

STUDY ON GEOPOLYMER CONCRETE WITH PARTIAL REPLACEMENT OF SCRAP STEEL SLAG AS COARSE AGGREGATE AND FOUNDRY SAND AS FINE AGGREGATE

Submitted in partial fulfillment of the requirement for the award of degree of
Master of Engineering in Structural engineering

Submitted by,

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(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of **KELVIN JOSE D (Reg No: 41380010)** who carried out the project entitled “**STUDY INVESTIGATION ON GEOPOLYMER CONCRETE WITH PARTIAL REPLACEMENT OF SCRAP STEEL SLAG AS COARSE AGGREGATE AND FOUNDRY SAND AS FINE AGGREGATE**” under our supervision from August 2022 to November 2022.

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DECLARATION

I **KELVIN JOSE D (41380010)**, here by declare that the Project Report entitled “**STUDY ON GEOPOLYMER CONCRETE WITH PARTIAL REPLACEMENT OF SCRAP STEEL SLAG AS COARSE AGGREGATE AND FOUNDRY SAND AS FINE AGGREGATE**” done under the guidance of Ms. S. Vanitha is submitted in partial fulfillment of the requirements for the award of Master of Engineering degree in Structural Engineering.

DATE : 05-05-2023

PLACE: Chennai

A handwritten signature in blue ink, appearing to read 'Kelvin', is positioned above the signature line.

SIGNATURE OF THE CANDIDATE

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ABSTRACT

Generation of waste foundry sand as by- the product of metal casting industries causes environmental problems because of its improper disposal. Thus, its usage in building material, construction and in other fields is essential for reduction of environmental problems. Similarly, in foundries (where the ferrous and non-ferrous metals are melted.), the slag is produced after the completion of the melting process it can also be used as a building material, construction and in another field. This research is carried out to produce low-cost and eco-friendly concrete. This paper demonstrates the use of waste foundry sand as a partial replacement by fine aggregate and slag is as coarse aggregate in concrete. An experimental investigation is carried out on concrete containing waste foundry sand in the range of 0%, 20 %, 40% by weight and slag is fully replaced (100%) for M-25 grade concrete (OPC). The material was produced, tested, and compared with conventional concrete in terms of workability and strength. These tests were carried on a standard cube of size 150mm×150mm×150mm for 7, 14 and 28 days to determine the mechanical properties of concrete.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL:

Concrete is an artificial material which is widely used in all the construction sectors. All the constructions around the world are constructed with the help of concrete such as Buildings, Roadways, Bridges, and Dams etc. The concrete is a costly material and due to which the cost of the construction increases with the increase in the quantity of the concrete. Overcome this problem, we have used industrial waste materials as a fine aggregate and coarse aggregate. Waste foundry sand is used as a fine aggregate and Steel slag is used as a coarse aggregate.

- 1) In India like fast developing countries, the growth of construction industry is on the hike, with increase in demand for concrete materials.
- 2) It remains a threat to the environment as the main ingredients of concrete are derived from non-renewable natural resources and the manufacturing ingredients highly releases CO₂.
- 3) Efforts are being made to make the concrete more sustainable.
- 4) In such a need, this research work focuses on replacing the major component of concrete, the coarse aggregate and fine aggregate.
- 5) Also, the research work continues to study the performance of this scrap steel slag and foundry sand in geo-polymer concrete, which makes it even more environmentally friendly and sustainable.

1.1.1 GGBS cements

Geopolymer cement is a type of cementitious material that is made by reacting various types of source materials, such as fly ash, ground granulated blast furnace slag (GGBFS), and other industrial by-products, with alkaline activators, such as sodium or potassium hydroxide, or sodium or potassium silicate. The chemical reaction that occurs between the source materials and the activators produces a

binder that can harden and gain strength over time, similar to traditional Portland cement.

Compared to Portland cement, geopolymers have several advantages, including:

- 1. Lower carbon footprint: Geopolymers require less energy and produce fewer carbon emissions during production, as they use industrial by-products that would otherwise be considered waste.
- 2. Better durability: Geopolymers have better resistance to acid, sulphate, and chloride attacks, which can lead to longer-lasting concrete structures.
- 3. Higher strength: Geopolymers can have higher compressive and flexural strength compared to traditional cement, making them suitable for high-stress applications.
- 4. Improved fire resistance: Geopolymers have good fire resistance properties due to their inorganic nature.
- Geopolymer cement is still relatively new, and more research is needed to optimize its production and application. However, it shows promise as a sustainable and durable alternative to traditional Portland cement.

1.1.1.1 Physical Properties of Geopolymer cement

- Density: The density of geopolymer cement can range from 1.5 to 2.5 g/cm³, depending on the specific composition.
- Compressive strength: Geopolymer cement can have a high compressive strength, typically ranging from 30 to 100 MPa or higher, depending on the curing time and conditions.
- Flexural strength: Geopolymer cement can also exhibit high flexural strength, typically ranging from 5 to 20 MPa, depending on the specific composition and curing conditions.
- Setting time: The setting time of geopolymer cement can vary depending on the specific composition and curing conditions, but it generally ranges from 1 to 4 hours.

- Water absorption: Geopolymer cement can have a relatively low water absorption rate, typically less than 10%, which indicates good durability and resistance to moisture damage.
- Shrinkage: Geopolymer cement can exhibit some degree of shrinkage during curing, but it is generally less than that of traditional Portland cement.
- Thermal properties: Geopolymer cement has good thermal stability and can withstand high temperatures, making it suitable for high-temperature applications.

1.1.1.2 Advantages of Geopolymer cement

Geopolymer cement has several advantages compared to traditional Portland cement, including:

- Lower carbon footprint: Geopolymer cement uses industrial by-products, such as fly ash and slag, that would otherwise be disposed of as waste. This reduces the need for mining and processing of raw materials and can result in significantly lower carbon emissions during production.
- Better durability: Geopolymer cement has better resistance to acid, sulfate, and chloride attacks than traditional cement, which can lead to longer-lasting concrete structures. It also has better resistance to fire and high temperatures.
- Higher strength: Geopolymer cement can have higher compressive and flexural strength than traditional cement, making it suitable for high-stress applications.
- Reduced water usage: Geopolymer cement requires less water than traditional cement, which can lead to reduced water consumption and improved sustainability.
- Reduced waste: Using industrial by-products to produce geopolymer cement can reduce the amount of waste generated by industries.
- Versatility: Geopolymer cement can be used for a variety of applications, including structural concrete, precast elements, and decorative finishes.

Overall, geopolymers offer several benefits in terms of sustainability, durability, strength, and versatility, which make it a promising alternative to traditional Portland cement.

1.1.2 Waste Foundry Sand (WFS)

Metal industries use sand casting in which moulds are made of uniform sized, clean, high silica sand. After the casting, process foundries recycle and reuse the sand several times but after some time, it is discarded from the foundries known as waste foundry sand. Its harmful effect on environment and disposal problem can be minimized if used in engineering structures. Indian foundries produce approximately 1.71 million tons of waste foundry sand each year (Metal World, 2006). Fig. 1: Waste Foundry Sand Chandrashekhar D. Sahare et al.; International Journal of Advance Research, Ideas, and Innovations in Technology © 2019, www.IJARIIIT.com All Rights Reserved Page | 6 Waste foundry sand is made up of mostly natural sand material. Its properties are like the properties of natural or manufactured sand, the fineness modulus of waste foundry sand is 2.62 thus it can normally be used as a replacement of sand.

1.1.3 Steel Slag

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Steel slag was used as fine or coarse aggregate in concrete mixtures. It is estimated that between 7.0 and 7.5 million metric tons (7.7 to 8.3 million tons) of steel slag is used each year in the United States. The primary applications for steel slag in the United States are its use as a granular base or as an aggregate



material

Fig 1.1 Steel Slag

in construction applications. While most of the furnace slag is recycled for use as an aggregate, excess steel slag from other operations (raker, ladle, clean out, or pit slag) is usually sent to landfills for disposal. The use of steel slag as an aggregate is considered standard practice in many construction sectors, with applications that include its use in granular base, embankments, engineered fill, highway shoulders, and hot mix asphalt pavement.

