrock is a compound made of 95% recycled materials that is based on iron. It has been proven to be less expensive, stronger, and more flexible than OPC

in building applications. Moreover, this exceptional material uses compressed carbon dioxide to speed up the curing process and does not require any additional heat to catalyze its chemical reaction, making it a carbon-negative substitute for OPC. As Ferrock is still a proprietary blend, much of the literature detailing its processes and impacts is written from a preliminary perspective. Nonetheless, the information available highlights several beneficial properties of this material. The first of two white papers, which were written by the product's founder, Dr. David Stone, in collaboration with several engineers from Arizona State University, defines the flexural strength and overall durability of the compound compared to OPC. The researchers concluded that "the fracture toughness and critical crack tip opening displacement (CTODC) of the iron-based binders were significantly higher than those of the OPC matrices." Porosity is another advantageous characteristic of the iron-based material when compared to OPC, which can be found in Dr. Stone's second white paper titled "Pore- and Micro-structural Characterization of a Novel Structural Binder based on Iron Carbonation." Information on the environmental impact of various components of concrete, such as fly ash and silica fume, can be found in scientific reports and studies, including "Sustainability of Construction Materials" and "Limestone Material Fact Sheet." More information on Ferrock and traditional concrete can be found in the review section.

1.2 NEED FOR RESEARCH

- The concrete has becoming an pollution in the world for that to overcome this the reduction of carbon emission variation material are substituted
- This research focuses on use of alternative building material ferrock as a carbon negative material in a structural element
- This research focuses on fully replacement of ferrock in place of cement to attain carbon negative building material

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

In order to study the behaviour of geopolymer ferrock and moreover to understand the Physical properties, mechanical properties and flexural behaviour of geopolymer Ferrock concrete with GFRP BARS a through literature review is planned in the present chapter.

2.2 REVIEW OF JOURNAL PAPERS

Ye et al. (2003) discussed through an investigation of the strain development and distribution within CFRP sheets, the study observed an improvement in ductility when the sheets were confined. Based on the experimental findings, the study proposed a confinement factor for CFRP as well as an equivalent transversal reinforcement index. These suggestions can be used in the seismic design method for reinforced concrete columns to determine the necessary amount of CFRP for seismic strengthening.

Muhammad and Shamim (2005) investigated the study evaluated the capability of GFRP wraps in the reinforcement and restoration of square concrete columns that had undergone damage. The results showed that square concrete columns retrofitted with GFRP wraps and subjected to axial compression and cyclic loading (mimicking seismic loads) exhibited significant improvements in comparison to non-retrofitted columns. The use of GFRP jackets in retrofitting damaged square concrete columns can lead to enhanced ductility and improved seismic performance.

Kumutha et al. (2007) evaluated The study aimed to assess the efficacy of external GFRP reinforcement in enhancing rectangular concrete columns by examining the impact of the number of GFRP layers on the ultimate load and ductility of confined concrete. The research revealed that effective confinement of concrete was achieved through the use of GFRP sheets, leading to an improvement in the compressive strength of the columns. Furthermore, increased numbers of GFRP

wrap layers led to better confinement, resulting in an increase in the load carrying capacity of the column, as well as an improvement in ductility.

Pallegrino and Modena (2008) focused on the study presents and discusses the findings of an experimental investigation on Reinforced Concrete (RC) rectangular beams that were reinforced in shear with externally bonded U-wrapped Carbon Fiber Reinforced Polymer (CFRP). The results provide novel insights into the intricate failure mechanisms that affect the ultimate shear capacity of RC members with transverse steel reinforcement and FRP sheets. The investigation also highlights the mechanisms of interaction between the externally applied FRP sheets and the internal shear steel reinforcement under different static schemes. These interactions, which are not currently considered in code provisions, significantly impact the efficiency of the shear strengthening rehabilitation technique and the calculation of the interacting contributions to the nominal shear strength of the structural member. Based on the experimental observations of shear behavior, the study proposes an analytical model for estimating the interacting contributions to the shear capacity of the strengthened beams.

Riad et al. (2008) observed investigated the study examined the reinforcement of a square prismatic concrete column using an external glass fiber composite. The research discovered that the stiffness of the FRP jacket applied to the column was the critical factor in designing external jacket retrofits.

Sangeetha and Sumathi (2010) observed Wrapping concrete columns with Fiber Reinforced Plastic (FRP) shells has been identified as an effective method that considerably enhances the strength and ductility of the columns. The authors of the paper investigate the behavior of concrete columns wrapped with GFRP under uniaxial compression. The concrete columns had a circular cross section with a diameter of 150mm and a height of 300mm. The study varied several parameters, including the wrapping shell materials (GFRP Materials Surface Mat (SM), Chopped Strand Mat (CSM), and Woven Roving Mat (WRM)), the number of plies (1Ply and 3plies), and the period of curing (7 and 28 days). Results from a series of experimental studies were presented and discussed. The investigation on small-scale specimens demonstrated that axial loading of confined concrete columns increased their strength.

Satpute Manesh et.al (2012) discussed the objective of this study was to investigate the effects of curing duration and temperature on the compressive strength of fly ash-based geopolymer concrete. Geopolymer concrete is produced by entirely replacing cement with processed low calcium fly ash, which is activated chemically by alkaline solutions such as sodium silicate and sodium hydroxide. Cubes measuring 150mm x 150mm x 150mm were fabricated using a solution-to-fly-ash ratio of 0.35 with 16 Mole concentrated sodium hydroxide solution. All the specimens were then subjected to oven curing at 600C, 900C, and 1200C for durations of 6, 12, 16, 20, and 24 hours. Test results revealed that the compressive strength of the geopolymer concrete increased as the duration and temperature of the oven curing increased.

Murugan et al. (2013) observed that the use of Fiber Reinforced Polymers (FRP) for external wrapping has gained popularity in recent years as a means of strengthening concrete and steel structures. To investigate the compressive behavior of concrete cylinders strengthened with FRPs, the effects of various parameters were examined. These included wrapping materials (such as glass and carbon Fiber reinforced polymers), number of plies (single and double plies), orientation of Fibers (along the length and circumference of the specimens), and curing period (wrapping after 7 and 28 days of water curing). Results of the experiments showed that specimens wrapped with carbon fiber reinforced polymers had higher compressive strength than those wrapped with glass Fiber reinforced polymers, in both single and double plies, for wrapping after 7 and 28 days of water curing.

Mariappan et al. (2013) discussed An experimental investigation was carried out to evaluate the strength and ductility of Steel Fiber Reinforced Concrete (SFRC) beams with Glass Fiber Reinforced Polymer (GFRP) laminates externally bonded. Ten beams, with a cross-section of 150×250 mm, were tested in the laboratory over an effective span of 2800 mm. Three beams made of Fiber reinforced concrete were used as reference beams, and six Fiber reinforced concrete beams were retrofitted with externally bonded GFRP laminates. One concrete beam was left unreinforced with any Fiber and external GFRP laminates. The experiment varied the volume fraction of Fiber reinforcement and the stiffness of GFRP laminates. The study

evaluated the static responses of all beams, including strength, stiffness, and ductility.

Manish kumar et al. (2014) focused attention the seismic retrofitting of reinforced concrete members that are vulnerable to strong earthquakes poses a significant problem. It has long been recognized that confining concrete compression members not only increases their strength but also improves their ductility. The current study focuses on the behavior of reinforced concrete specimens strengthened with glass Fiber reinforced polymer and subjected to axial compressive loading. Specimens with a circular cross-section, a length-to-diameter ratio of 2.0, and 0.96% longitudinal reinforcement were prepared and tested for 28 days compressive strength. The specimens were wrapped with 0, 2, 4, 6, and 8 layers of glass Fiber reinforced polymer on the surface as confinement. The results of the study showed that the strength of the specimen significantly increased with the increase in the number of confinement layers. The 28-day compressive strength of the specimen wrapped with 8 layers of GRRP increased by 47% compared to the strength of the specimen without any confinement.

Kannan et al. (2014) observed this study presents the findings of an investigation on the behavior of high strength concrete columns reinforced with Glass Fiber Reinforced Polymer (GFRP) wrapping under uniaxial compression. The columns had different slenderness ratios of 8, 16, 24, and 32, and were wrapped using three types of GFRP materials with thicknesses of 3 mm and 5 mm (namely, Chopped Strand Mat GFRP, Uni-Directional Cloth GFRP, and Woven Roving GFRP). The columns were then subjected to monotonic axial compressive loading until failure, and measurements of deflections and axial strain were recorded for each load increment. The results showed that the use of GFRP wrapping led to an improvement in load and deformation capacity of the HSC columns. Moreover, an Adaptive Neuro-Fuzzy Inference System (ANFIS) modeling technique was proposed to predict the performance parameters, and a strong correlation was observed between the predicted results and the actual test results.

Djamaluddin et al. (2015) focused on Fiber reinforced polymer (FRP) has become increasingly popular in civil engineering structures, as it can be used not only for new structures but also to strengthen deteriorating ones. FRPs are available in

various forms, such as rods, grids, and sheets, and are widely accepted because of their corrosion resistance and high tensile strength to weight ratio. Among the different types of FRP materials, Glass Fiber Reinforced Polymer (GFRP) sheets are the most commonly used due to their relatively lower cost. These sheets are typically applied externally by bonding them to the concrete surface.

Sadiqul Islam. et.al (2016) observed that the clear and colored glass powders have a similar chemical composition and can be classified as pozzolanic material according to ASTM standards. The addition of glass powder to the mortar resulted in a slightly higher flow and compressive strength at 90 days compared to the control specimen, with the optimal glass content being 20%. Furthermore, the use of glass as a replacement material can lower cement production costs by up to 14% while also reducing CO₂ emissions and mitigating the environmental impact associated with cement production. The increased surface area of the milled waste glass promotes a more favorable pozzolanic reaction and reduces the likelihood of the formation of an ASR gel.

Athira et al. (2016) discussed this paper presents an experimental investigation on the use of Hybrid FRP Sheets for strengthening reinforced concrete columns. External wrapping with high-strength fiber composites is a popular method for strengthening concrete structures. Fourteen columns were tested, including two control columns and twelve wrapped with various FRP sheets. The test specimens were subjected to axial compression until failure, and their ultimate load carrying capacity, axial deformation, and failure patterns were compared to unwrapped specimens. The effects of the number of layers of individual FRP sheets and the effectiveness of using hybrid FRP sheets were also investigated. The results indicated that the hybrid wrapping significantly increased the load carrying capacity and reduced sudden column collapse during loading.

