

A STUDY ON BEHAVIOUR OF REINFORCED FERROCK CONCRETE BEAMS.

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

By

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

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MAY2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafied work of **KATHIR VISWANATH L (41380008)** who carried out the project entitled "**A STUDY ON BEHAVIOUR OF REINFORCED FERROCK CONCRETE BEAMS**" under my supervision from December 2022 to May 2023

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DATE: 05-05-2023

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ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our thanks to **Dr. Devyani Gangopadhyay, B.Arch., M.T.P., Ph.D.**, Dean, School of Building and Environment and **Dr. S. Packialakshmi, M.E., Ph.D.**, and **Dr. R. Padmapriya, M.E., Ph.D.**, Head of the Department, Dept. of Civil Engineering for providing us necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to our Project Guide **Dr. R. Padmapriya, M.E., Ph.D.**, for her valuable guidance, suggestions and constant encouragement paved way for the successful completion of our project work.

We wish to express our thanks to all Teaching and Non-teaching staff members of the Department of Civil Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

With the world rapidly developing, there is a significant focus on improving infrastructure, with the construction industry playing a crucial role. Cement is a widely used material in construction, but its production results in the emission of around 6-8% of the total carbon dioxide in the world, contributing significantly to global warming. To address this issue and promote better waste management, the Ferrock product was developed. This review explores Ferrock, a product that aims to achieve carbon negativity and sustainable waste management. The product uses waste iron ore powder, which is typically discarded during mining and leads to air pollution, health hazards, and land consumption. Ferrock stands out among alternative cement supplements due to its unique strength gaining mechanism, which indirectly reduces carbon dioxide emissions. The curing process involves carbonation and air curing for several days to achieve desirable properties, including compression and tensile strengths. Ferrock is a promising eco-friendly binding material that addresses both carbon negativity and waste management challenges..

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Global warming is currently considered one of the major threats to our ecosystem. Carbon dioxide, which accounts for 76% of the greenhouse gases causing global warming, is a primary concern. To reduce the total percentage of carbon dioxide emissions, experts have analyzed and sorted the sources of this gas. Civil engineers are also contributing to the effort to create a greener environment by examining carbon emitters and identifying ways to address them. However, the world's fast-paced growth has led to a focus on infrastructure development, which has resulted in a linear increase in the construction of multi-story buildings, roads, bridges, towers, and more. The most critical material used in this construction is cement, which is a binding material that provides strength to sustain the applied loads. Cement is an artificially manufactured product that contributes approximately 6 to 8% of carbon dioxide emissions to the environment during the manufacturing process.

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."

In a brief essay titled, "Creating a Carbon-Negative Building Material from Recycled Glass, Steel Dust, and Carbon Dioxide," the Environmental Protection Agency provides additional details regarding the advantages of using recycled materials as substitute ingredients for the production of binding materials. All components required for the production of Ferrock, with the exception of iron powder, are common industrial materials. The compressive strength and durability of green concrete are increased by the tensile character of ferrock.

When compared to control mix, the original form of ferrock has five times the compressive strength and flexures much more before failing. The essential prerequisite for replacing cement completely is a 100% CO₂ atmosphere for curing, which our project was unable to provide. In accordance with the parameters of this document, we have replaced cement with ferrock in % weights. As a result, according to our findings, substitutes alone can attain the strength of the control mix. It has several uses similar to those of regular concrete in structures like buildings and bridges as well as other typical applications for concrete. Additionally, our specimen will be very helpful in polluted sites of industrial zones as it becomes stronger in CO₂ environments. Additionally, ferrock concrete can be used for buildings near the ocean because it strengthens ferrock and speeds up the rusting process.

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 building material that releases no carbon
- For Studying the Physical Properties of Ferrock.
- For Studying the Mechanical Properties Such as Flexural Strength, Split tensile strength for ferrock concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

A literature review is an academic document that presents the existing understanding of a specific topic, including significant discoveries, theoretical advancements, and research methods. Typically, the literature review comes before the methodology and results sections in a research paper. Below, you can find the literature that has been gathered from various sources to ensure the project's successful completion.

2.2 REVIEW OF JOURNAL PAPERS

D.Huntzinger and T.Eatmon (2009), made an study on production of traditional Portland cement, blended cement (natural pozzolans), cement where 100% of waste cement kiln dust is recycled into the kiln process, and Portland cement produced when cement kiln dust (CKD) is used to sequester a portion of the process related CO₂ emissions are the four cement manufacturing processes being experimentally studied to assess the environmental impact. This book gives a cradle-to-gate life-cycle assessment of several cement products to reduce uncertainty.

Benjamin C.McLellan et.al (2011), discussed an examination of study analyzed the lifecycle expenses and carbon footprint of Ordinary Portland Cement (OPC) and geopolymers. The findings revealed that the economic and environmental impact of geopolymers vary significantly and can either have positive or negative consequences depending on factors such as energy source, transportation mode, and source location. The research also evaluated several geopolymer concrete blends utilizing common Australian feedstocks and showed a possible reduction in greenhouse gas emissions between 44-64% while financial costs could be 7% lower to 39% higher than OPC.

Satpute Manesh B et.al (2012), discussed the study of influence of curing time and temperature on the compressive strength of geopolymer concrete made with fly ash. In order to create geopolymer concrete, processed low calcium fly ash that has been chemically activated by alkaline solutions like sodium silicate and sodium hydroxide is used to completely replace cement in the mix. With 16 Mole

of concentrated sodium hydroxide solution, cubes measuring 150mm X 150mm X 150mm were created at a solution to fly ash ratio of 0.35. All of the samples were baked at temperatures of 600°C, 900°C, and 1200°C for 6, 12, 16, 20, and 24 hours, respectively. According to test results, oven curing time and temperature improve the compressive strength.

Anita Bhatia et.al (2016), discussed that it is important to consider structural designs that incorporate low-energy, resource-efficient maintenance methods. Although green concrete appears to offer a lot of advantages, one must still take into account any potential roadblocks. They are the rising costs of recycling and reusing, as well as the need for additional energies and resources for the same, as well as the worry that green concrete, which is made from recycled materials, will fail.

Praveer Singh et.al (2016), concluded that the inclusion of silica fume in the right amounts enhances concrete conditions and increases resistance to acidic water assault. High fineness silica fume produces high normal consistency. Comparing it to other materials like fly ash and GGBS, silica fume provides a stronger compressive strength.

G. M. Sadiqul Islam et.al (2016), concluded that Because the chemical make-up of clear and coloured glass powders is so similar, they can both be classified as pozzolanic materials under ASTM standards. Given its cleaner nature, glass powder was found to marginally boost the flow of mortar when it replaced it. The ideal glass percentage is 20% when taking into account the 90-day compressive strength of both mortar and concrete. The compressive strength was discovered to be 2% higher at this age than the control concrete specimen. In general, adding glass can cut the cost of producing cement by up to 14% while maintaining performance levels comparable to those of the material it replaces. Additionally, the production of every six tonnes of glass powder concrete reduces the amount of CO₂ emitted during the manufacture of cement, saving the environment significantly by lowering the emission of greenhouse gases and particulates. The increased surface area of milled waste glass often modifies the kinetics of chemical reaction towards advantageous pozzolanic reaction using the available alkalis prior to development of a potential ASR gel.