1.1.4 GEOPOLYMER CONCRETE

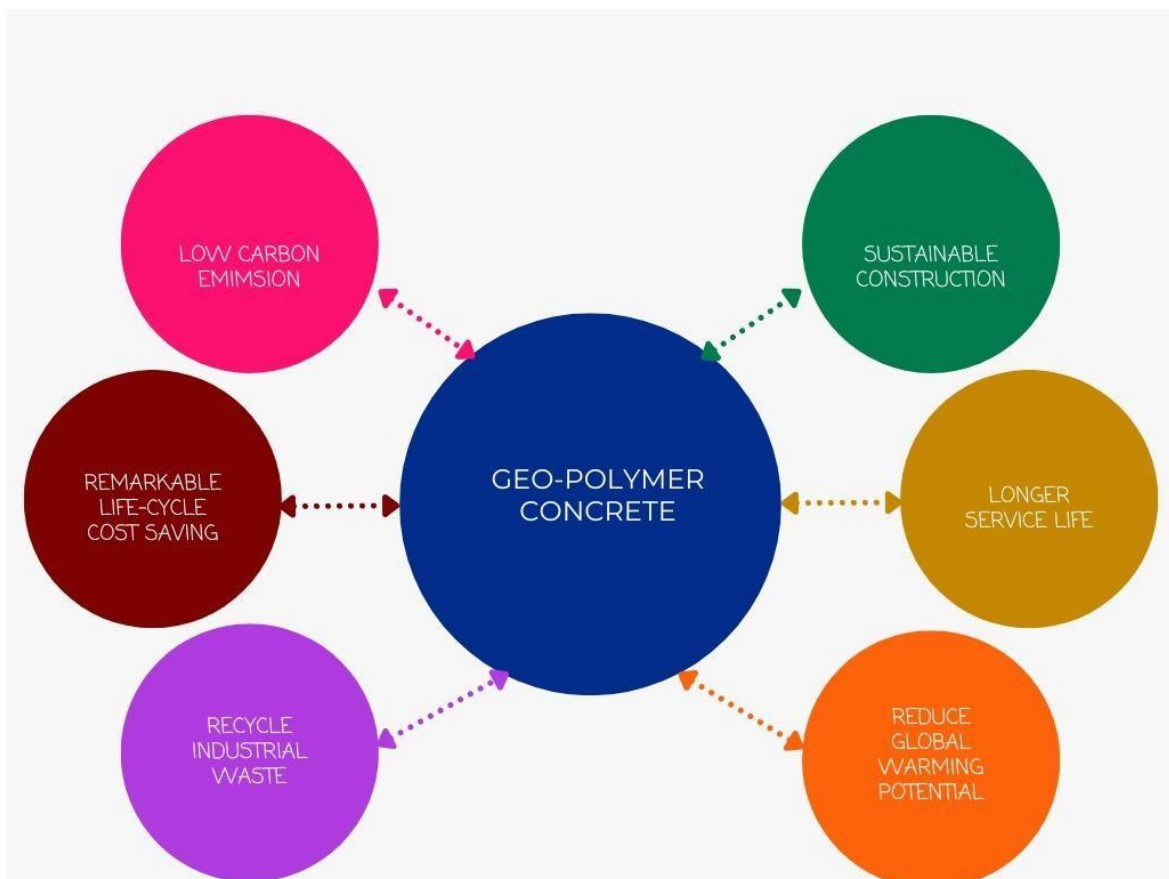


Fig 1.2 Geopolymer Concrete

Geopolymer was the name given by Daido its in 1978 to materials which are characterized by chains or networks or inorganic molecules. Geopolymer cement concrete is made from utilization of waste materials such as fly ash and ground granulated blast furnace slag (GGBS). Fly ash is the waste product generated from thermal power plant and ground granulate blast furnace slag is generated as waste material in steel plant. Both fly ash and GGBS are processed by appropriate

technology and used for concrete works in the form of geopolymer concrete. The use of this concrete helps to reduce the stock of wastes and also reduces carbon emission by reducing Portland cement demand. The main constituent of geopolymers source of silicon and aluminium which are provided by thermally activated natural materials (e.g., kaolinite) or industrial by products (e.g., fly ash or slag) and an alkaline activating solution which polymerizes these materials into molecular chains and networks to create hardened binder. It is also called as alkali-activated cement or inorganic polymer cement.

1.1.4.1 Composition of Geopolymer Concrete

1. Fly ash - A by product of thermal power plant
2. GGBS - A by product of steel plant
3. Fine aggregates and coarse aggregates as required for normal concrete.
4. Alkaline activator solution for GPCC as explained above. Catalytic liquid system is used as alkaline activator solution. It is a combination of solutions of alkali silicates and hydroxides, besides distilled water. The role of alkaline activator solution is to activate the geopolymer source materials containing Si and Al such as fly ash and GGBS.

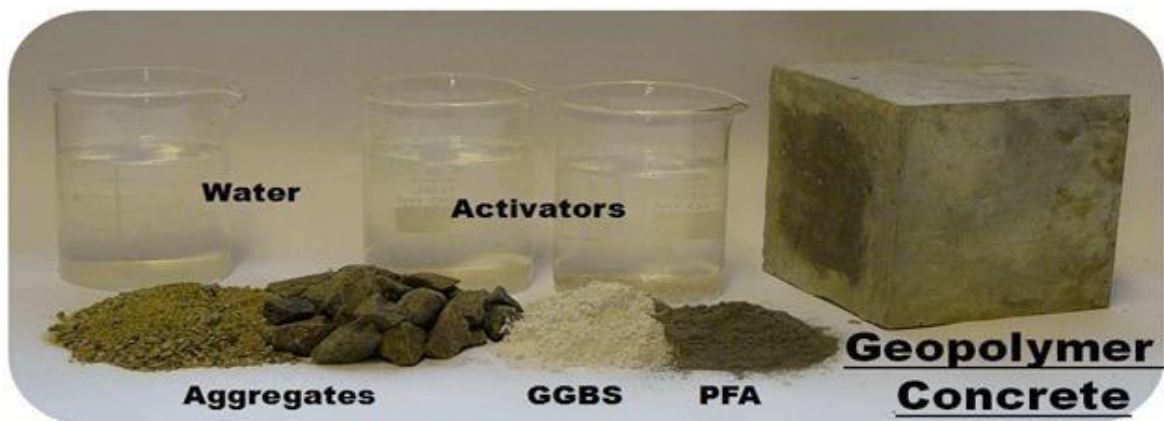


Fig 1.3 Composition of Geopolymer Concrete

1.1.4.2 Mechanical Properties of Geopolymer Concrete

Compressive strength of geopolymer concrete have been found up to 70 MPa (N/mm²). The concrete gains its compressive strength rapidly and faster than ordinary Portland cement concrete. The concrete strength after 24 hours has been found to be more than 25 MPa. Compressive strength after 28 days have been found to be 60 to 70 MPa. -Ref. Paper by - James Alder and John Day and Test results by SERC Chennai.

1.1.4.3 Other Properties of Geopolymer Concrete:

1. The drying shrinkage of is much less compared to cement concrete. This makes it well suited for thick and heavily restrained concrete structural members.
2. It has low heat of hydration in comparison with cement concrete.
3. The fire resistance is better than OPC based concrete. -Reference - Paper by - James Alder and John Day.
4. This concrete has chloride permeability rating of 'low' to 'very low' as per ASTM 1202C. It offers better protection to reinforcement steel from corrosion as compared to traditional cement concrete.
5. This concrete is found to possess very high acid resistance when tested under exposure to 2% and 10% sulphuric acids.

1.1.4.4 Applications of Geopolymer Concrete

The applications are same as cement concrete. However, this material has not yet been popularly used for various applications. This concrete has been used for construction of pavements, retaining walls, water tanks, precast bridge decks.

Recently world's first building Structural Building, The University of Queensland's Global Change Institute (GCI) has been constructed with the use of geopolymer concrete. It is a four-storey high building for public use.

1.2 OBJECTIVES

1. To check the behaviour of concrete after adding foundry sand and slag.
2. To check the difference in the cost of conventional concrete and foundry sand and slag concrete.
3. To create the best from the waste.
4. To make an Eco-friendly concrete.

1.3 SCOPE

This experimental study involves finding a sustainable alternative to natural coarse aggregate in cement concrete and checks its performance in cement – less Geopolymer concrete. The scope and objectives for this research work are,

1. To study the performance of scrap steel slag as coarse aggregate and foundry sand as fine aggregate in geopolymer concrete.
2. To formulate a mix design for various percentage of geopolymer concrete.
3. To study the Flexural strength, Split tensile strength, Compressive strength and deflection of beams.
4. To study the morphological characteristic of the specimen using SEM analysis.
5. To compare the analytical results with experimental results using ANSYS.
6. Based on the mechanical behaviour, durability and flexural behaviour of the concrete elements, results are drawn to conclusion which includes analytical and experimental analysis.

1.4 NEED FOR THE STUDY

1. It is found that enough literatures are available for geopolymer concrete with its own basic ingredients.
2. Steel slag and foundry sand collected from steel industries studied as partial replacement in concrete. In this literature background, attending the need of the hour in making the concrete more sustainable.
3. This present research work was initiated to use scrap steel slag as coarse aggregate and foundry sand as fine aggregate in geopolymer concrete.
4. The study evaluates the mechanical behaviour, durability, and flexural behaviour of reinforced beams of geopolymer concrete with steel slag and foundry sand.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURES

Rafat Siddique a et. al (2009) Compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with the increase in foundry sand contents. Compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with age for all the foundry sand contents. Increase in compressive strength varied between 8% and 19% depending upon UFS percentage and testing age, whereas it was between 6.5% and 14.5% for splitting-tensile strength, 7% and 12% for flexural strength, and 5% and 12% for modulus of elasticity. The used-foundry sand could be very conveniently used in making good quality concrete and construction materials.

Rafat Siddique a et. al (2009) Compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with the increase in foundry sand contents. Compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with age for all the foundry sand contents. Increase in compressive strength varied between 8% and 19% depending upon UFS percentage and testing age, whereas it was between 6.5% and 14.5% for splitting-tensile strength, 7% and 12% for flexural strength, and 5% and 12% for modulus of elasticity. The used-foundry sand could be very conveniently used in making good quality concrete and construction materials.

George Wang (2010) The Steel Slag should be selected for different kind of applications. the maximum expansion force is useful to evaluate and decide if a given steel slag is suitable for use in a given matrix with a constrained stress. There is some positive stability and strength related results for steel slag concrete samples, each specific slag should be fully quantified and checked for each specific use. The concrete containing the slag samples showed acceptable stability, it is necessary to confirm this through detailed durability testing of the concrete incorporating a specific slag

Dinesh Kumar et. al ((2016) A comparison was made between concrete having natural coarse aggregates and fine aggregate with various percentage so steel slag replaced by volume. Compressive strength, splitting tensile strength for steel slag was similar to conventional concrete. The strength may be affected with time and so long-term effects on hardened properties of concrete the demand for aggregates is increasing rapidly and so as the demand of concrete. Thus, it is becoming more important to find suitable alternatives for aggregates in the future. 0The steel slag could be utilized as coarse aggregate in all the concrete applications and shows a considerable improvement in the compressive strength of concrete over the control mixes by 7 to 8%.

Tarek Uddin Mohammed et. al (2016) The absorption capacity of steel slag aggregate is much lower. The specific gravity of lightweight slag aggregate is similar. r the heavier slag aggregate and mixed slag aggregate show more specific gravity. The modulus of elasticity and tensile strength of concrete made with slag aggregate is higher. Relationships between compressive strength of concrete and tensile strength of concrete, and compressive strength and modulus of elasticity of concrete are proposed for concrete made with different slag aggregates. The relationships are varied with the change of type of slag aggregates.