Prathamesh and Srivastava (2016) discussed Over time, structures may deteriorate to a point where repairs are no longer feasible and reconstruction would cause too much downtime. Retrofitting is an effective method to address these issues. In this article, the authors provide a comparative study of the percentage increase in strength achieved through RC jacketing and FRP wrapping. The study examines and compares the percentage increases in strength achieved through

these two retrofitting methods. The study's findings provide insight into the suitability of these methods for weakened structural members, aiding structural engineers in deciding which retrofitting method to adopt to achieve the desired increase in strength.

Vinodhini et al. (2016) explained the ageing and inadequate protection of concrete structures can lead to corrosion, which raises concerns about deteriorating civil engineering infrastructure. Rehabilitating and retrofitting such infrastructure is crucial. Glass Fiber, a composite material composed of glass and resins, is a promising solution for strengthening concrete. The effectiveness of confinement using glass fiber laminates for reinforced concrete columns is studied in this paper. The study investigates the use of glass fiber as an external restraint for concrete specimens, which can undergo significant strains near the reinforcement. The degree of strain depends on the reinforcement's distribution and subdivision throughout the concrete mass. The study aims to establish the effectiveness of confinement using glass fiber for reinforced concrete specimens.

Owais et al. (2017) discussed the use of Fiber reinforced epoxy composite laminates (FRECL) or sheets to externally confine RC columns is an important application of composite retrofitting technology, especially when the existing structure's capacity is insufficient. It can be a cost-effective alternative to upgrade the performance of existing RC columns. Further research is being carried out to analyze the flexural behavior of RC beams, the effectiveness of FRECL confinement with respect to the radius of the cross-section edges, and the size and shape of the concrete column cross-section. The objective of this study was to investigate the structural behavior of reinforced concrete columns strengthened with carbon Fiber laminates and glass Fiber laminates and compare their results with unretrofitted columns. The experiment aimed to investigate the effects of additional strengthening of reinforced columns. Composites have been of interest to specialists for several decades as they offer many advantages over metal alloys, including high strength and stiffness-to-weight ratio, excellent fatigue properties, and corrosion resistance

Shanmuga Priya et. al (2017), observed the primary objective was to enhance the load carrying capacity of columns by fastening glass fiber reinforced polymer using epoxy. Previous experimental research has focused on wrapping columns and

beams entirely with glass fiber reinforced polymer. However, complete wrapping can obscure cracks and prevent early identification of failure modes. Therefore, this study proposes a strapping method. Strapping of glass fiber reinforced polymer onto columns can increase their load carrying capacity by up to 15%, a significant improvement. Additionally, the strapping method uses fewer materials than fully wrapped columns, making it cost-effective.

Vardhan Nagarkar et.al (2017) discussed conventional concrete is responsible for amount of carbon-dioxide emission to some extent. So to reduce the emission, various types of concrete are developed using waste products from industries and agricultural use like blast furnace slag, silica fume, fly ash which requires low amount of energy and also cause least harm to the environment. Green concrete is a new technology developed now days to reduce the effect on environment by production of cement. Cement contains high amount of carbon-di-oxide which harms the environment drastically, so by replacing the cement by various materials which causes harm to the environment we not only reduce the problem of disposal of these materials but we reduce the emission of carbon-di-oxide from cement and as a result of which we reduces the negative effect on environment.

V Patel and H.Solanki (2018) observed In the realm of Civil engineering, concrete is a commonly employed building material. Over time, a multitude of "Green concrete" concepts have been developed, often with the aim of partially substituting cement with other materials to reduce the material's high CO₂ emissions. Ferrock was developed by a PhD student named David Stone, who aimed to create an effective replacement for cement. This material could be mixed and poured to create a substance that possesses both the strength and adaptability of concrete. As a matter of fact, Ferrock is significantly stronger than Portland cement, which is currently the most commonly used type of cement.

Dinesh Kumar and Janardhan reddy (2018) discussed Ferrock is a building material composed of an iron-based compound that utilizes 95% recycled materials, offering better strength and flexibility compared to OPC at a lower cost. Additionally, it is a carbon-negative option due to its use of compressed carbon dioxide to accelerate the curing process, requiring no external heat. However, due to its

proprietary nature, the available literature on Ferrock's manufacturing and environmental impact is primarily preliminary in nature.

Vijayan et.al (2019) observed key ingredient is iron mill waste, which cannot be recycled conventionally and is usually sent to the landfill, undergoes a process to recover iron which is not economically viable. Ferrock is formed by reacting the iron powder with carbon dioxide and rust, creating an iron carbonate matrix during the drying process. To achieve the desired binding and performance properties, we incorporate additional materials such as Metakoalin, limestone, and fly-ash. According to the available literature, the optimal ingredient proportions for Ferrock are 60% iron dust, 20% fly-ash, 12% Metakoalin, and 8% limestone. Atomic absorption spectroscopy analysis indicates that fully cured Ferrock samples capture between 8 and 11% of CO₂ by weight.

Palaniswamy (2020) observed this project involves the use of Ferrock, a waste material from steel production that possesses tensile properties, as a replacement for cement in M20 Grade concrete. A mix design was created for the concrete, incorporating varying proportions of cement, fine aggregate, coarse aggregate, Ferrock, and water. The cubes were subjected to testing after curing periods of 7, 28, and 56 days. The research involved the substitution of cement with Ferrock, ranging from 5% to 20% in varying percentages.

Niveditha et.al (2021) discussed in this paper presents a review of a product that aims to address waste management and carbon negativity. The product makes use of iron ore waste powder that is typically discarded during the mining process, leading to air pollution, health hazards, and occupying large areas. Ferrock, as the product is called, offers a unique strength-gaining mechanism through a curing process that involves carbonation and air curing for varying periods of time. Compared to cement, Ferrock indirectly reduces carbon dioxide emissions and is a more promising eco-friendly binding material due to its carbon negativity and efficient utilization of waste. The paper highlights the product's ability to achieve desirable properties such as compression and tensile strengths.

Shivani et.al (2022) observed the objective of this research is to evaluate the environmental effects of ordinary Portland cement and Ferrock, a compound

material comprising of 60% iron oxide powder, 20% fly ash, 12% metakaolin, and 8% limestone, focusing specifically on their carbon footprint, water consumption, and energy usage. The study aims to determine the ideal replacement ratio of cement with Ferrock in concrete to achieve optimal strength in compressive, split tensile, and flexural tests. Replacement ratios of 4%, 8%, and 12% are being investigated, and 8% has been found to yield the best results in terms of strength. The specific gravity of Ferrock mix was found to be lower than that of cement. Although Ferrock cube only achieved a maximum compressive strength of 2.68 N/mm², the mechanical strength of Ferrock cement concrete was superior to that of conventional concrete, and 8% replacement of cement resulted in increased strength. The curing process for Ferrock cement concrete included both water and carbon dioxide

.2.3 SUMMARY OF THE LITERATURE REVIEW

- From the detailed literature review on geopolymers ferrock concrete, it is evident that Ferrock is a carbon negative material which absorbs carbon-dioxide instead of emitting it into the atmosphere.
- Oxalic Acid acts as a catalyst and on reaction with CO₂ and water produces Iron Carbonates, which is the hardened product. It can enhance the environment by absorbing the atmospheric CO₂ for its Hardening Process.
- Since ferrock contains chemically inactive substances. Exposure to salt-water environments acts as a strengthening agent for Ferrock. This makes it an ideal building material for construction projects in marshes and other coastal construction sites that are heavily exposed to saltwater
- Ferrock is thus a more promising eco friendlier binding material in terms of its carbon negativity and in best usage of the waste

CHAPTER 3

SCOPE AND OBJECTIVES

3.1 AIM

To determine the best replacement percentages of acceptable concrete components for industrial byproducts in concrete.

3.2 OBJECTIVES

- To study the effect of Ferrock on the Environment
- To study the effectiveness of concrete by the replacement of the cement with ferrock
- To determine the mechanical properties of concrete- Compressive strength, flexural strength, split tensile strength
- To Determine the Flexural Behaviour of Ferrock concrete beams with GFRP BARS both analytically and experimentally
- To Compare the Analytical Results and Experimental Results

3.3 SCOPE

- Ferrock production presents an intriguing prospect for future applications, particularly as the energy industry seeks alternative fuel sources.
- Ferrock has been touted as a highly attractive material, but its unique properties have the potential to have a much greater impact on the sustainable well-being of homes and the prosperity of human progress, despite being somewhat unclear.
- The focus is on reducing carbon emissions and utilizing waste materials to create a more sustainable environment.
- The development of new engineered cementitious materials provides ample opportunities for the future.

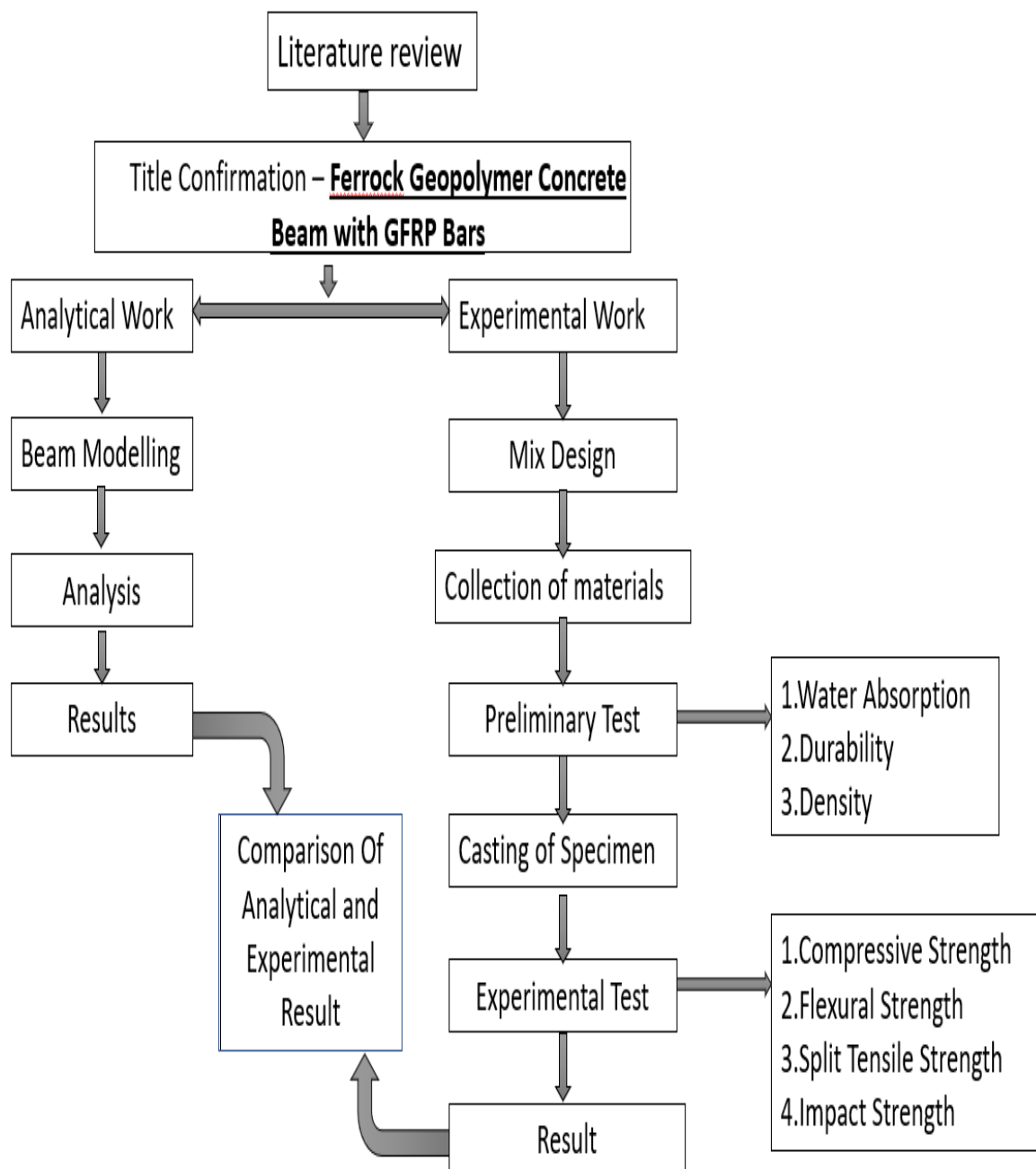
CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 AIM