J.Rosales et.al (2017), conducted a study that to assess the strength activity index and environmental impact of waste stainless steel slag, researchers investigate the cementation and pozzolanic reaction features. In order to find the best replacement ratio for the cement given its mechanical qualities, several replacement percentages of untreated stainless steel slag waste and treated slag waste from crushing, burning, and both processes were used in place of cement.

Vardhan Nagarkar et.al (2017), observed conventional concrete is responsible for to some extent, the amount of carbon dioxide emissions. Therefore, different types of concrete are created using agricultural and industrial waste products like fly ash, silica fume, and blast furnace slag that use little energy and have minimal negative environmental effects in order to reduce emissions. A modern technology called green concrete was created to lessen the impact cement production has on the environment. Because cement emits a large amount of carbon dioxide, which has a detrimental effect on the environment, replacing cement with other environmentally harmful materials not only solves the issue of how to dispose of these materials but also reduces the amount of carbon dioxide released into the atmosphere as a result of cement use.

M.Largeau et.al (2018), conducted a experimental research was done on the impact of iron powder (Fe_2O_3) on the compressive strength, tensile strength, workability, and porosity of the binary mixed concrete. By measuring iron powder, Portland cement was partially substituted for this purpose by 1.5%, 2.5%, 3.5%, and 5%. The water-binder ratio was thought to be constant.

V Patel and H.Solanki (2018), observed that one of the most often utilised construction materials in civil engineering projects is concrete. From this perspective, numerous variations of the idea of "green concrete" have been created over the years. The majority of these ideas centre on partially substituting alternative materials for cement, the component of concrete that produces the most CO₂ emissions. A PhD candidate named David Stone (yep, that's his real name) came up with Ferrock as a practical cement substitute. A substance that

might be combined and poured to create something with the strength and adaptability of concrete. In truth, Portland cement, the most common variety used today, is significantly weaker than ferrock..

K.DineshKumar and K.Janardhan reddy (2018), made an experiment research It has been demonstrated that Ferrock, an iron-based compound comprised of 95% recycled resources, is more affordable, stronger, more adaptable in its building applications than OPC. Additionally, this special substance accelerates the curing process by using compressed carbon dioxide and does not need additional heat to catalyse the chemical reaction, making it a carbon-negative substitute for OPC. The majority of the literature discussing Ferrock's procedures and effects is published from a preliminary standpoint because it is still a proprietary blend.

Tayeh,Bassam A (2018) conducted a research that is primarily concerned with determining the effects of employing waste materials—such as crushed glass, crushed marble, and burned wood in powder form—as partial substitutes for cement on the compressive strength of concrete. Investigations were done on both physical and mechanical qualities, including as compressive strength and workability.

D. Vijayan et.al (2019), made an an experimental investigation was conducted on iron dust, a byproduct of the iron industry that is usually disposed of in landfills since it cannot be recycled traditionally and the cost of extracting iron from the powder is too high. As Ferrock dries, the iron dust reacts with rust, carbon dioxide, and other substances to form an iron carbonate matrix. For suitable binding and performance requirements, we use materials like Metakoalin, limestone, fly-ash, and iron dust in this instance [3]. According to the literature that is currently accessible, the ideal ingredient ratio is iron dust (60%), fly ash (20%), metakoalin (12%), and limestone (8%). Fully-cured samples had between 8 and 11% of collected CO₂ by weight, according to analysis (atomic absorption spectroscopy).

E. .

Mouli Prashanth et.al (2019), observed by adjusting the proportions of oxalic acid (the catalyst) in the Ferrock mortar mix. According to the findings, ferrock also

absorbs a sizable quantity of CO₂ from the environment and lowers the amount of CO₂ released by industries. The optimum molarity of oxalic acid as a catalyst was 10 moles.

M.Palaniswamy (2020), made an study conducted in an experimental setting to replace cement with ferrock. Ferrock is a steel waste product with tensile characteristics. The concrete utilised in this project is M20 Grade, and the mix design was created with varied proportions of cement, fine aggregate, coarse aggregate, ferrock, and water. The cubes are evaluated after 7 days, 28 days, and 56 days of curing. In this study, ferrock was used in place of cement with a percentage variation of 5%, 10%, 15%, and 20%.

M.Miah and M.Ali (2020),made an experimental study examines the mechanical, durability, and residual compressive strength of mortar that includes recycled iron powder (RIP) as a fine aggregate after being exposed to 20, 120, 250, 400, and 600 °C. Due to its superior mechanical and durability performances, this study shows that RIP can be used as a fine aggregate in mortar up to 30% of the time.

Niveditha M et.al (2021), conducted a reducing carbon emissions and improving garbage management. It demonstrates the best approach to use iron ore waste powder that is typically obtained during the mining process and simply thrown outside of the mines, where it causes air pollution, health risks, and takes up more space. The product differs from many other cement supplements in that it indirectly lowers the carbon dioxide released by its special strength-gaining mechanism, which is the opposite of that of cement. For greater strength in terms of compression and tensile strengths as well as achieving desired qualities, ferrock undergoes a curing process involving carbonation and air curing in a variety of days. As a result, Ferrock offers greater environmental promise as a binding material because of its carbon negativity and efficient use of waste.

Shivani A.B et.al (2022), conducted a study which comparesferrock (iron oxide powder 60%, flyash 20%, metakaolin 12%, and limestone 8%) and regular

Portland cement have on the environment, with a focus on how much carbon pollution, water use, and energy they contribute. We are attempting to determine the ideal replacement ratio that will produce the required outcomes in both strength (compressive, split tensile, and flexural strength) by replacing cement with ferrock in concrete in varied proportions as low as 4%, 8%, and as high as 12%. 8% of the total test results have good strength scores. Additionally, it can be seen that the specific gravity of the ferrock mix is lower than that of the cement. The maximum compressive strength of the Ferrock cube was 2.68 N/mm². This is a result of the various iron powder particle sizes and environmental factors. According to the test results, ferrock cement concrete has a mechanical strength that is higher than regular concrete. 8% replacement of cement in ferrock cement concrete results in increased strength. Both water and carbon dioxide were used to cure the ferrock cement concrete.

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 determine the physical properties of materials - GGBS, Flyash, Limestone powder, Metakaolin, Oxalic acid powder, Fine Aggregate, Coarse Aggregate.
- To determine the mechanical properties of concrete- Compressive strength, flexural strength, split tensile strength,
- To determine the flexural behavior of Reinforced Ferrock concrete beams experimentally.
- To determine the flexural behavior of Reinforced Ferrock concrete beams analytically.
- To Compare the Analytical Results and Experimental Results.