N. Bhuvaneshwari and Dr. K. Nirmalkumar (2019) the comparison of steel slag and weld slag in strength of concrete. The compressive strength is increased by 15%

when compared with the steel slag concrete and the maximum strength is obtained in the concrete with 20% of sand reduction. The split tensile strength is increase by 16.88%. The increase in the strength is due to the reduction of sand content in the concrete. Optimum level of replacement for steel and weld slag is found as 20% increase in strength initially is attributed to shape effect and decrease the strength beyond 20% is attributed to porosity of steel slag.

Chandrashekhar D. Sahare et. al (2020) The waste foundry sand and steel slag is increased the strength of concrete. After the 7 days of curing of concrete cubes, tested cubes has given satisfactory results regarding their compressive strength and workability. According to these results, the foundry sand and slag concrete can easily be used for all types of concreting works. The use of waste foundry sand and slag concrete will help to achieve the required strength at a low cost.

S. Aparicio et. al (2020) Compressive strength measurements were also performed after 28 days of curing showing that the specimens with steel slag aggregates got the highest compressive strength values and these values increases with the percentage of replacement.

Yifei Cui ET. AL (2020) The geopolymer binder may be capable of additional elastic deformation compared to the OPC binder. It was found that the current provisions used for predicting the indirect tensile strength of OPCC do not accurately apply to CFGPC. It is noticed that the tensile strength of CFGPC increased in an approximately proportional manner with the increase in compressive strength, and the correlation was basically linear, whereas for OPCC. . It was proved that including density in the prediction contributed to capturing variations in the elastic modulus of CFGPC.

Aliakbar Gholampour et. al (2021) Replacing sand with 25% RFA causes a slight increase (i.e., 3%) in compressive strength. Replacing cement with FA or GGBS in concrete with 50% FS or RFA results in a decreased compressive strength.

Concrete containing FS with sand replacement level of up to 50% exhibits a similar water absorption to conventional concrete. Concrete containing FA develops a higher water absorption.

N. Santillan et. al (2021) The incorporation of steel slag aggregates significantly improves the conductive capacity of concrete. It can increase electrical conductivity. The concrete with slag and metallic fibres, improving the electrically conductive capacity by almost 70% and improving the mechanical performance by 14%.

Osman Gencil et. al (2021) When steel slag is used as aggregate in asphalt superstructure, it showed higher stability values. When steel slag is used as aggregate in asphalt superstructure, it showed higher stability values when compared to commonly used limestone samples. The reason for the better performance of the slag samples than the limestone samples is that steel slag aggregate has higher compressive strengths and is denser than limestone aggregate. The surface of steel slag is more porous and rougher than limestone aggregates, the adhesion between the aggregates and bitumen in the hot mixture is higher for steel slags.

Paul O. Awoyera et. al (2021) The validation phases confirm the efficiency of the model for its general application to the compressive and split tensile strengths. Compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with age for all the foundry sand contents.

Uday Kiran Danda et. al (2022) it is clearly observed that the compressive strength of cubes for 56 days is increased by 34.59%. It is also observed that the compressive strength of concrete increases when the molarity of NaOH increase. it is clearly observed that by increasing the molarity of NaOH the load carrying

capacity of the column increases. The ultimate load carrying capacity of columns which are tested gives the nearly equal results to theoretical results.

M.H. Lai et. al (2021) BOFSS could significantly improve the interfacial transition zone (ITZ) of concrete. The optimum replacement ratio of SSCA and SSFA, the 7-, 28- and 90-day compressive strengths were improved by 5.32%, 5.76% and 19.32% compared with ordinary concrete. the optimum replacement ratio of SSCA and SSFA, the volume of harmful pore, average pore diameter and the total pore volume were significantly reduced, while the bulk density and the durability in terms of anti-permeability of concrete were effectively improved.

P.R. Kalyana Chakravarthy et. al (2022) The concrete can be minimized by utilizing the waste products from various industries as an alternative for components in concrete. The reuse of industrial waste foundry sand and agricultural waste coconut shell in biased form for fine aggregate and coarse aggregate. The mechanical properties of concrete containing both the waste products, the optimum replacement levels were arrived at 25 % and 15% for waste foundry sand and coconut shell. The durability properties such as water absorption, porosity, sorptivity and water permeability are found for improvised concrete and compared with normal concrete.

N.T. Sithole et. al (2022) The concrete specimen with mix formulation containing 40% GGBFS binder, 30% WFS, and 30% crushed stones with 15% L/S ratio cured for 90 days yielded the highest UCS of 12.69 MPa. the synthesized concrete specimens cured at different curing periods can be used for different building and construction applications as all of them met the minimum required strength and the water absorption of less.

Blessen Skariah Thomas et. al (2022) Recycled aggregates in saturated surface dry condition improve the workability of geopolymer concrete. Workability of

concrete is increased with increase in the amount of recycled aggregates. The compressive strength of GRAC is found higher than OPC concrete, and it increases with the increase in slag content. High volume fly ash blended with 5-15% OPC and metakaolin is more resistant to surface abrasion. Geopolymer concrete is highly immune to sulfuric acid. At the same time, the GRAC (normal or blended) is less resistant to acid attack because of the reaction between acid and the calcium compounds present in the attached cement mortar, surrounding the recycled aggregates.

Qaiser Bashir et. al (2022) Workability of concrete increases as much water is available in fresh state for a material having steel slag. The 28 days' compressive strength increases from 3.24% to 5.79%. The 28-day split tensile strength of concrete increases for all mixes. The Flexural strength also increases for every concrete mix. The steel slag can be utilized as a partial replacement material of cement, and 30% replacement of cement with steel slag gives better result in compression, tensile and flexural strength as compared to the normal concrete.

D. Logeshwarin and Kiruthika (2022) flexural and spilt tensile strength was gave better strength but compressive strength is not giving better strength compared to other two strength. The spilt tensile strength of geopolymer concrete was high strength compared to conventional concrete at 7days, 14days and 28 days. Geopolymer concrete strength will be get good result at 28 days because we compared to compressive strength of specimen result value. Spilt tensile strength of geopolymer concrete is GRADUALLY increased with respect to molarity.

2.2 SUMMARY OF LITERATURES

- Compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity of concrete mixtures increased with the increase in foundry sand.

- Geopolymer concrete strength will be get good result at 28 days because we compared to compressive strength.
- Workability of concrete increases as much water is available in fresh state for a material having steel slag. The 28 days' compressive strength increases from 3.24% to 5.79%. The 28-day split tensile strength of concrete increases for all mixes.
- It is clearly observed that the compressive strength of cubes for 56 days is increased by 34.59%.
- The mechanical properties of concrete containing both the waste products, the optimum replacement levels were arrived at 25 % and 15% for waste foundry sand.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

This chapter is briefing the selection of materials for the preparation of geopolymer concrete beam partially replaced with scarp steel as course aggregate and foundry sand as fine aggregate, the various test to be conducted with geopolymer concrete to determine the various properties such as compressive, tensile, and flexural strength and modelling of Geopolymer concrete beam using FEM software ANSYS.

3.2 METHODOLOGY

This flowchart provides a step-by-step process for determining the various properties of concrete.

- The first step is to study the literature related to the material which is going to replace and identify the material properties which affects the Geo polymer concrete.
- Which helps in the selection of suitable replacement material.
- The study on determining the properties of materials to be conducted that can be useful in increasing the desirable properties of the concrete.
- The structural element (beam) is modelled using FEM software and analysis will be carried out.

- The mix design for M40 grade Geo polymer concrete will be done in this study.
- The casting of the specimen to conduct the experimental investigation for determining the properties of the Geo polymer concrete will be carried out.
- The results obtained from the experimental investigation will be compared with the results of FEM software ANSYS.