In this chapter, the methodology and materials collection have been discussed briefly.

4.2 METHODOLOGY



4.3 MATERIALS COLLECTION

4.3.1 Ferrock:

Steel slag, fly ash, limestone, metakaolin, and oxalic acid are used to make ferrock, which is poured and reacts with carbon dioxide to form iron carbonate, binds carbon dioxide from the air into the ferrock. Ferrock is really five times stronger than Portland cement, one of the most widely used types of cement in use today (produced from chalk and clay and having a hue similar to Portland stone). Because it is much more flexible and can withstand greater compression before breaking, it may be able to withstand the earth moment brought on by industrial processes or seismic activity. Because of one of ferrock's special characteristics, which makes it excellent for marine base construction projects, saltwater surroundings make the material even stronger. And as it dries, ferrock actually absorbs and binds carbon dioxide rather than emitting large amounts of it! These outcomes produce a carbon-negative process that in fact aids in the capture of greenhouse gases.

Alternative to traditional concrete is ferrock. Wherever within the garbage is being best utilised, it functions as a waste management tool. When the raw materials used in the production of ferrock are used in various ratios, the material's strength is maximised. Iron oxide powder is the main component of ferrock. Due to the product's versatility and compatibility with other building materials, various ferrock components are employed in comparison to cement for a variety of applications. By consuming carbon dioxide, which interacts with iron to create the iron carbonate that firmly attaches to the substrate, ferrock gains strength. Now, the curing method used for ferrock is carbon dioxide curing. It has been noted that air curing for three days and carbon curing for four days will produce the best test results. Contrary to cement, which uses it throughout the curing process to gain strength, water is only used to transport and mix raw materials. A material known as ferrock is a binder that is used in concrete as a partial or full replacement for cement. Based on testing with various ratios of the raw ingredients, ferrock was measured.

MATERIAL	PERCENT _(BY WEIGHT)
GGBS	60%
FLY ASH	20%
LIMESTONE	10%
METAKAOLIN	8%
OXALIC ACID	2%

Table 4.1 Constituents of ferrock

4.3.2 Ground granulated Blast Furnace (GGBS)

Iron oxide particles used in construction are much finer than cement particles, being about 10 times smaller. When added to a concrete mix, the iron oxide particles envelop and coat the cement particles. As a result, the integral color is usually measured based on the cement content, rather than on the quantities of water, stone, or sand. The elongated and angular shape of the iron oxide powder is observed and noted, and it possesses a large surface area, which enhances its reactivity.



Fig 4.1 GGBS

4.3.3 Fly Ash

Fly ash concrete is an environmentally friendly option as it utilizes a by-product or waste product, thereby reducing CO₂. This type of concrete offers excellent cold weather resistance and is non-shrinking. Additionally, fly ash concrete has good workability and permits a lower water-cement ratio while maintaining a similar slump to ordinary concrete. It also reduces issues such as heat of hydration, cracks, permeability, and bleeding. As a cost-effective alternative to Portland cement, it offers numerous benefits.



Fig 4.2 Fly ash

4.3.4 Limestone Powder

Incorporating limestone powder into cement offers several benefits such as improved grindability, reduced water demand, increased strength, and less bleeding in concrete. Due to its reactive nature, limestone provides nucleation sites for clinker hydration products, thus reducing the heat of hydration. Additionally, using limestone in cement production can lead to a reduction in CO₂ emissions. Limestone powder, which is a by-product of limestone quarries, has been used in cement-based materials. It can be formed from different environments such as marine organisms, lacustrine, and evaporate depositional environments.



Fig 4.3 Limestone powder

4.3.5 Metakaolin

High-quality pozzolanic substance is metakaolin. One of the most frequently utilised admixtures today is metakaolin. It aids concrete in achieving greater efficiency and performance. High Kaolin is used in its production. In the same way that other mineral admixtures react with calcium hydroxide at room temperature to generate



Fig 4.4 Metakaolin

calcium silicate hydrate-gel, metakaolin, which is composed of silica and alumina in an active state, raises the density of concrete and decreases porosity.

4.3.6 Oxalic acid

Oxalic acid, a weak acid, is said to speed up the hydration reaction of cement. Additionally, during the gel state, this may aid in the formation of a protective electrical double-layer film around the cement particle.



Fig 4.5 Oxalic acid

4.3.7 GFRP bars:

High strength glass fibre and resin curing agent are combined to create glass fibre reinforced plastic (GFRP) bolts, which are then heated during the curing process. The bolt is entirely threaded; it rotates in either a left- or right-handed fashion, and the thread distance is typically 10 mm.

After being driven into the rock, the fibreglass bolt's body bonds to the surrounding rock mass thanks to the action of the anchoring agent. The surrounding rock mass's stress state changes, its overall stiffness is improved, its deformation resistance and bearing capacity are improved due to the interaction between the fibreglass bolt and the surrounding rock mass.



Fig 4.6 GFRP bars

4.3.8 Fine aggregate

Good quality easily locally available M sand will be used. Generally fines are classified based on size, that is below 4.75mm is regarded as fine aggregate.



Fig 4.7 Fine aggregate

4.3.9 Coarse aggregate

Any particle larger than 0.19 inches is considered a coarse aggregate, which typically has a diameter between 3/8 and 1.5 inches. The majority of the coarse aggregate used in concrete is made up of gravel, while the majority of the remaining material is crushed stone.



Fig 4.8 Coarse aggregate

4.3.10 Water:

Potable water is used for mixing and curing of concrete as per IS 456-2005.

4.3.11 Sodium Hydroxide

The most crucial element in the production of geopolymers is sodium hydroxide concentration. Aluminosilicate becomes more soluble as the concentration of hydroxide rises. Higher sodium hydroxide concentration results in greater compressive strength of geopolymer concrete.

Sodium Hydroxide (Caustic Soda)



Fig 4.9 Sodium hydroxide

4.3.12 Sodium Silicate

In the process of geopolymerization, sodium silicate (Na_2SiO_3) is typically utilised as an alkaline activator. Na_2SiO_3 is a key component of the geopolymerization method. Therefore, this study's experimental focus is on the Na_2SiO_3 polymerization stage.



Fig 4.10 Sodium silicate

4.4 MATERIAL PROPERTIES

4.4.1 Ferrock

4.4.1.1 Ground granulated blast furnace slag

Cementitious material known as ground granulated blast furnace slag (GGBFS) is used primarily to make concrete. It is made from the waste materials left over after making iron in blast furnaces. These furnaces require a carefully measured blend of limestone, coke, and iron ore and operate at high temperatures of roughly $1,500^{\circ}\text{C}$.

Table 4.2 Chemical Composition of GGBS

S.No	Chemical Constituents	% Percentage in GGBS
1.	Calcium oxide CaO	42
2.	Silicon Di oxide SiO_2	37

3.	Aluminium oxide AlO_2	9-12
4.	Magnesium oxide MgO	7

4.4.1.2 Fly ash

Fly ash is a fine powder that is a byproduct of burning pulverized coal in electric power generating plants. It is a type of coal combustion residues. The specific composition of fly ash can vary depending on the type of coal being burned and the operating conditions of the power plant.

Table 4.3 Chemical Composition of Fly ash

S.No	Chemical Constituents	% Percentage in GGBS
1.	Calcium oxide CaO	42
2.	Silicon Di oxide SiO_2	37
3.	Aluminium oxide AlO_2	9-12
4.	Magnesium oxide MgO	7

4.4.1.3 Limestone Powder

The size of limestone powder, which is a finely powdered material, can range from a few microns to several millimetres. During the manufacturing process, the particle size distribution can be controlled and altered to ensure that the powder is suitable for its intended application. This enables manufacturers to modify the characteristics of the limestone powder to suit the particular needs of their clients. The typical colour of limestone powder is white or grayish-white, but it can also take on a variety of other hues depending on the impurities that were present in the original limestone rock.

Table 4.4 Physical Properties of Limestone powder

S.No	Property	Value
1	Colour	Light grey - Dark grey
2	pH(of water slurry)	11-13
3	Specific gravity	2.65-3
4	Bulk Density	0.7-1.1
5	Chlorides content	0.004-0.034

4.4.1.4 Metakaolin

High-quality pozzolanic substance is metakaolin. One of the most frequently utilised mineral admixtures today is metakaolin. It aids concrete in achieving greater efficiency and performance. It is not totally a natural product like some others, nor is it a by-product of an industrial process like GGBS. It is specifically made with premium Kaolin.

In the same way as other mineral admixtures react with calcium hydroxide at room temperature to generate calcium silicate hydrate (C-S-H)-gel, metakaolin, which is composed of silica and alumina in an active state, raises the density of concrete and lowers its porosity. As a result, the concrete becomes more durable and its permeability is reduced.

Concrete containing metakaolin tends to have smaller pores, increasing strength, density, and resistance as a result.