3.3 SCOPE

- Future possibilities for ferrock manufacturing are exciting, especially as the energy sector searches for alternate fuel sources.
- Although Ferrock has been portrayed as being very alluring, its ambiguous properties have the potential to have a much greater impact on the abode's sustainability and the prosperity of human advancement.
- Focusing on reducing carbon emissions and using waste products to create a better environment.
- creation of unique and customized cementitious materials with increased potential

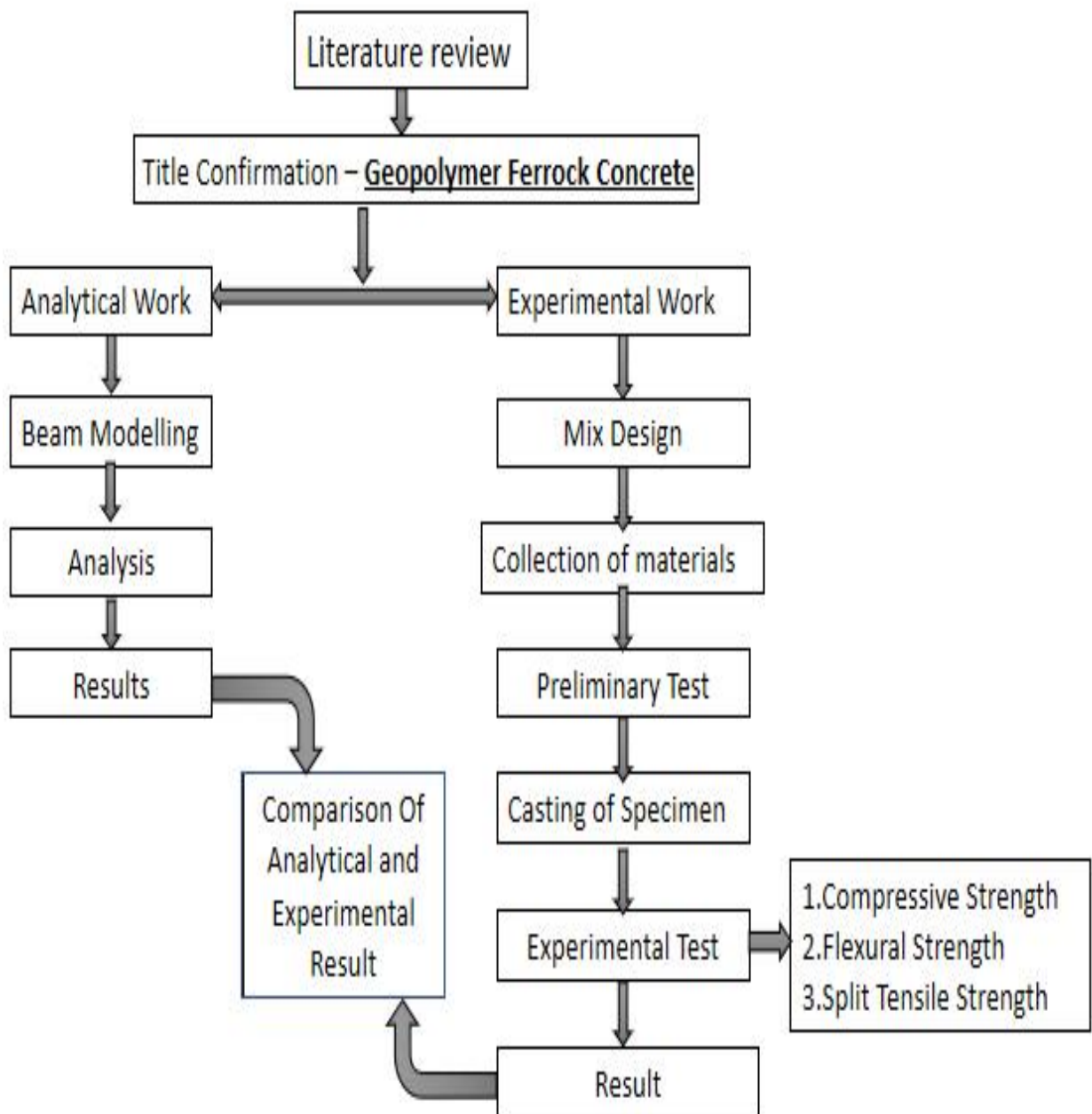
CHAPTER 4

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.

MATERIALS	PERCENTAGE (BY WEIGHT)	COMMENTS
GGBS	60%	an industrial byproduct obtained from the steel manufacturing industry.
Fly Ash	20%	finely divided residue that results from the combustion of pulverized coal
Limestone	10%	raw material in manufacture of cement
Metakaolin	8%	It is specially produced from high quality Kaolin
Oxalic Acid	2%	Oxalic acid has been used in previous research as catalyst

Table 4.1 Constituents of ferrock

4.3.2 Ground granulated Blast Furnace (GGBS)

Cement particles are 10 times coarser than iron oxide particles produced for the construction industry. The iron oxide particles really surround and coat the cement particles when they are introduced to a concrete mixture. Due to this, integral colour is metered or dosed based on cement content rather than on sand, stone, or water content. When iron oxide powder is analysed, it is discovered that the particles have an elongated, angular morphology. However, the large surface area makes it more reactive by increasing its surface area.



Fig 4.1 Ground granulated blast furnace slag

4.3.3 Fly Ash

Fly ash is a by-product or a waste product, hence use of fly ash concrete reduces CO₂ and is thus environment friendly. It has good cold weather resistance and non-shrink material. Fly ash concrete has great workability as well and allows for a

lower water-cement ratio similar slumps compared to the ordinary concrete. It reduces heat of hydration, cracks, permeability, bleeding. It is cost-effective substitute for Portland cement.



Fig 4.2 Fly ash

4.3.4 Limestone Powder

The addition of limestone powder makes concrete easier to grind, uses less water, is stronger, and has less bleeding. Due to its reactive nature, limestone serves as a nucleation site for clinker hydration products and lowers hydration heat.

..



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



Fig 4.4 Metakaolin

4.3.6 Oxalic acid

Oxalic acid is a weak acid and is reported to act as an accelerator for cement hydration reaction. This may also be helpful in the formation of a protective electrical double-layer film around the cement particle during gel state.



Fig 4.5 Oxalic acid

4.3.7 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. The required amount of water and cement may be cut down using aggregates that have larger diameters



Fig 4.6 Fine aggregate

4.3.8 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 4.7 Coarse aggregate

4.3.9 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.



Fig 4.8 Sodium Hydroxide

4.3.10 Sodium Silicate



Fig 4.9 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.

4.3.11 Water

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

4.4 MATERIAL PROPERTIES

4.4.1 Ferrock

4.4.1.1 Ground granulated blast furnace slag

Ground Granulated Blast Furnace Slag (GGBFS) is a type of cementitious material that is primarily utilized in the production of concrete. It is derived from the by-products of the blast-furnaces that are utilized in the production of iron. These furnaces operate at high temperatures of approximately $1,500^\circ\text{C}$ and require a precisely controlled blend of limestone, coke, and iron ore..

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

Limestone powder is a finely-ground substance that can vary in size from a few microns to several millimeters. 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 allows manufacturers to tailor the qualities of the limestone powder to meet the specific requirements of their customers. The usual color of limestone powder is white or grayish-white, but its color can also be influenced by the impurities that are present in the original limestone rock, resulting in a range of other colors.