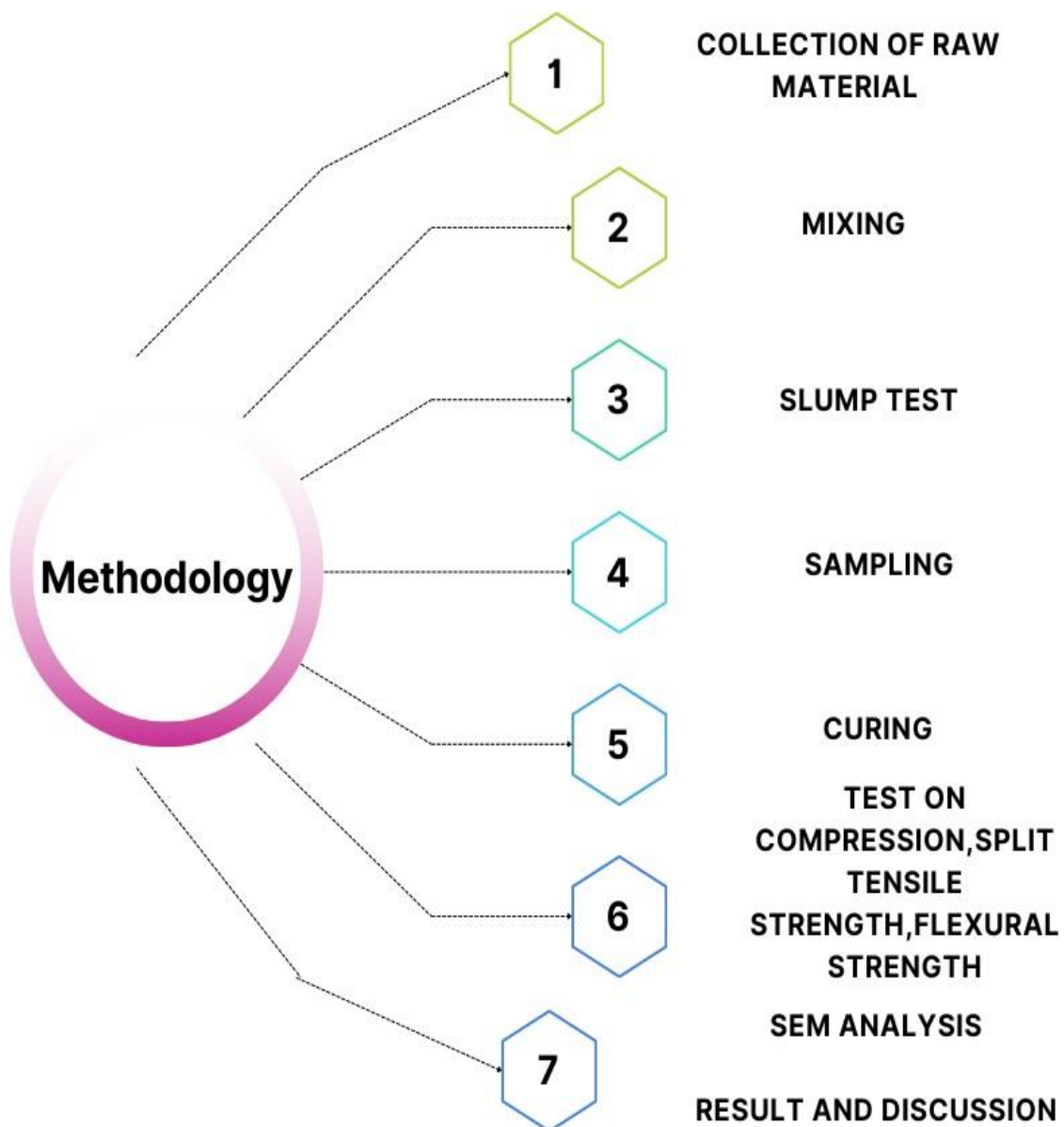


Fig 3.1 Methodology Flowchart

CHAPTER 4

MATERIALS AND EXPERIMENTAL INVESTIGATION

4.1 GENERAL

This chapter briefing about the materials used in geopolymer concrete and is partially replaced with steel slag as coarse aggregate and foundry sand as fine aggregate those materials physical properties through laboratory test and its results. Then the geopolymer concrete specimens are casted and tested in laboratory for the compressive, split-tensile, and flexural behaviour.

4.2 MATERIALS

Geopolymer concrete is made up of various essential ingredients, including cement, fine aggregate, coarse aggregate, sodium silicate, sodium hydroxide, water, chemical admixtures. The strength of geopolymer concrete is dependent on the quality of these ingredients, their appropriate proportions, and the mixing method employed.

4.3 MATERIAL USED

4.3.1 GGBS CEMENT

GGBS (Ground Granulated Blast Furnace Slag) cement is a type of cementitious material that is produced by grinding granulated blast furnace slag into a fine powder. Blast furnace slag is a by-product of iron production and is usually obtained by quenching molten iron slag in water or steam.

GGBS cement is used as a partial replacement for Portland cement in concrete, as it has several beneficial properties. It can improve the workability of concrete and reduce its permeability, which makes it more durable and resistant to chemical attack. GGBS cement also has a lower heat of hydration than Portland cement, which means it generates less heat during the setting and curing process. This property can be particularly useful in large concrete structures where heat build-up can cause cracking.

Overall, GGBS cement is a sustainable alternative to traditional Portland cement, as it reduces the carbon footprint of concrete and conserves natural resources by utilizing a by-product of industrial processes.

4.3.1.1 Properties of GGBS

GGBS (Ground Granulated Blast Furnace Slag) has several properties that make it a useful material for construction applications. Some of these properties include:

- Pozzolanic Activity: GGBS has pozzolanic properties, which means that it can react with calcium hydroxide (a by-product of cement hydration) in the presence of water to form additional cementitious compounds. This reaction results in denser and stronger concrete, which improves the long-term durability of the concrete.*
- Reduced Heat of Hydration: The use of GGBS in concrete can reduce the heat of hydration, which is the heat generated during the chemical reaction between cement and water. This property can help to reduce the risk of thermal cracking in large concrete structures and improve the long-term durability of the concrete.*
- Improved Workability: The use of GGBS can improve the workability of concrete by reducing the water demand and increasing the cohesiveness of*

the mix. This property makes it easier to place and finish the concrete, which can reduce construction time and costs.

- *Reduced Permeability:* GGBS can also reduce the permeability of concrete by filling voids and pores in the cement matrix. This property can make the concrete more resistant to water and chemical penetration, which improves its durability and reduces maintenance costs.
- *Environmental Benefits:* The use of GGBS in concrete reduces the amount of Portland cement required, which reduces carbon emissions and conserves natural resources. GGBS is a by-product of the steel industry, so its use in construction also helps to divert waste from landfills.

Table 4.1. Physical Properties of cement

S.NO	PROPERTY	LIMITS
1	APPEARANCE	A FINE WHITE/OFF WHITE POWDER FREE FROM LUMPS
2	BULK DENSITY @27°C	1.0 - 1.10
3	DRY SIEVE ANALYSIS (%RETENTION)	90 MICRON - MAX 10% PAN _ MIN 90%

4.3.2 Foundry sand

Foundry sand consists primarily of clean, uniformly sized, high-quality silica sand or lake sand that is bonded to form moulds for ferrous (iron and steel) and nonferrous (copper, aluminum, brass) metal castings. Although these sands are clean prior to use, after casting they may contain Ferrous (iron and steel) industries account for approximately 95 percent of foundry sand used for castings. The automotive industry and its parts suppliers are the major generators of foundry sand.

The most common casting process used in the foundry industry is the sand cast system. Virtually all sand cast moulds for ferrous castings are of the green sand type. Green sand consists of high-quality silica sand, about 10 percent bentonite clay (as the binder), 2 to 5 percent water and about 5 percent sea coal (a carbonaceous mould additive to improve casting finish). The type of metal being cast determines which additives and what gradation of sand is used. The green sand used in the process constitutes upwards of 90 percent of the moulding materials used.

4.3.2.1 Properties of foundry sand

Foundry sand is a by-product of metal casting processes and has several properties that make it a useful material for various applications. Some of these properties include:

- **High Compressive Strength:** Foundry sand typically has a high compressive strength, which makes it suitable for use in construction and road projects as a substitute for natural sand.
- **Good Drainage:** Foundry sand has a porous structure that allows for good drainage, making it suitable for use in soil stabilization and filtration applications.
- **Thermal Stability:** Foundry sand can withstand high temperatures and has good thermal stability, making it suitable for use as a refractory material in high-temperature applications such as furnace linings and metal casting molds.

- **Low Permeability:** Foundry sand has low permeability, which makes it suitable for use as a lining material in landfills and other containment structures.
- **Chemical Inertness:** Foundry sand is chemically inert and does not react with other materials, which makes it suitable for use in various applications where chemical stability is important.
- **Cost-Effective:** Foundry sand is a low-cost material as it is a by-product of metal casting processes. Its use in various applications can help to reduce the cost of construction and manufacturing processes.

4.3.2.1.1 Sieve Analysis

The sieve analysis of fine aggregate is a process utilized to determine the distribution of particle sizes present in materials like sand, silt, or clay that are smaller than 4.75mm in size but larger than 75 microns, as they pass through the former sieve and are retained by the latter. This test and results are conducted based on IS 2386 part1 1963 and IS 383.



Fig 4.1 Fine aggregate sample within the sieve

Apparatus

- Sieve
- Balance

Test Procedure

- The sample was brought to an air-dry condition before weighing and sieving.
- To achieve this, it was either dried at room temperature or heated at a temperature of 100 to 110°C.
- Once the sample was air-dry, it was weighed and started sieving it successively on the appropriate sieves, starting with the largest.
- It was ensured that the sieves were clean before use.
- The air-dry sample was weighed and began sieving it on the appropriate sieves, starting with the largest.
- Before use, it was made sure that each sieve was clean. 33
- Each sieve was shaken separately over a clean tray for not less than two minutes, using a varied motion that included backwards and forwards, left to right, circular clockwise and anti-clockwise, and frequent jarring.
- It was made sure that the material kept moving over the sieve surface in frequently changing directions.
- The material was not forced through the sieve by hand pressure, but on sieves coarser than 20 mm, particles were permitted to be placed.
- If there were lumps of fine material present, they were broken by gentle pressure with fingers against the side of the sieve.
- A soft brush was used to lightly brush the underside of the sieve to clear the sieve openings. • A fine camel hairbrush was used to lightly brush the 150-micron and 75-micron IS sieves to prevent the powder from aggregating and blocking the openings.
- It was made sure not to use stiff or worn-out brushes and avoided applying pressure to the surface of the sieve to force particles through the mesh.

- After finishing the sieving process, the material that remains on each sieve, along with any material that has been removed from the mesh, needs to be weighed.
- From the table 4.2 shown below we can identify the zone fine aggregate is after sieve analysis.

Table 4.2 Identification of fine aggregate zone from sieve analysis

Sieve size	Cumulative weight retained (gm)	Percentage retained	Cumulative percentage retained	Percentage passing
2 mm	0	0	0	100
1 mm	24	2.4	2.4	97.6
500 mic	344	34.4	36.8	63.2
300 mic	150	15.0	51.8	48.2
212 mic	180	18.0	69.8	30.1
90 mic	230	23.0	92.8	7.2

45 mic	50	5.0	97.8	2.2
Pan	22	2.2	100	-

Result

Conforming to grading Zone II of table 9 of IS 383

4.3.3 Steel Slag

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling.

Virtually all steel is now made in integrated steel plants using a version of the basic oxygen process or in specialty steel plants (mini mills) using an electric arc furnace process.