Table 4.5 Physical properties of Metakaolin

Ph (10% SUSPENSION)	5.5 – 6.5
BULK DENSITY (Kg / LITRE)	0.4 – 0.5
SPECIFIC SURFACE AREA m ² /g (BET)	10 – 12
OIL ABSORPTION g/100g	45 – 55
SPECIFIC GRAVITY	2.6
RET. ON 500 MESH	0. 05%

4.4.1.5 Oxalic acid

Iron carbonates, the hardened product, are formed when oxalic acid acts as a catalyst in the presence of CO₂ and water. The absorption of atmospheric CO₂ during the hardening process enables oxalic acid to the environment.

Table 4.6 Physical Properties of Oxalic acid

S.No	Properties	Value
1	Oxalic acid	C ₂ H ₂ O ₄
2	Molecular weight	90.03 g/mol
3	Density	1.90 g/cm ³
4	Appearance	White Crystals
5	Melting Point	189 to 190

4.4.2 Fine aggregate

In order to make concrete or mortar, granular material known as aggregate is used. It is referred to as fine aggregate when the granular material's particles are small enough to pass through a 4.75mm screen. To enhance the volume of concrete and lower costs, fine aggregate is frequently utilised in the building sector. The concrete or mortar mixture can be made more resilient, robust, and economical by choosing fine aggregate based on characteristics such grading zone, particle form and surface texture, abrasion and skid resistance, absorption and surface moisture. The fine aggregate has a specific gravity of 2.61.

Table 4.7 Physical Properties of Fine Aggregate

S.No	Properties	Value
1.	Specific gravity	2.61
2.	Density kg/m ³	1580
3.	Water absorption	1.0
4.	Zone	II

4.4.3 Coarse aggregate

Aggregates are a vital component of concrete as they help in providing body to the concrete mixture while also reducing shrinkage. Coarse aggregates are categorized based on their shape and size, which can range from round, irregular, angular, flaky, to elongated.

The category can also include gravels, cobble, and boulders depending on the size of the coarse aggregate. Coarse aggregates can be used in normal to high strength concrete with a size range of 4mm to 256mm. In order to achieve optimum strength, the coarse aggregates used must be strong, impermeable, durable, and capable of forming a workable mixture. For a 20mm size, crushed stone with a specific gravity of 2.68 should be included.

- Uncrushed Gravel or Stone: Such aggregate is formed by natural disintegration of rocks.
- Crushed Gravel or Stone: It is the outcome of crushing of gravel or hard stone.
- Partially Crushed Gravel or Stone: It forms by blending of the above two aggregate.

Table 4.8 Physical Properties of Coarse Aggregate

S.No	Properties	Value
1.	Specific Gravity	2.74
2.	Crushing value	14.21%
3.	Impact value	2.5
4.	Density kg/m ³	1560
5.	Water absorption	0.74%

4.4.4 Water

The amount of water used in concrete mixing has an impact on the final hardened product. Water impurities may interact with cement setting, reducing the strength

and durability of concrete. For casting and curing the specimen, fresh and pure water that is free of organic debris, silt, oil, and acid material is employed.

4.4.4 Sodium Hydroxide (NaOH)

The Authors have found that the geopolymer concrete made using the Class-F Fly ash based is activated using the alkaline activators. The alkaline activators are mainly composed of Sodium hydroxide and Sodium Silicate.

This Project mainly deals with the study of Variation in Molarity of Sodium Hydroxide in Alkaline Solution. The Properties of sodium hydroxide are as follows. They are

Table 4.9 Physical Properties of Sodium Hydroxide

S.No	Properties	Value
1	Chemical Formula	NaOH
2	Molar mass	39.997 g/mol
3	Density	2.13 g/cm ³
4	Melting Point	318.4 °C
5	Boiling Point	1.388 °C

4.4.5 Sodium Silicate (Na₂O₃SiO₂)

Sodium Silicate is one of the major component in geopolymer solution which is used to undergo geopolymerization process in geopolymer concrete. It is the alkaline activators used in geopolymerization of concrete.

The Composition of sodium silicate used in the concrete is as follows. They are

Table 4.10 Physical Properties of Sodium Silicate

S.No	Properties	Value
1	Physical state	liquid
2	Appearance	Clear liquid
3	Colour	Transparent yellow
4	Odour	Odourless
5	Boiling Point	100 °C

4.5 TRIAL MIX

4.5.1 General

The experimental study consists of a number of procedures, such as developing the grade of concrete through trial mixes, analysing its consistency and wet density, preparing specimens, and conducting testing after the proper curing. Each of these steps is fully explained.

4.5.2 Mix Design

Mix design involves choosing the appropriate ingredients for concrete and determining their respective proportions based on initial laboratory tests in order to obtain an economical mix that adheres to IS:10262-1982 standards.

4.5.2 Design Mix Calculations

The mix design calculations are done as per the following procedure

I) unit weight of geopolymer concrete = 2400 kg/m^3

II) aggregates is 77% of mass of concrete

$$\text{i.e } 0.77 \times 2400 = 1848 \text{ kg/m}^3.$$

The Finness modulus of combined aggregate is approximately 5.0.

iii) Alkaline liquid to fly ash by mass = 0.35

$$\begin{aligned} \text{Mass of fly ash and liquid} &= 2400 - 1848 \\ &= 552 \text{ kg/m}^3. \end{aligned}$$

$$\begin{aligned} \text{Mass of fly ash} &= [552 / (1 + 0.35)] \\ &= 408 \text{ kg/m}^3. \end{aligned}$$

$$\begin{aligned} \text{Mass of alkaline liquid} &= (552 - 408) \\ &= 144 \text{ kg/m}^3 \end{aligned}$$

Note: [Ratio of sodium silicate to sodium Hydroxide] = 2

$$\begin{aligned} \text{Mass of Na-OH} &= [144 / (1 + 2)] \\ &= 48 \text{ kg/m}^3. \end{aligned}$$

Mass of sodium silicate solution = (144-48)
= 96 kg/m².

Trial mix proportion

Combined Aggregates	1848 kg/m ³
Low - calcium fly ash	408 kg/m ³
Sodium Hydroxide	48 kg/m ³
Sodium Silicate Solution	96 kg/m ³

For A53 with SiO₂, to Na₂O ratio by mass 2

i.e Na₂O = 14.7%

SiO₂ = 29.4%

Water = 55.9%

Mixed with water to make a solution with concentration of 8Molar (8M)

26% of Na-OH solids & 74% water

Sodium silicate solution:

Mass of solids = (0.26 x 48)
= 12.48 kg

Mass of water = (14 - 12.48)
= 35.52 kg

Total mass of water = 71.04 + 35.52
= 106.56 kg

Total mass of geopolymer solids = [Mass of fly ash + Mass of solids in NaOH +
Mass of water in Na₂SiO₃]
= (408+24.96+12.48) = 445.44 kg

Hence water to geopolymer solids = [Total mass of water / Total mass of solids]

$$\begin{aligned}\text{ratio by mass} &= [106.56 / 445.44] \\ &= 0.2\end{aligned}$$

Table 4.11 Mix Propotion

Ferrorock (kg/m³)	Fine aggregate (kg/m³)	Coarse aggregate (kg/m³)	Water (kg/m³)
408	739.2	1108.8	48
1	1.81	2.17	0.11

4.6 CASTING AND CURING

4.6.1 GENERAL

The quality of concrete work can be effectively managed through the implementation of testing procedures. Such procedures should involve systematic testing of raw materials, as well as fresh and hardened concrete, and form an essential component of any concrete quality control program. By adopting simple, direct, and convenient testing methods, higher levels of efficiency can be achieved.

When taking all of the aforementioned factors into account, it becomes clear that the preparation of test specimens plays a crucial role. This process encompasses a variety of activities such as batching and weighing, mixing, casting, demoulding, and curing, which should all be executed in accordance with code recommendations and design mix requirements. By preparing different types of concrete test specimens, one can effectively assess both the strength and durability parameters.

When preparing test specimens, it is crucial to exercise additional care and avoid neglecting any important aspects. The process of preparing concrete test specimens must involve excellent workmanship as well as rigorous supervision, and each step of the process is directly linked to the strength parameters.

4.6.2 CASTING

The casting of various concrete specimens such as cubes, cylinders and reinforced beams are described as follows.

4.6.1.1 Casting of Cubes

The concrete cube specimens are casted by the consideration of following steps

- *Cube Mould*

The cube moulds of required size 150 x 150 x 150 mm for nominal size of aggregate not exceeding 38 mm. Cube moulds shall be provided with a base plate and they shall be as per IS:10086-1982.

- *Tamping Rod*

As per IS:10086-1982, the tamping rod shall be 16 ± 0.5 mm dia and 600 ± 2 mm long with a rounded working end and shall be made of mild steel.

- *Casting Process*

The cube mould plates should be removed, properly cleaned assembled and all the bolts should be fully tight. A thin layer of oil then shall be applied on all the faces of the mould. It is important that cube side faces must be parallel. After taking concrete samples and mixing them, the cubes shall be cast as soon as possible. The concrete sample shall be filled into the cube moulds in layers approximately 5 cm deep.

In placing each scoopful of concrete, the scoop shall be moved around the top edge of the mould as the concrete slides from it, in order to ensure a symmetrical distribution of the concrete within the mould. Each layer shall be compacted either by hand or by the vibration as described below.

- *Compaction By Hand*

Each layer of the concrete filled in the mould shall be compacted by not less than 35 strokes by tamping bar. The strokes shall be penetrate into the underlying layer and the bottom layer shall be rodded through its depth. Where voids are left by the tamping bar the sides of the mould shall be tapped to close the voids.

4.6.2.2 Casting of Cylinders

The material properties of concrete can only be properly evaluated if test specimens are made and cured according to standards. Concrete cylinders are typically made to evaluate the compressive strength of the concrete as well as Split tensile strength.

- *Cylinder Mould*

Metal 100 x 200 mm or 150 x 300 mm cylinder moulds are used for casting concrete test specimens in the field. Before filling, they should be placed on a smooth, firm, level surface.

- *Tamping Rod*

If 100 mm diameter moulds are used then it should be filled in 3 equal layers and each layer rodded uniformly 20 times with a 10 mm diameter x 450 - 600 mm long hemi spherically tipped steel rod.

If 150 mm diameter moulds are used then it should be filled in 3 equal layers and each layer rodded uniformly 25 times with a 16 mm diameter x 450 - 600 mm long hemi spherically tipped steel rod.

4.6.2.3 *Casting of Beams*

According to standards Concrete beam are casted to evaluate the flexural strength of the concrete. The casting and testing procedure to be followed as Indian standard code IS 516:1959.