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 produced specifically with top-quality Kaolin.

Metakaolin, which is made of silica and alumina in an active state, increases the density of concrete and decreases its porosity in the same way as other mineral admixtures react with calcium hydroxide at room temperature to create calcium silicate hydrate (C-S-H)-gel. As a result, the permeability of the concrete is decreased and it becomes more resilient.

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

Table 4.5 Physical Properties of Metakaolin powder

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

Oxalic acid serves as a catalyst with water, CO₂, and CO₂ to produce iron carbonates, the hardened result. Oxalic acid benefits the environment by absorbing CO₂ from the atmosphere during the hardening process.

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 as 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:** This type of aggregate is created when rocks naturally disintegrate.
- The result of crushing gravel or hard stone is known as crushed gravel or stone.

- When the two aggregates mentioned above are blended, partially crushed gravel or stone is created.

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 is 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 ($\text{Na}_2\text{O}_3\text{SiO}_2$)

One of the main ingredients in the geopolymer solution that is used to create geopolymer concrete is sodium silicate. The alkaline activators are what are utilised to geopolymerize 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 various techniques, 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 for you to have an economical mix that adheres to IS:10262-1982 standards.

4.5.3 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

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

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

$$\begin{aligned}\text{Mass of fly ash} &= [552/(1+0.35)] \\ &= 408 \text{ kg/m}^2.\end{aligned}$$

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

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

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

$$\begin{aligned}\text{Mass of sodium silicate solution} &= (144-48) \\ &= 96 \text{ kg/m}^2.\end{aligned}$$

Trial mix proportion

$$\text{Combined Aggregates} \quad 1848 \text{ kg/m}^3$$

$$\text{Low - calcium fly ash} \quad 408 \text{ kg/m}^3$$

$$\text{Sodium Hydroxide} \quad 48 \text{ kg/m}^3$$

$$\text{Sodium Silicate Solution} \quad 96 \text{ kg/m}^3$$

For A53 with SiO_2 , to Na_2O ratio by mass 2

$$\text{i.e } \text{Na}_2\text{O} = 14.7\%$$

$$\text{SiO}_2 = 29.4\%$$

$$\text{Water} = 55.9\%$$

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

26% of Na-OH solids & 74% water

Sodium silicate solution:

$$\text{Mass of solids} = (0.26 \times 48)$$

$$= 12.48 \text{ kg}$$

$$\begin{aligned} \text{Mass of water} &= (14 - 12.48) \\ &= 35.52 \text{ kg} \end{aligned}$$

$$\begin{aligned} \text{Total mass of water} &= 71.04 + 35.52 \\ &= 106.56 \text{ kg} \end{aligned}$$

$$\begin{aligned} \text{Total mass of geopolymer solids} &= [\text{Mass of fly ash} + \text{Mass of solids in NaOH} + \\ &\quad \text{Mass of water in Na}_2\text{SiO}_3] \\ &= (408 + 24.96 + 12.48) = 445.44 \text{ kg} \end{aligned}$$

$$\begin{aligned} \text{Hence water to geopolymer solids} &= [\text{Total mass of water} / \text{Total mass of solids}] \\ \text{ratio by mass} &= [106.56 / 445.44] \\ &= 0.2 \end{aligned}$$

4.5.4 Mix Proportion

Table 4.11 Mix Proportion

Ferrock (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

By using testing processes, the quality of concrete work can be successfully managed. Any concrete quality control programme must include such procedures, which should involve systematic testing of raw materials as well as freshly laid and hardened concrete. 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. One can efficiently evaluate both the strength and durability criteria by creating several types of concrete test specimens.

It is essential to take extra precautions when assembling test specimens and to avoid skipping any necessary steps. Each stage in the process of creating concrete test specimens is closely related to the strength specifications, requiring great workmanship and strict supervision.

4.6.2 Casting

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

4.6.2.1 Casting of Cubes

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

- ***Cube Mould***

The required cube moulds are 150 x 150 x 150 mm for aggregate with a maximum nominal size of 38 mm. Cube moulds must have a base plate and be constructed in accordance with IS:10086-1982.

- ***Tamping Rod***

According to IS:10086-1982, the tamping rod must be mild steel, 16 0.5 mm in diameter, 600 2 mm long, with a rounded working end.

- ***Casting Process***

The cube mould plates must be disassembled, cleaned thoroughly, then assembled with all bolts fully tightened. Then, all of the mold's faces should be covered in a thin layer of oil. The cube's side faces must be parallel, which is crucial. The cubes must be cast as quickly as feasible after concrete samples are taken and mixed. The cube moulds must be filled with layers of the concrete sample that are around 5 cm deep.

To achieve a symmetrical distribution of the concrete inside the mould, each scoopful of concrete must be placed while being moved around the top edge of the mould as the concrete slides from it.

- ***Compaction By Hand***

A minimum of 35 strokes with a tamping bar are required to compact each layer of the concrete that has been added to the mould. The bottom layer must be rodded through to its depth and the strokes must reach the underlying layer. The sides of the mould must be tapped to fill any voids left by the tamping bar.

4.6.2.2 Casting of Cylinders

Concrete's material qualities can only be accurately assessed if test specimens are created and cured in accordance with regulations. Concrete cylinders are frequently created to test both the concrete's tensile and compressive strengths.

- *Cylinder Mould*

Concrete test specimens are cast in the field using metal 100 x 200 mm or 150 x 300 mm cylinder moulds. They must be put on a flat, smooth, sturdy surface before filling.

- *Tamping Rod*

If 100 mm diameter moulds are used, the mould should be filled in three equal layers and rodded 20 times uniformly through each layer with a steel rod with a hemispherically pointed tip measuring 10 mm in diameter and 450–600 mm in length.

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.

- *Casting Process*

The compaction must be applied evenly across the mould portion. The depth of the bottom layer must be rodded. The rod must pierce the underlying layer by roughly 25 mm for each top layer. Before adding the next layer of material, the sides of the mould should be tapped to fill any spaces that the rod may have left.