In the basic oxygen process, hot liquid blast furnace metal, scrap, and fluxes, which consist of lime (CaO) and dolomitic lime (CaO. MgO or "do lime"), are charged to a converter (furnace). A lance is lowered into the converter and high-pressure oxygen is injected. The oxygen combines with and removes the impurities in the charge. These impurities consist of carbon as gaseous carbon monoxide, and silicon, manganese, phosphorus, and some iron as liquid oxides, which combine with lime and do lime to form the steel slag. At the end of the refining operation, the liquid steel is tapped (poured) into a ladle while the steel slag is retained in the vessel and subsequently tapped into a separate slag pot.

4.3.3.1 Properties of steel slag

Steel slag is a by-product of the steelmaking process and has several properties that make it a useful material for various applications. Some of these properties include:

- **High Compressive Strength:** Steel slag has high compressive strength, which makes it a suitable material for use as an aggregate in construction applications, such as road base and concrete.
- **Good Drainage:** Steel slag has a porous structure that allows for good drainage, making it suitable for use in soil stabilization and filtration applications.
- **Abrasion Resistance:** Steel slag is highly resistant to abrasion and wear, which makes it suitable for use in road surfaces, such as pavements and asphalt.
- **Chemical Inertness:** Steel slag is chemically inert and does not react with other materials, which makes it suitable for use in various applications where chemical stability is important.
- **Thermal Stability:** Steel slag can withstand high temperatures and has good thermal stability, making it suitable for use as a refractory material in high-temperature applications such as furnace linings.
- **Environmental Benefits:** The use of steel slag in construction applications reduces the need for virgin aggregates, which conserves natural resources and reduces carbon emissions associated with mining and transportation. Additionally, the use of steel slag in road construction can improve the durability and lifespan of road surfaces, reducing maintenance needs and associated environmental impact.

Steel slag is a versatile material with several properties that make it useful in various applications, particularly in construction and road building. Its reuse in other applications can also help to reduce waste and environmental impact.

4.3.3.1.1 Specific Gravity and Water Absorption test on steel slag

The determination of specific gravity is a useful test for identifying stones. Additionally, the water absorption test provides an indication of the strength of a slag. Steel slag with higher water absorption rates is

typically more porous and are generally considered unsuitable unless they are found to be acceptable based on their strength, impact resistance, and hardness, among other tests. Tests are conducted based on IS 2386 part 3 1963.

Apparatus required.

- Balance
- Oven
- Wire basket
- Two soft absorbent cloths
- Airtight container
- Watertight container

Test Procedure

- The sample was immersed in distilled water at a temperature of 22°C to 32°C in a wire basket with at least 5 cm of water above the top of the basket.
- Before immersing the sample, it was drained and thoroughly washed to remove finer particles and dust.
- After immersing the sample in distilled water, the entrapped air from the sample was removed by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per second.
- The basket and slag remained completely immersed. during the operation and for a period of $24 \pm 1/2$ hours afterwards.
- After the immersion and waiting period, the basket and sample were jolted and weighed in water within the temperature range of 22 to 32°C.
- If the weighing needed to be done in a different tank, the basket and sample were jolted 25 times in the new tank before weighing to ensure accuracy (weight A).

- After draining for a few minutes, the basket and the slag were removed from the water.
- The slag was gently emptied from the basket onto a dry cloth. Then, the empty basket was returned to the water, jolted 25 times, and weighed in water (weight B).
- The slag was then gently transferred from the basket onto a dry cloth and gently surface dried by using the cloth. It was then transferred to the second dry cloth when the first cloth removed no further moisture.
- The slag was spread out, not more than one stone deep, on the second cloth, and left exposed to the atmosphere away from direct sunlight or any other source of heat for not less than 10 minutes or until it appeared to be completely surface dry.
- It was turned over at least once during this period, and if necessary, a gentle current of unheated air was used to accelerate the drying of difficult slag.
- Finally, the slag was weighed (weight B). it was placed in a shallow tray and put inside an oven with a temperature range of 100 to 110°C for $24 \pm 1/2$ hours.
- Once the time was up, the slag was taken out of the oven, allowed to cool in an airtight container, and then weighed again (weight C).

- *Specific Gravity*

$$C / B - A = 2.520 / 2.540 - 1.70 = 3$$

- *Water Absorption (Percent of dry weight)*

$$100(B - C) / C = 2.540 - 2.520 / 2.520 = 0.79\%$$

Were,

A = the weight in g of the saturated slag in water (A1-As) =

1.70 kg

$B = \text{the weight in g of the saturated surface – dry slag in air} = 2.540 \text{ kg}$

$C = \text{the weight in g of oven dried slag in air} = 2.520 \text{ kg}$

Results

- Specific Gravity of fine aggregate = 3
- Water Absorption of Fine Aggregate = 0.79%

4.3.3.1.2 Sieve Analysis

Sieve analysis is a commonly used method to determine the particle size distribution of steel slag. The procedure involves passing a sample of the slag through a series of standardized sieves of decreasing size and measuring the amount of material retained on each sieve. The results of the test are presented in a graphical form called a sieve analysis curve.

Procedure:

- Obtain a representative sample of the slag. The sample size should be sufficient to provide accurate results and should comply with the relevant standards or specifications.
- Clean and dry the sample to remove any moisture or contaminants that may affect the test results.
- Prepare the sieves by arranging them in a stack in decreasing order of size. The number of sieves used will depend on the size range of the slag being tested and the requirements of the standard or specification.
- Weigh each sieve before use and record the weight.
- Place the sample on the top sieve and cover it with a lid.
- Set the sieving apparatus in motion using a mechanical shaker or hand-operated method. The duration and intensity of the sieving should be consistent with the relevant standard or specification.

- After the sieving is complete, remove the lid from each sieve and weigh the amount of material retained on each sieve. Record the weight of each fraction.
- Calculate the percentage of material retained on each sieve by dividing the weight of the retained material by the total weight of the sample and multiplying by 100.

Table 4.3 Identification of steel slag zone from sieve analysis

S.NO	IS SIEVE	WEIGHT RETAINED(g)	CUMULATIVE WEIGHT RETAINED	CUMULATIVE % OF WEIGHT RETAINED	% OF PASSING
1	80	0	0	0	100
2	60	0	0	0	100
3	40	1295	1295	25.9	74.1
4	20	1690	2985	59.7	40.3
5	10	1025	4010	80.2	19.8
6	4.75	840	4850	97	3
7	2.36	150	5000	100	0
8	1.18	0	5000	100	0
9	600	0	5000	100	0
10	300	0	5000	100	0
11	150	0	5000	100	0

4.3.3.1.3 Crushing Test

Crushing under compressive stress is one of the models in which pavement material might fail. The crushing strength of steel slag is measured using a test that adheres to the standards set forth in IS:2386 part-IV. The slag crushing value provides a relative measure of resistance to crushing under a gradually applied crushing load. The test entails running a compression test with a standard load on an slag specimen in a standard mould.

Dry slag that have been screened through 12.5 mm sieves and kept through 10 mm sieves are put into a cylindrical shape with an 11.5 mm diameter and three layers of 18 cm height. 25 times are used to tamper each layer using a typical tamping rod. To perform the slag crushing value test, a sample of the aggregate is taken and weighed before being placed in a cylindrical mold in three layers. Each layer is then compacted by tamping 25 times using a standard tamping rod. A compressive load of 40 tonnes is then gradually applied to the specimen at a rate of 4 tonnes per minute until the total load is reached. The crushing value is calculated as the ratio of the weight of fines passing the specified sieve to the total weight of the sample, expressed as a percentage.

The slag crushing value is then determined by sieving crushed aggregates through a 2.36 mm screen and expressing the weight of the material that passes as a percentage of the weight of the entire sample. A score of less than 10 denotes an unusually strong aggregate, whereas a value of more than 35 would often be considered weak.

4.3.4 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. Fine. They are essentially any natural sand particles won from the land through the mining process. It consists of natural sand or any crushed stone particles that are 1/4" or smaller. This product is often referred to as 1/4" minus as it refers to the size, or grading, of this particular aggregate.

The fine aggregate may be one of the following types:

- Natural sand i.e., the fine aggregate resulting from the natural disintegration of rock and/or that which has been deposited by the stream and glacial agencies.
- Crushed stone sand, i.e., the fine aggregates produced by crushing hard stone, or
- Crushed gravel sand, i.e., the fine aggregate produced by crushing natural gravel.

4.3.4.1 Physical Properties of Fine Aggregates

- Sieve Analysis
- Surface texture
- Water absorption
- Specific gravity
- Moisture content
- Bulk density
- Bulking

Above few are the physical properties of the fine aggregate but for my thesis I needed few of those physical properties. Which are determined from the laboratory test results which are describe briefly below,

4.3.5 Coarse Aggregate

Crushed angular metal of 10mm size from local source will be used as Coarse aggregate. In General, Coarse Aggregate used for concrete is blast out of quarries and crushed or broken to a size of less than 20mm. This we make use in Conventional concrete preparation. On the contrary for SCC Coarse Aggregate size is limited to 10 to 12mm size such that it passes through 12.5mm sieve. These aggregates are made use in SCC.

4.3.5.1 Physical Properties of Coarse Aggregate

- Specific gravity and density
- Soundness
- Shape and size
- Bulk density

- Surface moisture
- Elongation index
- Fineness modulus
- Silt content
- Water absorption
- Hardness

Above few are the physical properties of the coarse aggregate but for my thesis I needed few of those physical properties. Which are determined from the laboratory test results which are describe briefly below,

4.3.6 Water

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

4.3.7 Sodium silicate

Sodium silicate is a common alkaline solution used as a binder in geopolymer concrete. Geopolymer concrete is an alternative to traditional Portland cement-based concrete, which uses a chemical reaction between an alkaline solution and a source of alumina and silica to create a binder that can bind aggregates together.

Sodium silicate is made up of a mixture of sodium oxide and silica, and its properties make it an ideal choice for geopolymer concrete. When sodium silicate is mixed with an alumina and silica source, it forms a polymerized material that can bind together the aggregates in the concrete mix.