- *Cylinder Mould*

The mould standard size will be 150 x 150 x 700 made out of metal. The tamping bar shall be a steel bar weighing 2kg, 40 cm long and shall have a ramming face 25 mm square. The test specimen shall be made as soon as practicable after Mixing and in such way as to produce full compaction of concrete while neither segregation nor excessive laitance.

- *Casting Process*

The compaction shall be distributed uniformly over the section of the mould. The bottom layer shall be rodded throughout its depth. For each upper layer, the rod shall penetrate about 25 mm into the underlying layer. If voids are left by the rod, the sides of the mould should be tapped to close voids before adding the next layer of material.

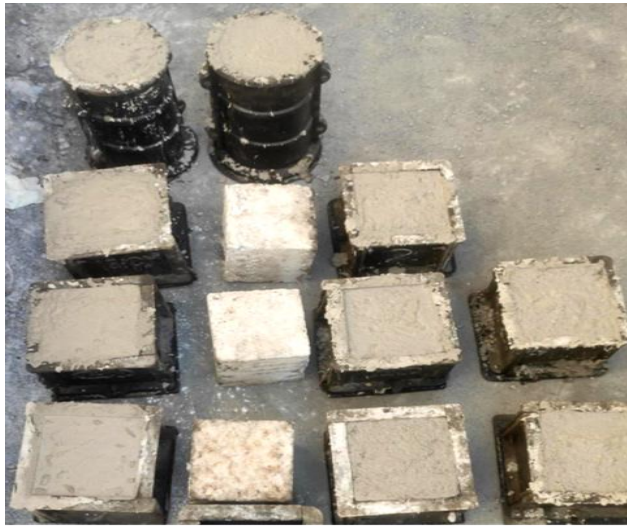


Fig 4.11 casting of beam,cube cylinder,prism

4.6.3 DEMOULGING

For optimal results, it is recommended to demould test concrete specimens within 16 to 24 hours after production. If the concrete has not achieved sufficient strength to withstand demoulding without damage, it is best to wait an additional 24 hours. During the demoulding process, it is essential to dismantle the mould entirely to prevent any damage to the specimens. Any cracks caused during this process can reduce the overall strength of the specimens. Once demoulded, each specimen should be clearly marked with a waterproof crayon or ink for easy identification. It is important to thoroughly clean the mould after demoulding and ensure that no grease or dirt is present between the flanges. Otherwise, the two halves of the mould may

not fit correctly, causing leakage through the joint and an irregular shape of the specimens.

4.6.4 AIR CURING

Air curing refers to the process of allowing a substance, usually a material or a product, to cure or harden by exposure to air, without any additional curing agents or external heat sources. This process is commonly used in the manufacturing of certain materials such as concrete and clay bricks, where the products are left to cure in a dry and well-ventilated area. The air curing process allows the material to slowly and naturally gain strength over time, without the need for additional energy inputs. Air curing is often preferred over other curing methods because it is cost-effective, energy-efficient, and environmentally friendly. However, it can also be a slow process and may require a longer time to achieve the desired level of strength and durability.

4.7 TEST ON FRESH CONCRETE

The fresh concrete test is defined as a Green properties of concrete which is carried out by the method of workability (slump), air content test, bleeding tests which are described as follows.

4.7.1 SLUMP

This procedure outlines the methodology for testing the workability of plastic concrete in a laboratory setting using the slump cone apparatus. Prior to beginning the test, it is imperative to ensure that the internal surface of the mould is thoroughly cleaned and free from any moisture. The mould should then be placed on a smooth, horizontal, non-absorbent metal surface that has been carefully levelled.

The concrete sample should be added to the mould in four equal layers, with each layer being tamped with twenty-five strokes of a 16mm diameter, 600mm long rounded end tamping rod, as shown in figure 4.13. The strokes must be uniformly distributed over the cross-section of the mould and should penetrate into the underlying layer for the second and subsequent layers. The bottom layer should be tamped throughout its depth.

Once the top layer has been rodded, any excess concrete should be removed and levelled with a trowel or the tamping rod to ensure that the mould is completely filled. Any mortar that may have leaked out between the mould and the base plate should be cleaned away.

The mould should then be slowly and carefully raised in a vertical direction to remove it from the concrete immediately. The slump should be measured immediately by determining the difference between the height of the mould and the highest point of the specimen being tested. The measured slump should be recorded in millimeters as the subsidence of the specimen during the test.

Slump

The height of the slump cone = 300mm

The height of concrete after subsidence = 110mm

Hence, the slump measured = 180mm



Fig 4.12 slump cone test

4.8 TEST ON HARDENED CONCRETE

The hardened concrete test consists of both the strength properties of the concrete. The strength properties of concrete is carried out by compressive strength test, split tensile strength test, flexural strength test, cylindrical compression test, and young's modulus test as follows.

4.8.1 Compressive Strength Test

This procedure is relevant for establishing a testing method to determine the compressive strength of concrete specimens. Specimens that are stored in water should be immediately tested upon removal from the water while still in the wet condition. To maintain the wet condition, the specimens should be covered with wet burlap. The bearing surfaces of the testing machine should be wiped clean and free of dry loose sand or any other material before the surfaces of the specimen that will be in contact with the compression platens are also cleaned. In the case of cubes, the specimen should be placed in the machine such that the load is applied to the opposite sides of the cube as it was cast and not to the top and bottom. The axis of the specimen should be aligned with the center of thrust of the spherically seated platen. No packing should be used between the faces of the test specimen and the steel platen of the testing machine. To uniformly load the specimen, the loading rate should be set to 5.2 KN/sec for 15 cm cube, as shown in fig 4.20. The load should be applied gradually, without shock, and increased continuously until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen should be recorded, and the appearance of the concrete and any unusual features in the type of failure should be noted.

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{\text{Ultimate load in N}}{\text{Area of cross section(mm}^2\text{)}}$$



Fig 4.13 compression strength test

4.8.2 Split Tensile Test

This method is suitable for establishing a testing procedure for determining the split tensile strength of concrete specimens. Upon receipt, dry specimens must be immersed in water for 24 hours before testing. Unless specified otherwise for laboratory investigations, wet specimens should be tested immediately upon removal from the water, after wiping off any surface water and grit, and removing any projecting fins from the surfaces that will be in contact with the packing strips. The two ends of the specimen should be marked with diametral lines using a suitable procedure and device to ensure they are in the same axial plane. The bearing surfaces of the testing machine and packing strips should be wiped clean, as shown in Figure 4.21. To position the specimen, one of the plywood strips should be centered along the center of the lower platen, and the specimen should be aligned so that the marked lines on the ends of the specimen are vertical and centered over the plywood strip. The second plywood strip should be placed lengthwise on the cylinder, centered on the marked lines on the ends of the cylinder. The load should be applied without shock and increased continuously at a rate to produce a splitting tensile stress of approximately 14 to 21 kg/cm²/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen should then be recorded, and the appearance of the concrete and any unusual features in the type of failure should be noted. The measured splitting tensile strength (T_{sp}) of the specimen should be calculated to the nearest 0.01N/mm² using the following

formula.

$$\text{Split tensile strength (N/mm}^2\text{)} = \frac{2P}{\pi L D}$$

Where,

P= maximum load in N applied to the specimen,

d= measured diameter in mm of the specimen, and

l = measured length in mm of the specimen.



Fig 4.14 split tensile test

4.8.3 Flexural Strength Test

This method is intended for establishing a testing procedure for measuring the flexural strength of concrete specimens. The specimens, after being stored in water at a temperature ranging from 24°C to 30°C for 48 hours prior to testing, should be tested as soon as they are removed from the water while still in a wet condition. No surface preparation is necessary.

Before testing, the supporting and loading rollers' bearing surfaces must be cleaned, and any loose materials or sand removed from the surface of the specimen where they will make contact with the rollers. The specimen should be placed in the machine so that the load is applied to the surface that was cast uppermost in the mould, along two lines spaced 200 mm apart. The loading device's axis should be carefully aligned with the specimen's axis. The testing machine bed should be

equipped with two steel rollers, 38mm in diameter, on which the specimen will be supported. These rollers should be spaced 600mm c/c apart. No packing should be used between the specimen's bearing surfaces and the rollers, as depicted in Figure 4.22.

The load should be applied without shock and increased continuously at a rate such that the extreme fibre stress increases by approximately 0.7 kg/sq cm/min, or at a loading rate of 400kg/min for the 150 mm specimens. The load should be increased until the specimen fails, and the maximum load applied to the specimen during the test should be recorded. The appearance of the fractured concrete faces and any unusual features in the failure mode should be noted.

The specimen's flexural strength should be expressed as the modulus of rupture and calculated to the nearest 0.05 N/mm² as follows:

$$\text{Flexural strength (N/mm}^2\text{)} = \frac{P L}{B D^2}$$

Where,

b= measured width in mm of the specimen,

h= measure depth in mm of the specimen at the point of failure,

l= length in mm of the span on which the specimen was supported,

P= maximum load in N applied to the specimen.



fig 4.15 fexural strength test

4.8.4 Modulus of Elasticity

The ratio of normal stress to corresponding strain for compressive or tensile stresses that are below the proportional limit of concrete, as defined by ACI 318-14, determines the modulus of elasticity of concrete. Although different codes provide formulas to calculate the value of elastic modulus of concrete, the accuracy of these values may not be guaranteed. To obtain an accurate value, various tests can be conducted. One such method is ASTM C469 (Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression), which can determine the modulus of elasticity of concrete with precision. For this test, the moulded cylindrical specimen should be tested within an hour after being removed from the curing or storage room. Alternatively, the modulus of elasticity can also be determined using a drilled core specimen, and the requirements for storage and ambient conditions prior to the test should be the same as for the moulded cylindrical specimens. During the test, maintain a steady ambient temperature and use two specimens to specify the compressive strength before conducting the modulus of elasticity test. Attach strain-measuring equipment to the specimen and place it on the lower platen or bearing block of the testing machine. Carefully load the specimen to seat the gauge, and correct any abnormal responses. Then, apply the load continuously, recording the applied load and longitudinal strain when the longitudinal strain reaches 50 millionths and the applied load is 40% of the ultimate load. The modulus of elasticity of concrete can be calculated to the nearest 50000 psi (344.74 MPa) using the following equation:

$$E_c = (S_2 - S_1) / (\epsilon_2 - 0.00005) \quad \text{Equation 1}$$

Where,

E = modulus of elasticity, psi,

S2 = stress corresponding to 40% of ultimate load.

S1 = stress corresponding to a longitudinal strain of 50 millionths, psi

e2 = longitudinal strain produced by stress S2.