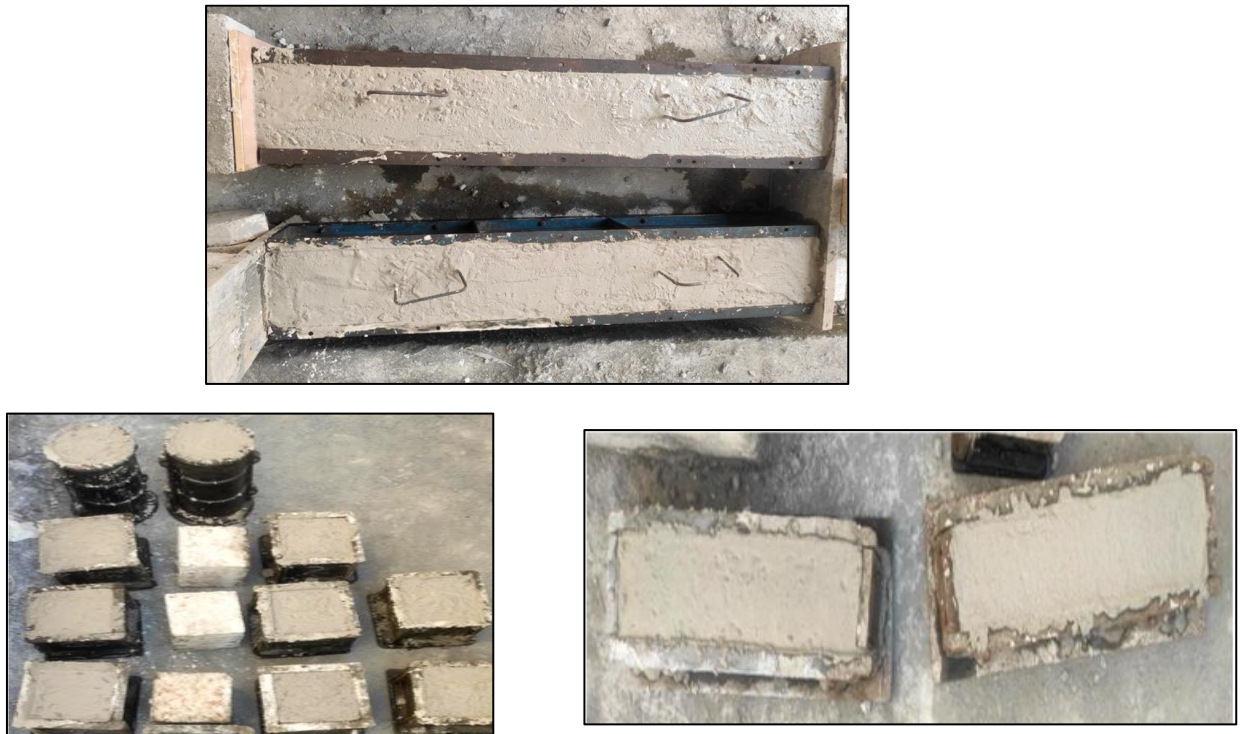


Fig 4.10 Casting of beams , Cubes, Cylinders and Prism

4.6.3 Demoulding

Demould testing concrete specimens between 16 and 24 hours after manufacturing is advised for best results. It is recommended to wait another 24 hours if the concrete has not grown strong enough to withstand demoulding without being harmed. During the demoulding process, it is essential to dismantle the mould entirely to prevent any damage to the specimens. The overall strength of the specimens may be weakened by any cracks developed during this process. Each specimen ought to be distinctly marked with a waterproof crayon or ink once it has been demolded for simple identification. After demoulding, it's critical to thoroughly clean the mould and check that there are no traces of grease or debris in the spaces between the flanges. Otherwise, the mould's two halves might not fit together properly, leading to specimens with irregular shapes and leakage through the joint.

4.6.4 Air Curing

Air curing of a concrete is a process by which concrete is allowed to cure or harden by exposure to air. The length of time required for air curing depends on

different factors, including the type of concrete used, the thickness of concrete and the ambient temperature and humidity. In general, air curing can take a long duration for large structures.

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

The methods for evaluating the workability of plastic concrete in a laboratory setting utilising the slump cone equipment is described in this procedure. It is essential to make sure that the internal surface of the mould has been well cleaned and is dry before starting the test. The mould should then be positioned on a flat, horizontal, smooth, non-absorbent metal surface.

As illustrated in figure 4.13, the concrete sample should be placed to the mould in four equal layers and tamped with 25 strokes with a 16mm diameter, 600mm long tamping rod with a rounded end. For the second and subsequent layers, the strokes must penetrate the underlying layer and be evenly distributed across the mould's cross section. The bottom layer needs to be well tamped.

Any extra concrete should be removed and levelled using a trowel or the tamping rod after the top layer has been rodded to make sure the mould is entirely filled. It is necessary to remove any mortar that may have leaked out between the mould and the base plate.

The mould should then be gently elevated vertically and removed from the concrete as soon as possible. By calculating the height difference between the mould and the test specimen's highest point, the slump should be measured as soon as possible. The specimen's sinking during the test should be measured and documented in millimetres.

The height of the slump cone	= 300mm
The height of concrete after subsidence	= 110mm
Hence, the slump measured	= 180mm



Fig 4.11 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 process is important for developing a test method to evaluate concrete specimens' compressive strength. When samples that have been kept in water are removed from the water while still wet, they should be examined right after.

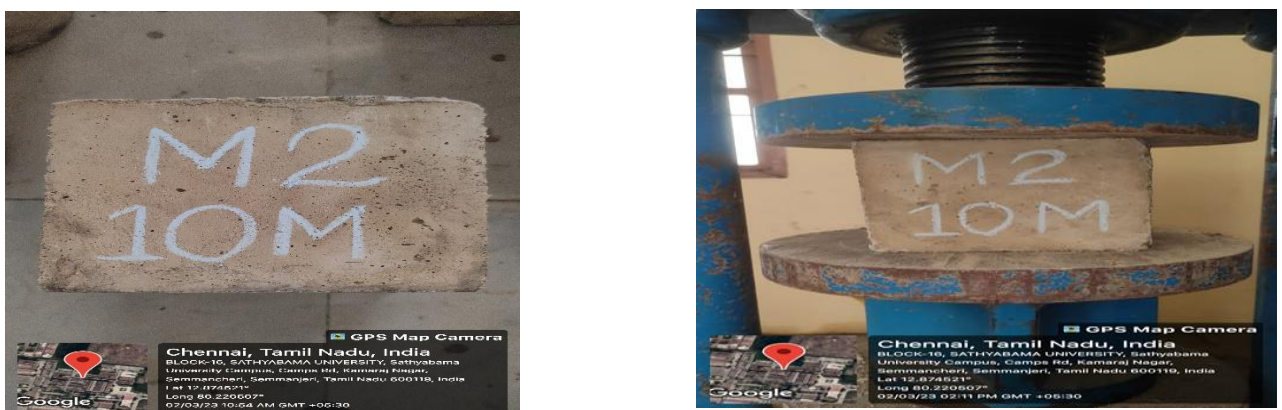


Fig 4.12 Compressive strength test

The specimens should be wrapped in damp hessian to keep them moist. Before cleaning the surfaces of the specimen that will come into

contact with the compression platens, the bearing surfaces of the testing apparatus should be wiped clear and free of any debris.. Between the test specimen's faces and the steel platen of the testing device, there shouldn't be any packing. As indicated in fig. 4.20, the loading rate should be adjusted to 5.2 KN/sec for a 15 cm cube in order to load the specimen uniformly. The load should be introduced gently, without shock, and raised steadily until the specimen loses its ability to withstand the rising strain and no more stress can be sustained. The highest force applied to the specimen, the look of the concrete, and any unexpected characteristics in the kind of failure should all be noted.

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

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. Cleaning should be done to the packing strips and the testing machine's bearing surfaces, as indicated in Figure 4.21. In order to set up the specimen, place one of the plywood strips vertically in the middle of the lower platen, then align the specimen so that the designated lines on its ends are horizontal and centred over the plywood strip.