4.3.7.1 Physical Properties of Sodium silicate

- **High Strength:** Geopolymer concrete made with sodium silicate as a binder has been shown to have high compressive and tensile strengths, making it suitable for use in structural applications.
- **Durability:** Geopolymer concrete has been shown to have good resistance to chemical and environmental degradation, which can help to increase the durability and lifespan of the concrete.
- **Lower Carbon Footprint:** The production of geopolymer concrete produces fewer carbon emissions compared to traditional Portland cement-based concrete, which can help to reduce the environmental impact of construction projects.
- **Resistance to Fire:** Geopolymer concrete made with sodium silicate has been shown to have good fire resistance, which can help to improve the safety of structures.

Overall, the use of sodium silicate in geopolymer concrete can offer several advantages over traditional Portland cement-based concrete, including higher strength, durability, and lower environmental impact.

4.3.8 Sodium hydroxide

Sodium hydroxide, also known as caustic soda, is another common alkaline solution used as a binder in geopolymer concrete, alongside sodium silicate. When sodium hydroxide is mixed with an alumina and silica source, it can create a highly alkaline solution that can trigger the polymerization reaction, resulting in the formation of a geopolymer binder.

4.3.7.1 Physical Properties of Sodium hydroxide

- **High Strength:** Geopolymer concrete made with sodium hydroxide as a binder has been shown to have high compressive and tensile strengths, similar to those made with sodium silicate.
- **Rapid Setting Time:** Sodium hydroxide can trigger the polymerization reaction faster than sodium silicate, resulting in a faster setting time for the concrete mix.

- **Good Workability:** Geopolymer concrete made with sodium hydroxide has been shown to have good workability, making it easier to pour and shape.
- **Cost-Effective:** Sodium hydroxide is generally less expensive than sodium silicate, which can make it a more cost-effective option for large-scale construction projects.

However, there are some potential disadvantages to using sodium hydroxide in geopolymer concrete. It is highly reactive and can be hazardous to handle, requiring proper safety precautions. In addition, it can be more sensitive to variations in mix design, which can affect the final properties of the concrete.

Overall, the use of sodium hydroxide in geopolymer concrete can offer several advantages, but it is important to carefully consider the specific requirements of the construction project and weigh the potential benefits and drawbacks of using sodium hydroxide as a binder.

4.4 EXPERIMENTAL INVESTIGATION

4.4.1 MIX DESIGN

Mix design for M40 grade geopolymer concrete involves selecting the appropriate materials and proportions to achieve the desired compressive strength and other performance characteristics of the concrete. Here is a general outline of the mix design process for M40 grade geopolymer concrete:

Selection of materials: The materials required for geopolymer concrete include an alumina and silica source, alkaline solution, aggregates, and water. The alumina and silica source can be fly ash, ground granulated blast furnace slag (GGBS), or metakaolin. The alkaline solution can be sodium silicate, sodium hydroxide, or a combination of both. Aggregates should be clean, free from impurities, and of the appropriate size and grading.

4.4.1.1 Mix Proportions

The proportions of the materials used in the mixture are determined based on the desired strength and workability of the concrete. For M40 grade geopolymer concrete, a typical mix design might include:

TABLE 4.4 MIX DESIGN OF M40 GEOPOLYMER CONCRETE

MATERIALS	QUANTITY
GGBS	386 kg/m ³
COARSE AGGREGATE (20mm)	743.4kg/m ³
COARSE AGGREGATE (12.5mm)	495.6 kg/m ³
FINE AGGREGATE	618.5 kg/m ³
SODIUM SILICATE	116.8 kg/m ³
SODIUM HYDROXIDE	46.7 kg/m ³
MOLARITY OF NAOH	10M
ADMIXTURE (0.4% OF CONENTITIOUS)	1.54 kg/m ³
WATER	33 kg/m ³
DENSITY	2476.5

Mix Design Testing: Once the materials and proportions have been selected, the mix design should be tested to ensure that it meets the desired performance criteria, such as compressive strength, workability, and durability. The mix should

be tested using standard procedures to ensure that it meets the specified requirements.

Optimization: If necessary, the mix design can be optimized to further improve the performance characteristics of the concrete. This may involve adjusting the proportions of the materials, using different types of aggregates or additives, or modifying the curing conditions.

The specific mix design for M40 grade geopolymer concrete may vary depending on the specific materials and requirements of the construction project. A qualified engineer or concrete technologist should be consulted to ensure the appropriate mix design is used for the specific application.

4.4.2 Concrete Specimen Casting Process

The concrete specimen casting process involves the following steps:

- Preparation of molds: The molds for casting concrete specimens should be cleaned and coated with a releasing agent to prevent the concrete from sticking to the mold.
- Mixing of concrete: The concrete mix should be prepared according to the specific mix design, ensuring that the materials are mixed thoroughly and evenly.
- Filling the molds: The mixed concrete should be poured into the molds in layers, ensuring that each layer is compacted properly using a vibrating table or a vibrating needle. The molds should be filled to the top, and the excess concrete should be struck off using a trowel.
- Curing: The specimens should be cured in a moist environment, such as a curing tank or a covered area, to prevent the loss of moisture and to ensure proper hydration of the concrete.

- Demoulding: The specimens should be demoulded after 24 hours of casting, or once the concrete has reached sufficient strength to be handled without being damaged.
- Storage: The specimens should be stored in a moist environment until they reach the desired age for testing.

The casting process is carried out properly, as any errors or inconsistencies in the process can affect the strength and durability of the concrete. The use of appropriate equipment, such as vibrating tables and curing tanks, can help to ensure that the concrete specimens are cast and cured properly.



Fig 4.2 Cube, cylinder and beam mould with oil applied and casting process.

4.4.3 REINFORCED CONCRETE BEAMS

Reinforced concrete is one of the most important construction materials, widely used in many types of engineering structures, such as buildings, bridges, hydroelectric and nuclear power plants, treatment plants, containment structures, and wharves, among others. The economy, efficiency, strength, and stiffness of reinforced concrete make it an attractive material for a wide range of structural

applications, in addition to generating direct and indirect employment. Understanding the behaviour of structural elements during applied action is fundamental for the design of a reliable, feasible, and safe structure. There are different methodologies to study the response of structural elements. Experimentally, the behaviour of reinforced concrete beams is studied, which is performed on a large scale. Experimental results are compared with theoretical calculations that estimate the internal distribution of tensile and compressive stresses, as well as deflections and deformations in beams. Another type of analysis can be performed using finite element modelling to estimate the behaviour of the element and to compare the experimental results with those obtained using the finite element method, which provides a complement to the experimental results.

4.4.3.1 Modelling of RCC Beams

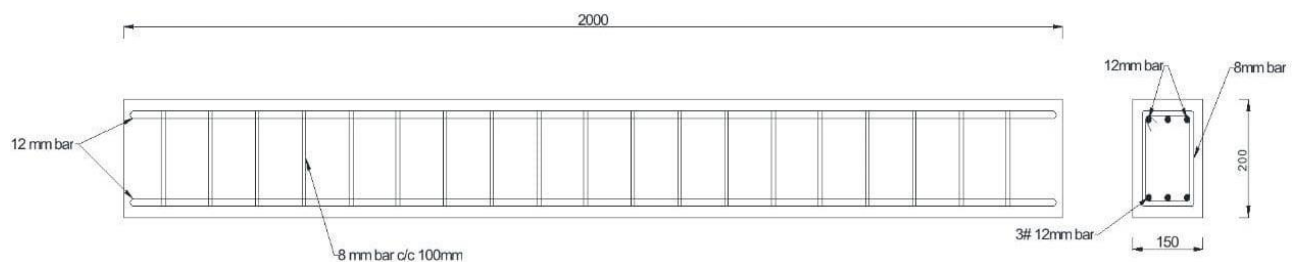


Fig 4.3 Beam Longitudinal and Cross-Section View

4.4.4 Experimental Tests and Results

The test is conducted on Fresh Concrete is,

- Slump Cone Test The various test is conducted on hardened concrete is,
- Comparison of weight

- Compression Test on Concrete
- Split Tensile Strength of Concrete
- Flexural Behaviour on RC beam

The tests are conducted on concrete specimen to study microscopic images,

- Field Emission - Scanning Electronic Microscope Topography (FE-SEM)

4.4.5 Test on Fresh Concrete

4.4.5.1 Slump Cone Test

The slump cone test on concrete is to find out the workability which is a property of fresh concrete. Workability is the property of fresh concrete which means it is easy to place and workable concrete is the concrete which shall be placed and compacted with ease and without any segregation. Workability is capacity working without any extra labour and strength loss. The concrete strength depends upon the water percentage. Water percentage and slump are taken from this slump test. It is the vertical height of the fresh concrete compared to its mould height.



Fig 4.4 Slump Cone Test

The workability is determined by using the slump cone test in fresh concrete. The code book IS: 1199-1959 is required.

- Slump cone
- Tamping rod
- Metallic sheet

Procedure

- The mould is cleaned thoroughly, and the inner surface should be free from moisture and the attached old concrete is cleared before the test is started.
- The mould is placed on a smooth and clean surface and compacted for every layer.
- Each layer is tamped 25 times using the tamping rod which distributes the equal strokes. The remaining concrete is cleared using the trowel to level.
- The mould is removed in a vertical direction from the concrete by raising the mould slowly and with care.
- The fresh concrete is allowed to subside. This form of concrete is termed a slump.
- The height between the top of the slump cone and the top of the deformed concrete is measured and noted. The height difference in mm is known as the slump of the fresh concrete.

- The slump of the fresh concrete indicates the concrete characteristics with the slump value. If the fresh concrete slumps evenly then it is called a true slump. If one-half of the fresh concrete slides down, then it is called a collapsed slump. In a shear slump, the variation in height between the top of the mould and the average value of the slump is measured as the slump value.