4.8.5 Beam - Load Vs Deflection Test

RCC beams are commonly utilized as structural members in various types of constructions. RCC is a uniform material possessing multiple properties. On the basis of analysis, RCC beams are categorized as under reinforced, balanced, or over reinforced sections. Both concrete and steel in RCC beams reach the stress and corresponding strains simultaneously due to external loads.

When steel fails before the stress in concrete reaches the maximum permissible stress in an RCC beam, it is referred to as an under reinforced section. If both concrete and steel reach the permissible stress values simultaneously, such beams are known as balanced sections. On the other hand, if the concrete tends to fail before the stress in steel reaches the maximum permissible stress, the beams are categorized as over reinforced sections.

The primary design criteria for any type of structure include safety, serviceability, and economy. RCC elements are extensively used in all structural applications due to these essential properties. For the structural use of RCC elements, the following parameters must be met:

- The structure must be safe and cost-effective, with the ability to resist both tensile and compressive stresses.
- The structure must be rigid and unimpaired to resist the bending moments and shear forces generated by external applied loads.
- The structure must be cost-effective by using materials that can resist all types of stress.

To predict the safe and cost-effective conditions of RCC, it is necessary to assess the ultimate loads and corresponding deflections under specific constraints. Conducting an experimental analysis is necessary to obtain desirable results. When an RCC beam is subjected to external loads, it tends to bend with some deflection.

Table 4.12 Cross section area of beam

MIX	VARIATIONS	GRADE OF STEEL, Fe	C/S area (mm ²)	SIZE OF THE BEAM
MIX 1	8M of NaOH	415D	74.63	1500*230*230
MIX 2	10M of NaOH	415D	74.63	1500*230*230
MIX 3	12M of NaOH	415D	74.63	1500*230*230
MIX 4	14M of NaOH	415D	74.63	1500*230*230
MIX 5	16M of NaOH	415D	74.63	1500*230*230

The primary aim of this research is to establish the correlation between loading and the corresponding deflection of a simply supported beam under a point load. Determining the stress-strain behavior of brittle materials, such as concrete, through simple compression tests can be difficult. Therefore, to anticipate the flexural behavior of concrete, a load deflection method on three points was necessary. The experimental setup in this study aimed to investigate the following:

- a) Loads and corresponding deflections
- b) The impact of length and cross-sections on deflections per unit load.

After curing for 28 days, the beams were subjected to three-point loading. Dial gauges were placed at the bottom of the beam, and hydraulic load was applied linearly. Deflection of the beam was measured at each interval of 5KN load, and the first crack at which load and corresponding deflection were observed.

To analyze the relationship between load and deflection of a beam, the beam was placed on two bearers affected by a concentrated load at the center. The bearers were set so that a span of 1500 mm was maintained, and the interval between each groove on the beam of the apparatus was 100 mm. A test specimen with dimensions of 100 x 200 mm was placed on the bearers, and the load device was mounted in the center of the test specimen. The testing device was set so that the top of the gauge was centered on the upper plane of the load device. The gauge was then lowered, and its small hand was set at about 10 before being zeroed by twisting its outer ring, as shown in figures 4.27 and 4.28.



Fig 4.16 testing of beams

CHAPTER 5

RESULTS AND DISCUSSION

5.1 EXPERIMENTAL TEST RESULTS

The following test results have been discussed below with tabulation and figures.

5.1.1 General

- As this study deals with Fully replacing cement in terms ferrock, which is geopolymer ferrock concrete with variation of the Molarity of Sodium hydroxide which is the main component in undergoing geopolymerization process along with the Sodium Silicate
- The Molarity of Sodium Hydroxide is varied in the concrete in 5 variations such as 8M, 10M, 12M, 14M, 16M respectively
- In accordance with the literature review undergone before the study, the optimum variation of Molarity of Sodium hydroxide is seems to 12M among the 5 variations

5.1.2 Compressive strength test

- The Compressive strength is carried out in Cube specimens of size (0.15m x 0.15m x 0.15m) and testing is carried out and results are provided for 7th day, 14th day, 28th day in the table provided below

Table 5.1 compressive strength of cube

Compressive strength of cubes (N/mm ²)			
Trial mixes	7 th day	14 th day	28 th day
Mix 1- 8M	18.04	23.4	32.6
Mix 2- 10M	17.68	32.5	37.8
Mix 3- 12M	25.8	36.16	41.66
Mix 4- 14M	20.85	32.15	38.6
Mix 5- 16M	22.15	31.8	37.83

The above chart shows the compressive strength of the cube specimens which are tested for 7th day, 14th day, 28th day with the variation of molarity of sodium hydroxide in the geopolymer solution of the concrete.

5.1.3 Split tensile strength

- The maximum tensile strength created at the moment of failure is then calculated to determine the concrete's tensile strength.
- The durability and resistance of concrete to cracking and deformation under tensile loading are closely associated with its split tensile strength, making it a crucial attribute of concrete
- Split tensile test in cylinder is most famous and important test which is carried out in total 10 numbers of trial mixes
- In this the test specimen is cylinder of whose dimension is 0.15 m diameter and 0.3 m height.

Table 5.2 Split tensile strength of cylinder

Split tensile strength of cylinder(N/mm ²)		
Trial mixes	14 th day	28 th day
Mix 1- 8M	2.7	3.9
Mix 2- 10M	3.2	4.1
Mix 3- 12M	3.5	4.45
Mix 4- 14M	3.3	4.32
Mix 5- 16M	3.4	4.25

- The above chart shows the split tensile strength of cylindrical specimens for 14days and 28 days curing.
- As discussed above in the previous sections , 12M of Mix 3 shows better strength than the other variations. The strength gradually increases from the 8M and gets its higher strength 12M which is the optimum variation and it gradually decreases after 12M to 16M
- Thus the optimum variation is 12 Molarity of Sodium hydroxide.

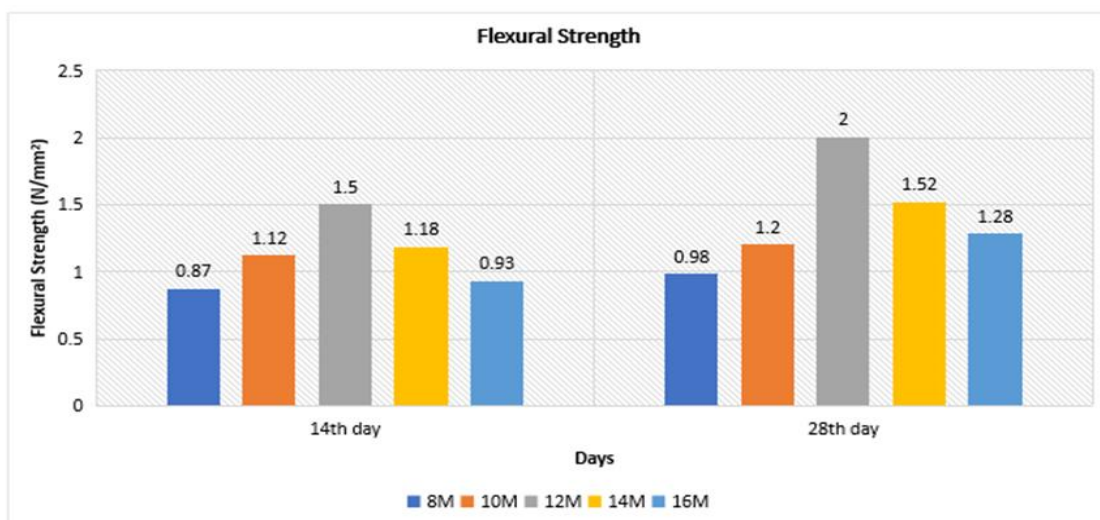
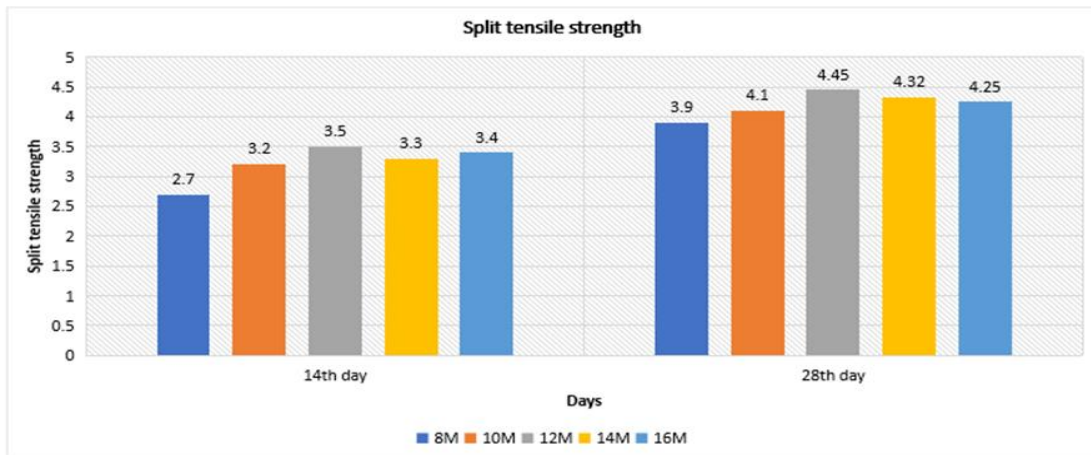
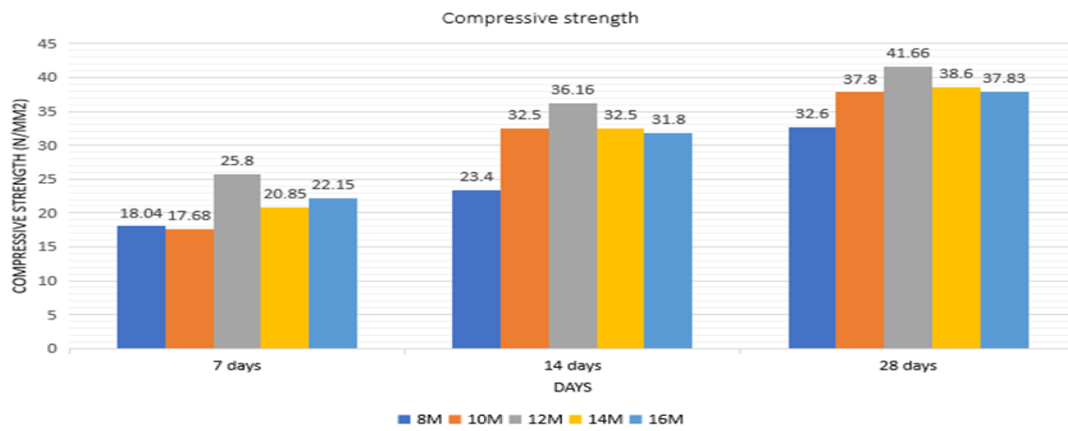
5.1.3 Flexural strength

- Flexural strength of a prism refers to the maximum stress that a rectangular or square cross-section prism can withstand before breaking or fracturing under bending. This property is important in evaluating the strength and durability of materials
- The flexural strength of a prism depends on several factors, including the size and shape of the cross-section, the composition and quality of the material, and the curing conditions.
- In this test the specimen prism is of size (0.5m x 0.1m x 0.1m) and the test is carried out and curing is done and experimental test is carried out after 14days and 28days of curing.
- From the experimental results obtained above after the 14days and 28 days curing the higher strength is obtained in the MIX-3 12M.
- The Strength tends to be increasing gradually from 8M and attains higher in 12M and after that it reduces gradually when coming to 16M.