Fig 4.13 Split tensile strength test

The second plywood strip has to be centred on the indicated lines on the ends of the cylinder and laid lengthwise. When the specimen's resistance to the increasing load breaks down and no more load can be sustained, the load should be applied gradually at a rate that produces a splitting tensile stress of roughly 14 to 21 kg/cm²/min.

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

4.8.3 Flexural Strength Test

This method is intended for establishing a testing procedure for measuring the flexural strength of concrete specimens.



Fig 4.14 Flexural strength test

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

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:

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

4.8.4 Modulus of Elasticity

The modulus of elasticity of concrete is defined by ACI 318-14 as the ratio of normal stress to corresponding strain for compressive or tensile stresses below the proportional limit of concrete. Although various codes offer formulas to determine the elastic modulus of concrete, there is no guarantee that these values are accurate. There are many tests that may be performed to get an accurate value. One method that can accurately ascertain the static modulus of elasticity of concrete is ASTM C469 (Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression). The moulded cylindrical specimen for this test has to be examined within an hour of being taken out of the

curing or storage chamber. The parameters for storage and ambient conditions prior to the test should be the same as for the moulded cylindrical specimens. Alternatively, the modulus of elasticity can also be measured using a drilled core specimen. Maintain a constant ambient temperature throughout the test, and before performing the modulus of elasticity test, define the compressive strength using two specimens. The specimen should be equipped with strain gauges and set on the testing machine's lower platen or bearing block. Load the specimen carefully into the gauge's seat, being sure to adjust any irregular reactions. Once the longitudinal strain reaches 50 millionths and the applied load is 40% of the ultimate load, continue applying the load continuously while recording it.

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

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

In many different types of structures, RCC beams are frequently used as structural elements. RCC is a homogenous material with a variety of attributes. RCC beams are divided into under-, balanced-, and over-reinforced portions based on analysis. Due to external loads, the concrete and steel in RCC beams experience the stress and related strains concurrently. Under reinforced sections are those in which the steel fails before the tension in the concrete reaches the maximum stress allowed in an RCC beam. Such beams are referred to be balanced sections if both the concrete and the steel meet the acceptable stress levels simultaneously. On the other hand, the beams are categorised as over reinforced portions if the concrete begins to collapse before the stress in steel exceeds the maximum permitted stress. Safety, serviceability, and affordability are the three main design considerations for any kind of construction. Due to these crucial qualities, RCC elements are widely used in all structural applications. The following requirements

must be satisfied for RCC components to be used structurally:

- 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.

It is required to evaluate the ultimate loads and accompanying deflections under certain limits in order to anticipate the safe and economically advantageous RCC conditions. To acquire desired findings, an experimental analysis must be conducted. When an external load is applied to an RCC beam, it typically bends with some deflection..

Table 4.12 Cross section 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.

The beams were exposed to three-point loading after 28 days of cure. At the bottom of the beam, dial gauges were positioned, and a linear hydraulic load

was applied. At each interval of a 5KN load, the beam's deflection was monitored, and the first fracture where the load and corresponding deflection were noticed. All of the beam sections underwent this procedure, recording the maximum load and related deflection for each.

The beam was supported by two bearers under a concentrated load in the centre in order to study the connection between load and deflection. The bearers were adjusted to maintain a 1500 mm span, and each groove on the apparatus's beam was spaced 100 mm apart. The bearers held a test specimen with dimensions of 100 x 200 mm, and the load device was installed in the test specimen's centre. The load device's upper plane was aligned with the top of the gauge thanks to how the testing apparatus was configured.



Fig 4.15 Reinforcement for beams

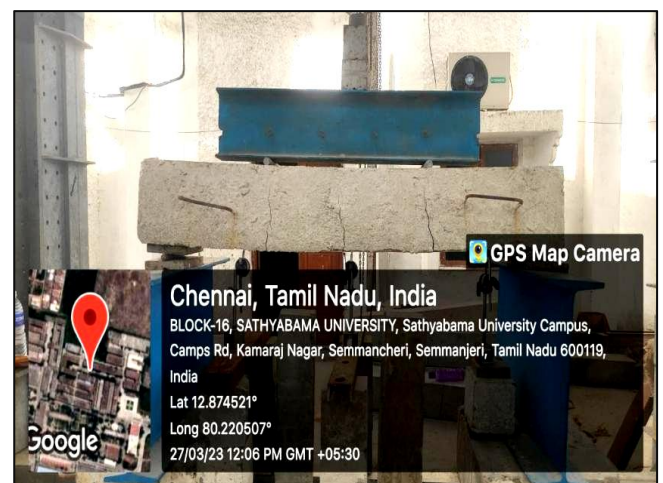


Fig 4.16 Testing of beams

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 seems to be 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 cubes

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.

Table 5.3 Flexural strength of prism

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

- From the experimental results obtained above after the 14days and 28 days curing the higher strength is obtained in the MIX-3 12M. T
- The Strength tends to be increasing gradually from 8M and attains higher in 12M and after that it reduces gradually when coming to 16M.