Table 4.5 THE SLUMP VALUES

PERCENTAGE	SLUMP VALUE (mm)
GEOPLYMER CONCRETE	135
20% STEEL SLAG AND 25% FOUNDRY SAND	145
30% STEEL SLAG AND 35% FOUNDRY SAND	147
35% STEEL SLAG AND 40% FOUNDRY SAND	148

4.4.6 Tests on Hardened concrete

4.4.6.1 Comparison of Weight

After being removed from the mould, the cubes were weighed before being stored for curing. The cubes were weighed once more after 28 days of drying. Table 4.6 displays the Average Cube Specimen Weight Before and After Curing for both conventional and lightweight concrete and table 4.7 displays the dry density of conventional and lightweight concrete.

Table 4.6 THE DRY DENSITY

PERCENTAGE	DRY DENSITY IN kg/m ³
GEOPLYMER CONCRETE	2446
20% STEEL SLAG AND 25% FOUNDRY	2345.45

SAND	
30% STEEL SLAG AND 35% FOUNDRY SAND	2365.48
35% STEEL SLAG AND 40% FOUNDRY SAND	2367.37

**Table 4.7 THE AVERAGE WEIGHT OF CUBE SPECIMEN BEFORE AND
AFTER CURING**

PERCENTAGE	AVERAGE WEIGHT BEFORE CURING	AVERAGE WEIGHT AFTER CURING	AVERAGE
GEOPLYMER CONCRETE	8.115	8.243	8.179
20% STEEL SLAG AND 25% FOUNDRY SAND	7.920	8.054	7.987
30% STEEL SLAG AND 35% FOUNDRY SAND	7.911	7.960	7.935
35% STEEL SLAG AND 40% FOUNDRY SAND	7.892	7.945	7.918

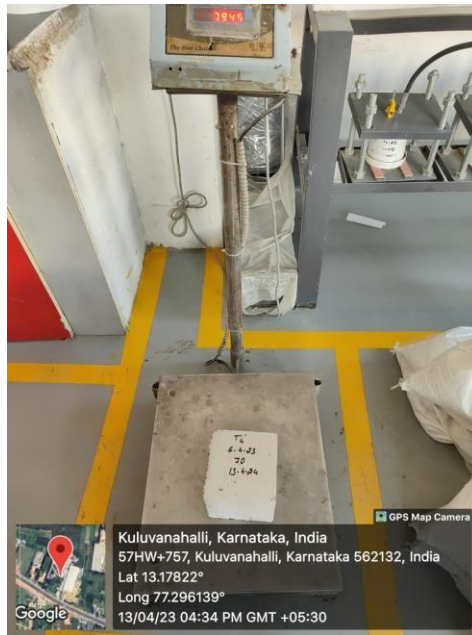


Fig 4.5 WEIGHT OF CUBE

4.4.6.2 Compression Test on Concrete

Apparatus Required

- Non-porous enamel tray
- Trowel
- Cube Mould of size 150mm x 150mm x 150mm
- Platform Vibrator
- GGBS
- Foundry Sand
- Steel Slag
- Compression Testing Machine
- Balance to Measure Weight Materials Required
- Cement
- Fine Aggregates
- Coarse Aggregates
- Sodium Hydroxide
- Sodium Silicate

Procedure

- The required quantities of cement, fine aggregate, steel slag, foundry sand and coarse aggregate in a non-porous enamel tray and mix them with a trowel for 1 minute.
- The required water, sodium hydroxide, sodium silicate quantity is taken in the non-porous enamel tray and mix the 3 ingredients thoroughly until the mixture is in uniform colour.
- The time of mixing should not be less than 3 minutes and not more than 4 minutes.
- Immediately after mixing, the concrete will be filled into a cube mould size of 150mm x 150mm x 150mm. 50
- The concrete is to be compacted by using trampling rod in a standard specific manner.
- The mould is to be placed in the cabin at temp 60°C for 24 hours.
- The specimen is removed from the mould and kept in room temperature 28 days.
- From table 4.8 we can see the average compressive strength of both conventional and lightweight concrete for 7, 14 and 28 days.



Fig 4.6 Cube specimen in compression testing machine

**TABLE 4.8 THE AVERAGE COMPRESSIVE STRENGTH OF
GEOPOLYMER CONCRETE FOR 7,14,28 DAYS**

S.NO	PERCENTAGE	AVERAGE COMPRESSIVE STRENGTH IN (N/mm ²)		
		7 days	14 days	28 days
1	GEOPOLYMER CONCRETE	49.03	55.6	57.8
2	20% STEEL SLAG AND 25% FOUNDRY SAND	44.5	47.8	50.16
3	30% STEEL SLAG AND 35% FOUNDRY SAND	41.5	44.48	49.89
4	35% STEEL SLAG AND 40% FOU SAND	39.41	42.68	46.0

4.4.6.3 Split Tensile Strength of Concrete

Apparatus Required

- Compression Testing Machine
- Two Packing Strips of Plywood 30 cm long and 12 mm wide

Theory:

The concrete is very weak in tension due to its brittle nature and is not expected to resist direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack.

Procedure:

- The specimen is immersed in the water and taken out of water after 7 days of curing.
- The water in the surface of the specimen will be wiped with dry clothes.
- The diametrical lines are drawn on the 2 ends of the specimen to ensure that they are on the same axial plane.
- The weight and dimension of the specimen will be noted.
- The compression testing machine is settled for the required range.
- The plywood strip is fixed on the lower plate and place the specimen.
- The specimen is aligned so, that the lines marked on the ends are vertical and centred over the bottom plate.
- The other plywood strip is placed above the specimen.
- The upper plate is brought down to touch the plywood strip.
- A total load of 990 kg/min to 1485 kg/min will be applied.
- A breaking load P is recorded.



Fig 4.7 Cylinder specimen for split tensile.

Formula Used

As per IS 456 2000, the Split tensile strength of concrete is $0.7 \times \sqrt{f_{ck}}$.

The split tensile strength is calculated using the formula.

$$T_{sp} = \frac{2P}{\pi DL}$$

Where,

P = Applied Load

D = Diameter of the Specimen

L = Length of the Specimen

Observation

Length of the Specimen = 300mm

Diameter of the Specification = 150mm

From the Table 4.9 we can see the Average Split Tensile strength of both conventional and lightweight concrete for 7, 14 and 28 days.

**TABLE 4.9 THE AVERAGE SPLIT TENSILE STRENGTH
OF GEOPOLYMER CONCRETE FOR 7,14,28 DAYS**

S.NO	PERCENTAGE	AVERAGE SPLIT TENSILE STRENGTH IN (N/mm ²)		
		7 days	14 days	28 days
1	GEOPLYMER CONCRETE	2.87	3.01	3.67
2	20% STEEL SLAG AND 25% FOUNDRY SAND	2.66	2.9	3.14
3	30% STEEL SLAG AND 35% FOUNDRY SAND	2.43	2.65	2.86
4	35% STEEL SLAG AND 40% FOUNDRY SAND	2.34	2.48	2.68

4.4.6.4 Flexural Behavior of RC Beam

All four beams were tested under a Four-point bending configuration so that the length of both the pure bending span and the shear span is 1400 mm. The vertical load was applied under displacement control at a rate of 1 mm/min until obvious concrete crushing and spalling were observed at the top surface of the beams. Three linear variable differential transformers (LVDTs) were installed in the pure bending span to measure the deflections at the midspan of the beam and the loading points. For the strengthened beams, the LVDT arrangement for each beam was designed based on the configuration of the strengthened scheme.



Fig 4.8 RCC BEAMS IN TWO-POINT LOADING (a)GPB (b) GPC TYPE 1 (c) GPB TYPE 2 (d) GPC TYPE 3

Apparatus Required

- RC beam specimen
- Loading frame
- Hydraulic Jack 57
- Load Cell for the measurement of load
- LVDT (or) dial gauges for the measurements of deflections

Theory

The behaviour of the given RC beam at various stages of loading is to be studied from the initial uncracked phase to the final ultimate phase at collapse.

Procedure

- The RC beam has dimensions of 150×200mm in cross section and of length 2000mm. The reinforcement consists of 4 numbers of 10mm diameter bars, 2 at the top and 2 at the bottom along with 6mm diameter stirrups spaced at 100mm c/c.
- M30 concrete mix will be prepared, casting of the RC beam and comparison specimens.
- After 28 days of curing the specimens will be white-washed and marked with a grid line to facilitate the easy marking of the crack pattern.
- The RC beam is tested by using the Universal Testing Machine or loading frame. The test setup is shown in fig. Two-point loading is applied on the specimen to produce flexure failure. Dial gauges are fixed at three locations to measure the deflections of the beam under loading.
- If the test is conducted with the help of a loading frame, the load is applied by means of a hydraulic jack and a proving ring is used to assess to load level.
- The load is applied gradually till the failure of the specimen takes place. The deflection readings are taken at periodic intervals of loading. The load at which cracks have been formed is noted down as the first cracking load.
- As the load level is increased further cracks have been propagated and the widening of cracks has taken place. The corresponding deflections show that there is a sudden increase in deflection readings while the loading reaches nearer to the yield loading.
- The specimen is loaded up to the ultimate level and the failure pattern is to be observed.
- The value of the bending moment corresponding to the load level is determined. The theoretical cracking moment of resistance is calculated and to be compared with the experimental results.

- In the linear cracked phase, the stresses developed in concrete and steel will be computed.
- Using the strength of materials principle, the deflection of the beam under the load is calculated.
- By substituting the deflection value obtained from the experimental results in the formula the Modulus of Elasticity of the RC beam is computed.