Table 5.3 Flexural strength of cylinder

flexural strength of cylinder(N/mm ²)		
Trial mixes	14 th day	28 th day
Mix 1- 8M	0.87	0.98
Mix 2- 10M	1.12	1.2
Mix 3- 12M	1.5	2
Mix 4- 14M	1.18	1.52
Mix 5- 16M	0.93	1.28

Fig 5.1 Graphical representation of results of experimental test



5.1.4 Modulus of elasticity

- The ASTM method is used to determine the stress-strain relationship of concrete in compression for all partial replacement trial mixes, including the control mix at 28 days. The findings show that the partial replacement trial mix concrete has a greater Young's modulus value than the standard control concrete of the M45 grade.
- Moreover, as specified in IS 456:2000 for Young's modulus of M45 grade concrete value is relatively comparable to all the mixes, especially optimum content of 12M is shows higher value(i.e. $5000\sqrt{f_{ck}}$) compared to other mix were tabulated in table

Table: 5.4 Young's Modulus of MIX1 - 8M

Load (KN)	Stress (N/mm ²)	Change in length (mm)	Strain	Young's modulus (Mpa)
25	1.414	0.019	5.49×10^{-5}	49967
50	2.829	0.031	12.4×10^{-5}	47854
75	4.244	0.058	4.69×10^{-4}	49245
100	5.658	0.063	3.87×10^{-4}	48144
125	7.073	0.091	4.36×10^{-4}	46548
150	8.488	0.097	5.85×10^{-4}	48126

Table: 5.5 Young's Modulus of MIX 2 - 10M

Load (KN)	Stress (N/mm ²)	Change in length (mm)	Strain	Young's modulus (Mpa)
25	1.414	0.019	5.45×10^{-5}	47954
50	2.829	0.031	12.1×10^{-5}	46768
75	4.244	0.058	4.64×10^{-4}	45142
100	5.658	0.062	3.82×10^{-4}	46996
125	7.073	0.091	4.25×10^{-4}	47284
150	8.488	0.094	5.21×10^{-4}	45146

Table: 5.6 Young's Modulus of MIX 3 - 12M

Load (KN)	Stress (N/mm2)	Change in length (mm)	Strain	Young's modulus (Mpa)
25	1.414	0.019	5.2×10^{-5}	45368
50	2.829	0.032	11.9×10^{-5}	47259
75	4.244	0.046	4.34×10^{-4}	46952
100	5.658	0.071	3.45×10^{-4}	48011
125	7.073	0.081	4.12×10^{-4}	49126
150	8.488	0.095	5.4×10^{-4}	44629

Table: 5.7 Young's Modulus of MIX 4 - 14M

Load (KN)	Stress (N/mm2)	Change in length (mm)	Strain	Young's modulus (Mpa)
25	1.414	0.019	5.05×10^{-5}	44689
50	2.829	0.031	12.2×10^{-5}	46862
75	4.244	0.047	4.1×10^{-4}	45974
100	5.658	0.069	3.2×10^{-4}	43259
125	7.073	0.086	4.04×10^{-4}	46824
150	8.488	0.091	5.9×10^{-4}	45168

Table: 5.8 Young's Modulus of MIX-5 16M

Load (KN)	Stress (N/mm2)	Change in length (mm)	Strain	Young's modulus (Mpa)
25	1.414	0.019	5.49×10^{-5}	49967
50	2.829	0.031	12.4×10^{-5}	47854
75	4.244	0.058	4.69×10^{-4}	49245
100	5.658	0.063	3.87×10^{-4}	48144
125	7.073	0.091	4.36×10^{-4}	46548
150	8.488	0.097	5.85×10^{-4}	48126

5.1.5 Beam – Load Vs Deflection Test

- The RC beam was subjected to three point loading system which was casted for partial replacement of 15 %. The result of Load Vs Deflection curve and stress Strain behavior shows that partial replacement beams has carried more load.
- The maximum load attain by 15% partial replacement of FLYASH and GGBS and copper slag beam shows the maximum moment carrying capacity compare to Normal control mix were tabulated in tables

Table: 5.9 Deflection of Beam – (MIX 1 - 8M)

S.No	Load (kN)	Deflection
1	10	0.39
2	20	0.79
3	30	0.97
4	40	1.34
5	50	1.87
6	60	2.33
7	70	2.60
8	80	3.3
9	90	3.7
10	100	4.5

Table: 5.10 Deflection of Beam – (MIX 2- 10M)

S.No	Load (kN)	Deflection
1	10	0.39
2	20	0.79
3	30	0.97
4	40	1.34
5	50	1.87
6	60	2.33
7	70	2.60
8	80	3.3

9	90	3.7
10	100	4.5

Table: 5.11 Deflection of Beam – (MIX 3 - 12M)

S.No	Load (kN)	Deflection
1	10	0.39
2	20	0.79
3	30	0.97
4	40	1.34
5	50	1.87
6	60	2.33
7	70	2.60
8	80	3.3
9	90	3.7
10	100	4.5

Table: 5.12 Deflection of Beam – (MIX 4 - 14M)

S.No	Load (kN)	Deflection
1	10	0.39
2	20	0.79
3	30	0.97
4	40	1.34
5	50	1.87
6	60	2.33
7	70	2.60
8	80	3.3
9	90	3.7
10	100	4.5

Table: 5.13 Deflection of Beam – (MIX 5 - 16M)

S.No	Load (kN)	Deflection
1	10	0.39
2	20	0.79
3	30	0.97
4	40	1.34
5	50	1.87
6	60	2.33
7	70	2.60
8	80	3.3
9	90	3.7
10	100	4.5

5.2 ANALYTICAL TEST RESULTS

5.2.1 Finite Element Analysis

Finite Element Analysis (FEA) is a numerical method used to solve complex engineering problems that involve structural mechanics, heat transfer, fluid dynamics, and other physical phenomena. It is widely used in the design and analysis of structures and components in various industries, including aerospace, automotive, civil engineering, and biomechanics

5.2.2 Abaqus

Abaqus is a popular commercial finite element analysis software developed by Dassault Systèmes. It is widely used in the simulation and analysis of various physical phenomena, including structural mechanics, heat transfer, fluid dynamics, and electromagnetics.

Abaqus provides a powerful platform for building and simulating complex models using various elements, materials, and loading conditions. It has a user-friendly interface that allows users to create, edit, and mesh models, define boundary conditions and material properties, and run simulations

Some of the features and capabilities of Abaqus include:

- Nonlinear analysis: Abaqus can simulate complex nonlinear behaviors such as large deformations, material plasticity, contact, and damage.
- Multiphysics analysis: Abaqus can simulate the interactions between different physical phenomena such as thermal-structural, fluid-structure, and electromagnetic-thermal.
- High-performance computing: Abaqus can take advantage of parallel computing to speed up simulations and handle large-scale models.
- Customization: Abaqus provides a scripting language (Python) that allows users to automate tasks, customize the user interface, and extend the software's functionality.
- Integration: Abaqus can be integrated with other software tools such as CAD software, optimization software, and data analysis software.

5.2.3 Properties

One crucial step in the finite element modeling process is to define the properties of the material and section being used. For instance, in the case of a composite beam made of concrete and basalt fiber bars, with a yield stress of 415 MPa, defining the properties of the section involves specifying the section's thickness and all the relevant material properties necessary for the analysis

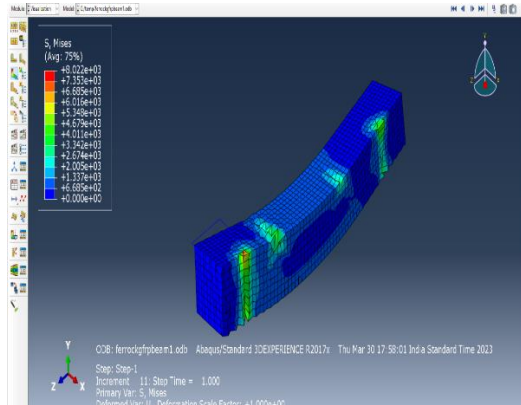
Table 5.14 Properties of materials

PROPERTIES	VARIATION IN THE MOLARITY OF SODIUM HYDROXIDE				
	8M	10M	12M	14M	16M
Young's modulus	43.27 Gpa	44.36 Gpa	43.65 Gpa	42.5Gpa	42.9Gpa
Poisson's Ratio	0.28	0.23	0.29	0.24	0.27

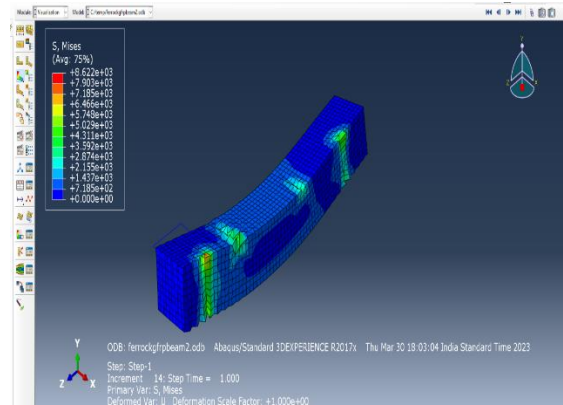
5.2.4 Analytical results

The results of the analytical model of the beam is tabulated and the images of the results are also shown:

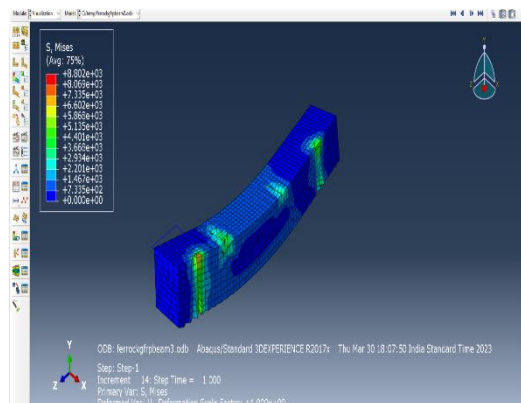
The results indicate that the optimum variation of the Sodium hydroxide is found to be MIX 3 - 12M which outperformed among the other variations of Molarity of sodium hydroxide. The reinforced concrete beams is to have higher strength and lower deflection in the MIX 3 - 12M whereas in the other beams it seems to have lower strength and more deflection.