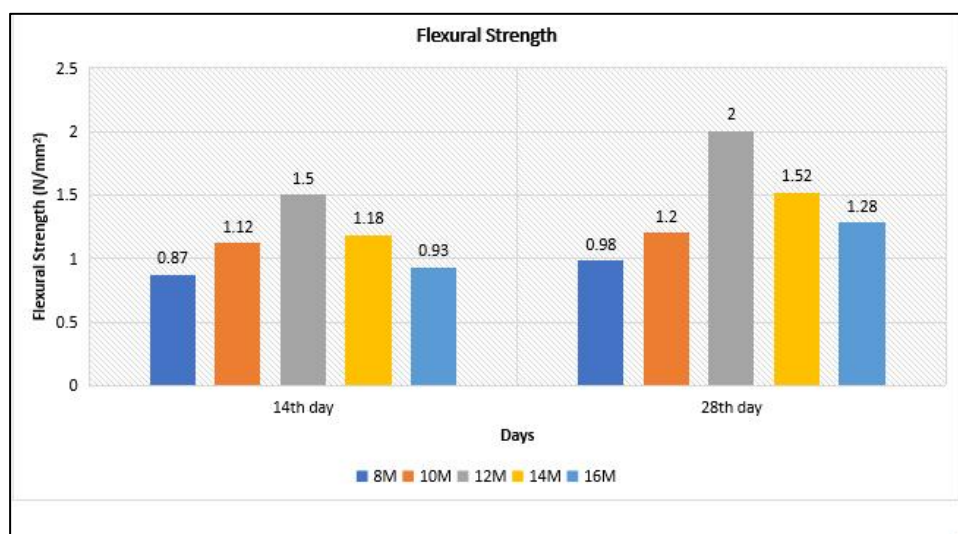
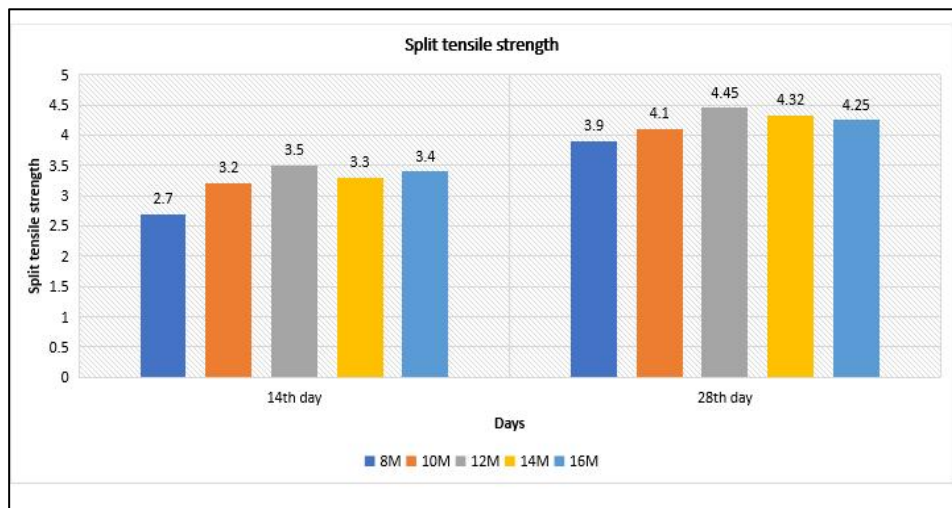
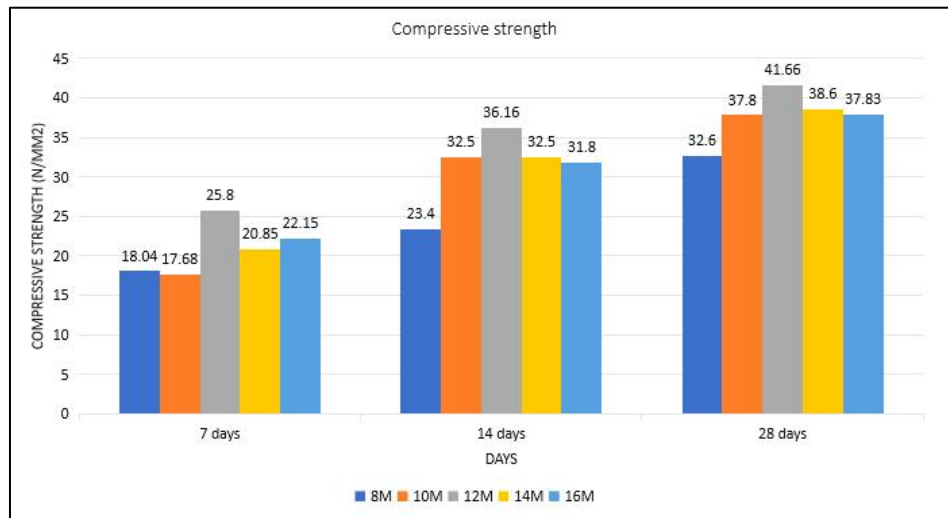


Fig 5.1 Graphical Representation of Results of Experimental Test

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
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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's extensively utilised 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 Systems. It's extensively utilised in the simulation and analysis of various physical phenomena, including structural mechanics, heat transfer, fluid dynamics, and electromagnetic.

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

The definition of the characteristics of the material and section being utilised is a vital stage in the finite element modelling procedure. For instance, establishing the parameters of the section entails providing the section's thickness and other pertinent material properties required for the analysis in the case of a composite beam built of concrete and basalt fibre bars with a yield stress of 415 MPa.

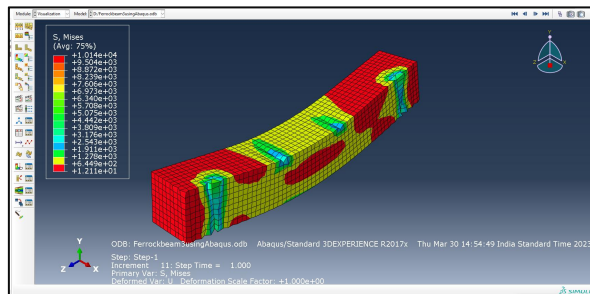
Table 5.14 Properties of materials

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

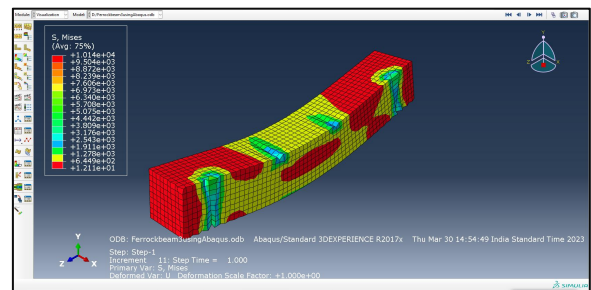
5.2.4 Analytical results

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

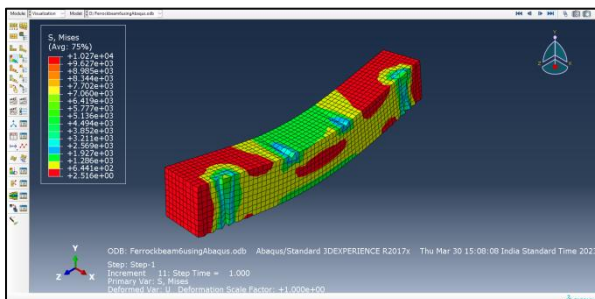
The results indicate that the optimum variation of the Sodium hydroxide is found to be MIX 3 - 12M which outperformed among the other variations of Molarity of sodium hydroxide. The reinforced concrete beams is to have higher strength and lower deflection in the MIX 3 - 12M whereas in the other beams it seems to have lower strength and more deflection. The deflection of the beam occurred in a particular direction under four-point loading, with Abaqus analysis showing downward deflection and values indicating the load at which high deflection occurs.



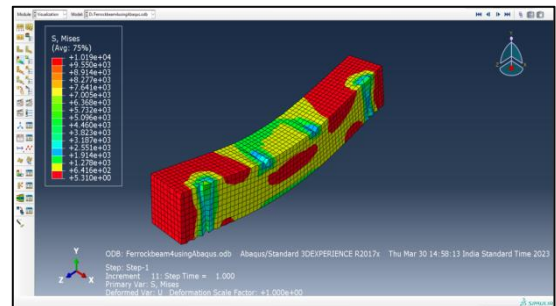
Mix 1 - 8M



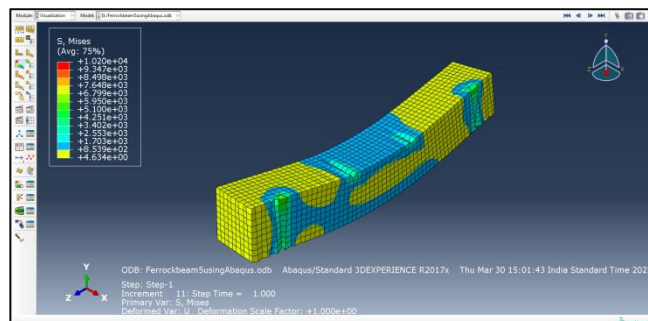
Mix 2 - 10M



Mix 3 - 12M



Mix 4 - 14M



Mix 5 - 16M

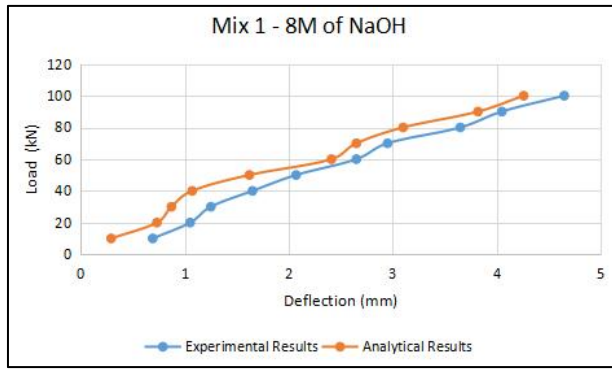
Fig 5.4 Analytical models of Ferrock reinforced concrete beams

Table 5.15 Analytical results of load & deflection of beam

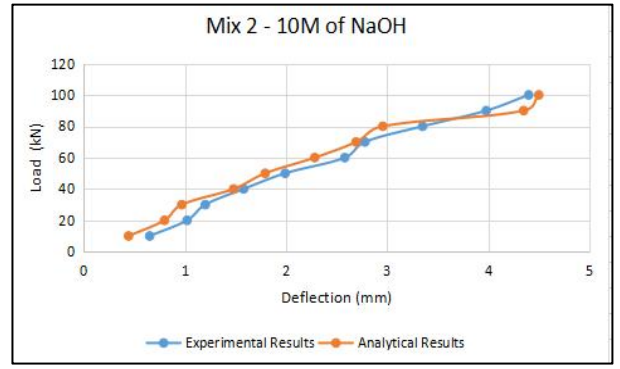
S. No	Load	Deflection				
		Mlx 1	Mix 2	Mix 3	Mix 4	Mix 5
1	10	0.2991	0.4407	0.3028	0.5741	0.2991
2	20	0.7364	0.7961	0.478	0.7932	0.7364
3	30	0.8715	0.968	0.7368	0.9455	0.8715
4	40	1.0727	1.4798	1.1149	1.2948	1.0727
5	50	1.6237	1.7928	1.6558	1.5362	1.6237
6	60	2.4123	2.2831	2.3937	1.7924	2.4123
7	70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

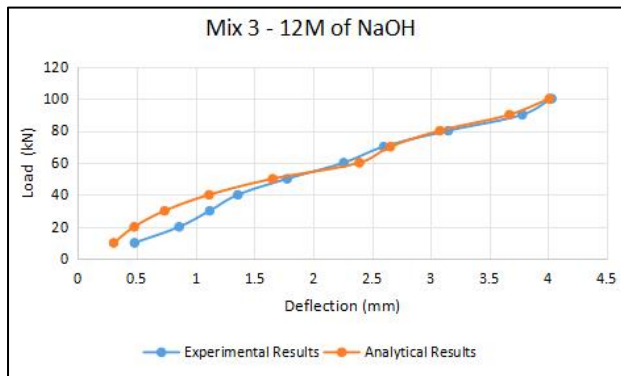
- The flexural test is conducted in compliance with the standards outlined in IS 516-1999. Beams with a length of 1500mm, breadth of 230mm, and depth of 230mm are placed at two points of a hydraulic jack.
- Four-point loading is carried out, and the top two points are subjected to weight distribution. As a result, cracks start to appear on the beam's surface.
- 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 flexural test results are shown in the graph below.



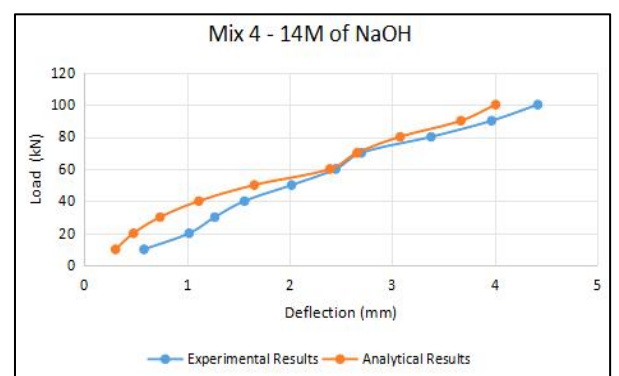
Mix 1 - 8M of NaOH



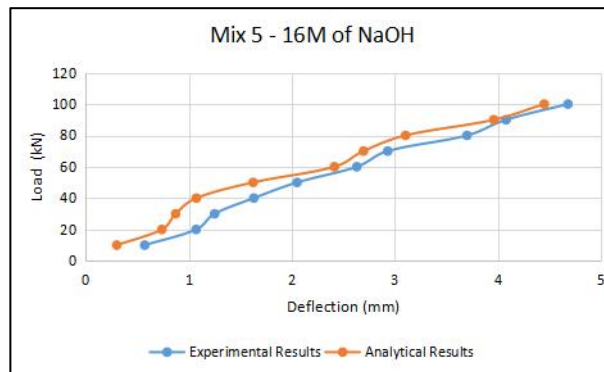
Mix 2 - 10M of NaOH



Mix 3 - 12M of NaOH



Mix 4 - 14M of NaOH



Mix 5 - 16M of NaOH

Fig 5.5 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

- This study reviewed various journals and literatures on the variation of Sodium hydroxide in geopolymer solution of “Geopolymer ferrock concrete”.
- Based on the literature survey, the project objectives, scope, and methodology were formulated.
- 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 examines the concrete that's fully replaced with FERROCK by varying the Molarity of NaOH in geopolymer solution, focusing on its hardened properties, micro-structural properties, and flexural behavior.

- When compared to other solutions, the variation of sodium hydroxide's molarity at the optimal concentration in the geopolymer solution provides good strength.
- In response to environmental concerns in the cement industry, by-products like FLYASH and GGBS are used as raw materials in the making of concrete. With this method, concrete is not only more environmentally friendly but also costs less to produce.
- The geopolymer binder, which is commonly manufactured from materials like fly ash, slag, or clay, is combined with industrial waste that is high in iron oxide as the binding agent in Ferrock geopolymer concrete. High quantities of iron are present in the iron oxide-rich waste materials used to

make Ferrock, and when combined with the geopolymer binder, they produce a strong and long-lasting concrete.

- Flexural Behaviour of concrete is its ability to bend or flex without breaking. Usage of ferrock in place cement in concrete gives a good results when test for its flexural behaviour. The reason for this is that the mixture is denser and more compact, which reduces the occurrence of empty spaces and enhances the interlocking of particles.
- The most efficient combination for decreasing concrete bending or sagging is obtained by establishing the optimal value of sodium hydroxide's molarity in a geopolymer solution, which is found to be 12M.
- Cement may be replaced with Ferrock to cut down on the amount of carbon dioxide that is emitted into the atmosphere during cement manufacture. The concrete is now more ecologically friendly as a result.

Overall, replacing cement with ferrock in M45 grade concrete with geopolymer solution with 12M of sodium hydroxide and sodium silicate can improve its flexural strength and reduce deflection. Additionally, can help reduce carbon dioxide emissions, making it a more sustainable option.

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