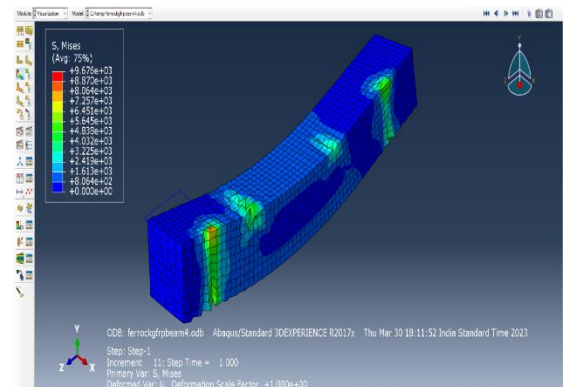
MIX 1 - 8M



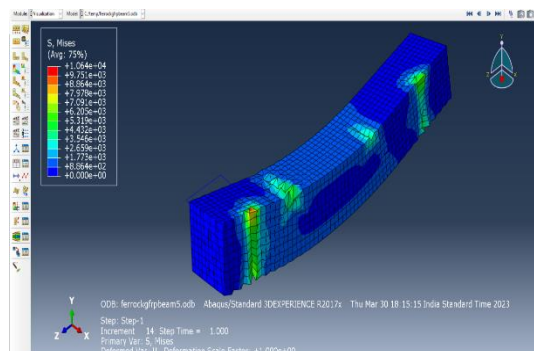
MIX 2 - 10M



MIX 3 - 12M



MIX 4 - 14M



MIX 5 - 16M

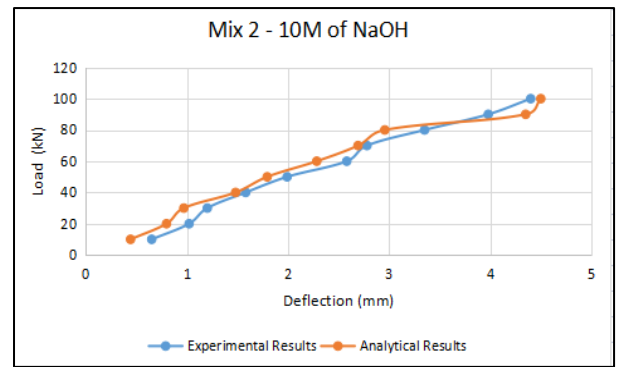
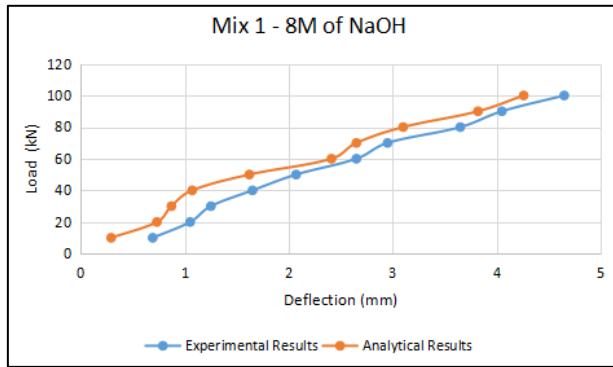
Fig 5.2 Analytical models of ferrock GFRP beams

Table 5.15 Analytical results of load & deflection of beam

S. No	Load	Deflection				
		Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
1	10	0.2991	0.4407	0.3028	0.5741	0.2991
2	20	0.7364	0.7961	0.478	0.7932	0.7364
3	30	0.8715	0.968	0.7368	0.9455	0.8715
4	40	1.0727	1.4798	1.1149	1.2948	1.0727
5	50	1.6237	1.7928	1.6558	1.5362	1.6237
6	60	2.4123	2.2831	2.3937	1.7924	2.4123
7	70	2.695	2.6914	2.6584	2.3641	2.695
8	80	3.1035	2.9563	3.0781	2.8571	3.1035

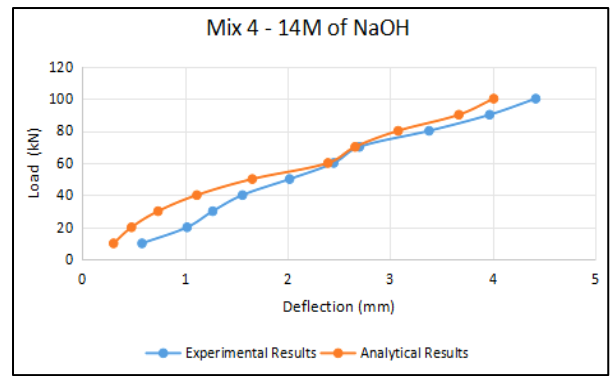
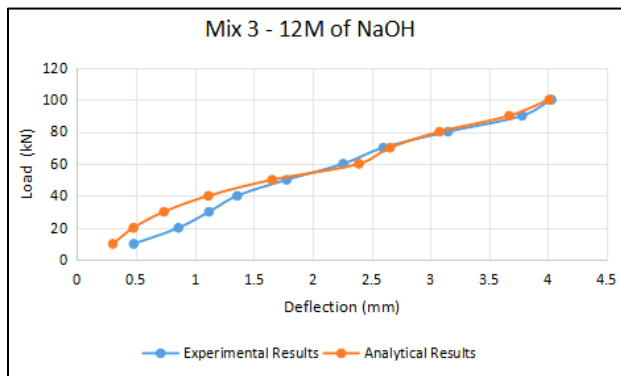
5.3 COMPARISION OF EXPERIMENTAL AND ANALYTICAL RESULTS

- The flexural test is conducted in compliance with the standards outlined in IS 516-1999. Beams with a length of 1500mm, breadth of 230mm, and depth of 230mm are placed at two points of a hydraulic jack.
- The top two points are subjected to load distribution and four-point loading is executed. This results in the formation of cracks at the surface of the beam.
- Both experimental and analytical tests have their advantages and disadvantages, and the choice between them depends on factors such as the available resources, the level of accuracy required, and the specific requirements of the project. It is often useful to combine both types of tests to obtain a more comprehensive understanding of the behavior of the reinforced beam
- The graph below represents the results of the flexural test



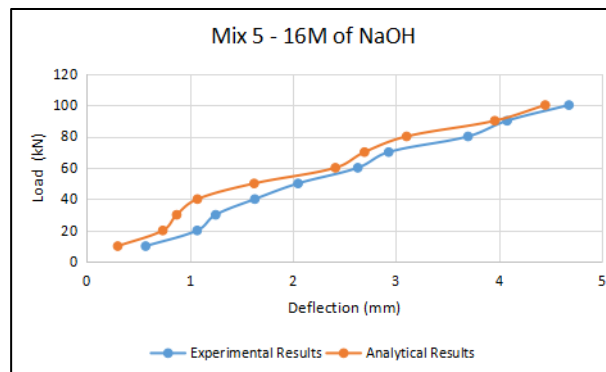
Mix 1 - 8M of NaOH

Mix 2 - 10M of NaOH



Mix 3 - 12M of NaOH

Mix 4 - 14M of NaOH



Mix 5 - 16M of NaOH

Fig 5.3 Graphical representation of comparison of experimental and analytical results

- The above graph shows the experimental and analytical results of the “Geopolymer ferrock reinforced concrete beams” in which the Sodium hydroxide geopolymer solution is varied by changing its Molarity from 8M to 16M.
- The values of deflection indicate the extent of deformation experienced by the concrete samples when subjected to the given loads.
- From the graph, it is evident that as the applied load increases, the deflection of all concrete mixes increases. However, the rate of deflection growth varies for different mixes, implying differences in their structural response.
- Mix 3 - 12M of NaOH shows the lowest deflection for its increasing load implementation in the both experimental and analytical results. Mixes other than Mix 3 such as Mixes 1,2,4,5 exhibit higher deflection values than Mix 3 - Beam, indicating their relative stiffness
- This reveals that the Mix 3 - 12M of NaOH shows relatively good stiffness than others
- All mixes demonstrate deflection values within acceptable limits, which implies that they meet the design requirements for the intended application. However, it's crucial to recognize that the deflection values can significantly influence the structural behavior and performance of concrete structures. Therefore, selecting the most suitable mix requires a comprehensive assessment of several parameters, including durability, cost, flexural strength, and compressive strength.

CHAPTER 6

CONCLUSION

6.1 SUMMARY

- Investigation on the Ferrock as an alternative for the cement concrete was carried out in the present work to improve the strength of the materials when used as Solid block.
- The implementation of geopolymer ferrock concrete with GFRP bars in structural element is done analytically and experimentally in this study.
- In phase 2, investigating this project in all dimensions eg: test on materials, taking experimental test , making ferrock concrete with help of GFRP bars.
- The Materials which are used are Ground granulated blast furnace slag, Flyash, metakaolin, limestone, oxalic acid, and the geopolymer solution is Sodium hydroxide and Sodium silicate.
- Mechanical properties such as compressive strength, split-tensile strength, and flexural strength of the concrete will be tested in this study.
- The experimental results will be compared with the analytical results obtained from ABAQUS software, and the conclusions will be drawn by comparing both results.

6.2 CONCLUSION

This study investigates the use of FERROCK, a geopolymer concrete using GFRP bars made from a mixture of iron oxide-rich industrial waste and a geopolymer binder, as a replacement for traditional cement in concrete production. The study examines the effects of varying the molarity of sodium hydroxide in the geopolymer solution on the hardened properties, micro-structural properties, and flexural behavior of the concrete. Results show that using the optimum molarity of 12M of sodium hydroxide in the geopolymer solution results in good strength and improved flexural behavior compared to other molarities.

The use of by-products such as FLYASH and GGBS in Ferrock production is an eco-friendly and cost-effective approach that also reduces carbon dioxide emissions during production. The denser and more compact mixture of

Ferrock reduces the occurrence of empty spaces and enhances the interlocking of particles, resulting in improved flexural behavior.

In conclusion, using Ferrock as a replacement for cement in M45 grade concrete with geopolymer solution containing 12M of sodium hydroxide and sodium silicate can significantly improve its flexural strength and reduce deflection. Furthermore, the use of Ferrock as a more sustainable option can help reduce carbon dioxide emissions during concrete production.

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