**TABLE 4.10 EXPERIMENTAL DEFLECTION RESULTS
FOR FOUR BEAM SPECIMEN**

Sl. No	Load (KN)	Displacement in 'mm'			
		GPC	GPC-20% SLAG 25% FOUNDRY SAND	GPC-30% SLAG 35% FOUNDRY SAND	GPC-35% SLAG 40% FOUNDRY SAND
1	10	0.25	0.24	0.18	0.21
2	20	0.32	0.39	0.28	0.35
3	30	0.48	0.52	0.45	0.48
4	40	0.77	0.72	0.73	0.73
5	50	1.02	0.98	0.91	0.97

6	60	1.32	1.11	1.21	1.28
7	70	1.81	1.32	1.28	1.58
8	80	2.10	1.9	1.85	2.04
9	90	2.15	2.21	2.1	2.18
10	100	2.43	2.51	2.40	2.49

CHAPTER 5

ANALYTICAL MODEL

5.1 FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) is a computational method used to determine the behaviour of a complex system or structure under various conditions. It is widely used in engineering and science to simulate the physical behaviour of materials and structures in response to external forces, such as stress, vibration, heat, and fluid flow.

The FEA process involves dividing the structure or system into smaller, more manageable parts, known as finite elements. Each finite element is modelled using mathematical equations that describe the behaviour of the material under various

conditions. The equations are solved using numerical techniques, such as the finite element method, to simulate the response of the structure or system to external forces.

Here are the general steps involved in performing a finite element analysis:

- Define the problem: The first step is to define the problem and the goals of the analysis. This includes specifying the geometry, materials, and boundary conditions of the structure or system.
- Create a mesh: The structure or system is divided into smaller elements, and a mesh is created to connect the elements. The size and shape of the elements are chosen based on the complexity of the problem and the desired level of accuracy.
- Define the material properties: The material properties, such as stiffness and density, are defined for each element.
- Apply loads and boundary conditions: The loads and boundary conditions, such as external forces and constraints, are applied to the structure or system.
- Solve the equations: The mathematical equations for each element are solved numerically using the finite element method. The equations are combined to simulate the behaviour of the entire structure or system.
- Analyse the results: The results of the analysis are analysed to determine the behaviour of the structure or system under various conditions. This includes analysing the stresses, strains, and deformations in the structure or system.
- Refine the model: The model is refined based on the results of the analysis. This includes adjusting the mesh size, material properties, and boundary conditions to improve the accuracy of the analysis.

FEA has many practical applications, including the design and optimization of structures and systems, such as bridges, aircraft, and automobiles. It can also be used to simulate the behaviour of materials under extreme conditions, such as high temperatures and pressures, and to optimize manufacturing processes.

5.2 ABAQUS

Abaqus is a powerful and widely used software for performing Finite Element Analysis (FEA) simulations. It is developed and marketed by Dassault Systems, a leading software company in the engineering and scientific domains. Abaqus is used in a wide range of industries, including aerospace, automotive, biomedical, civil engineering, and defence, among others.

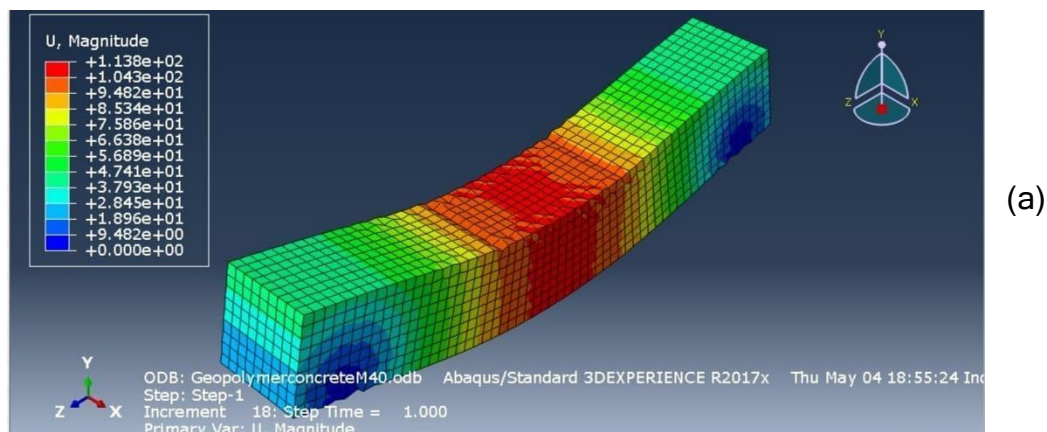
Here are some of the key features and capabilities of Abaqus:

- **Finite element modelling:** Abaqus provides a robust set of tools for creating and analysing complex finite element models. Users can create geometric models, define materials and boundary conditions, and generate meshes for various types of analyses.
- **Material modelling:** Abaqus includes a comprehensive range of material models, including elastic, plastic, hyper elastic, viscoelastic, and damage models. These models enable accurate representation of material behaviour under different loading conditions.
- **Multiphysics simulations:** Abaqus can perform Multiphysics simulations, including structural, thermal, acoustic, and fluid analyses. It allows the coupling of different physics models to simulate complex real-world problems.
- **User-defined elements and subroutines:** Abaqus provides the capability to create user-defined elements and subroutines, which can be used to implement custom material models, boundary conditions, and other specialized features.
- **Parallel processing:** Abaqus can take advantage of parallel processing capabilities to accelerate the solution of large and complex problems. It can run on both shared and distributed memory architectures.
- **Post-processing:** Abaqus includes a suite of post-processing tools for visualizing and analysing simulation results. It allows users to create plots, animations, and other visualizations to better understand the behaviour of the system or structure under study.

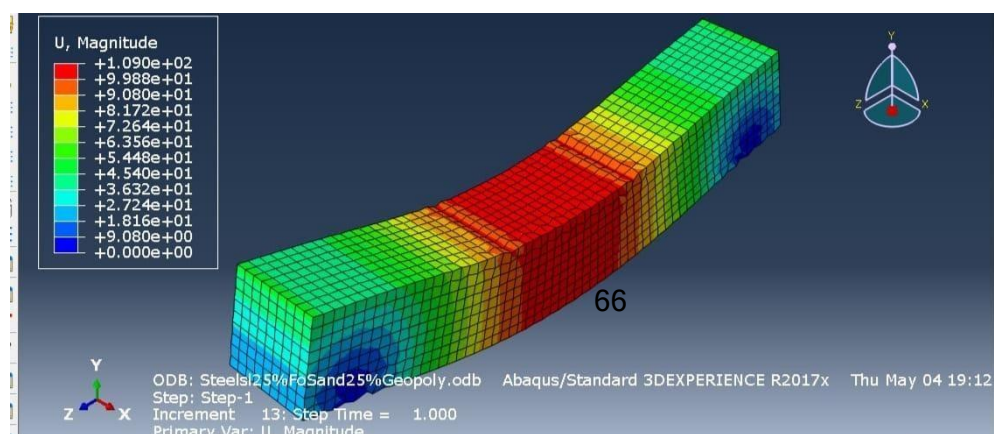
- Customization and automation: Abaqus provide a scripting interface that allows users to customize and automate simulation workflows. This feature can significantly improve productivity and efficiency in modelling and analysis.

In summary, Abaqus is a versatile and powerful software package for performing FEA simulations. It offers a range of features and capabilities for creating and analysing complex models and provides tools for post processing and visualization of simulation results.

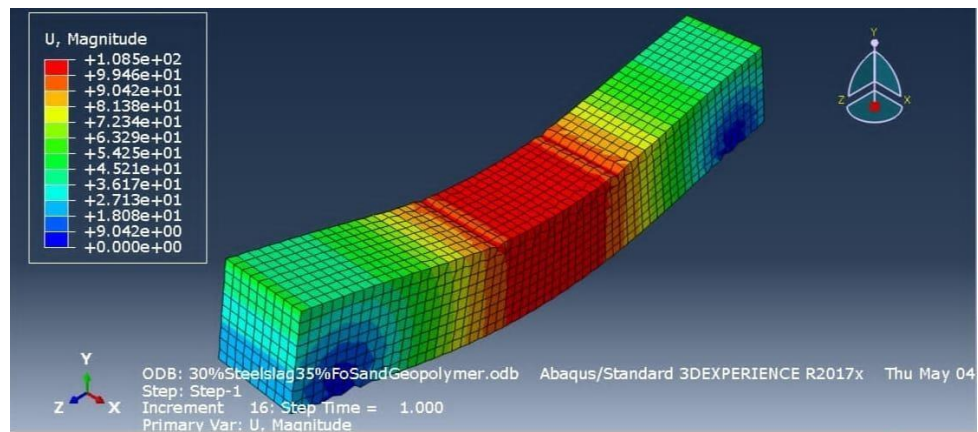
5.3 ANALYTICAL MODEL



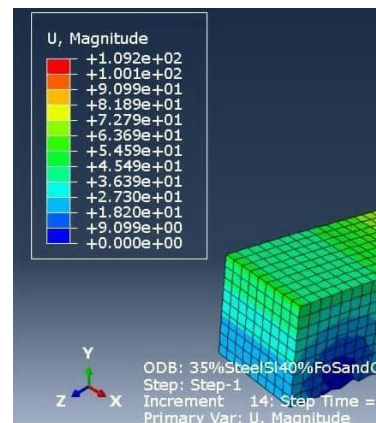
(a)



(b)



(c)



(d)

FIG 5.1 DEFLECTION RESULTS FROM ABAQUS ANALYSIS

5.3.1 Analytical Table

5.1 ANALYTICAL RESULTS FOR 4 BBEAMS

Sl. No	Load (KN)	Displacement in 'mm'			
		GPC	GPC-20% SLAG 25% FOUNDRY SAND	GPC-30% SLAG 35% FOUNDRY SAND	GPC-35% SLAG 40% FOUNDRY SAND
1	10	0.25	0.24	0.18	0.21
2	20	0.32	0.39	0.28	0.35

3	30	0.48	0.52	0.45	0.48
4	40	0.77	0.72	0.73	0.73
5	50	1.02	0.98	0.91	0.97
6	60	1.32	1.11	1.21	1.28
7	70	1.81	1.32	1.28	1.58
8	80	2.10	1.9	1.85	2.04
9	90	2.15	2.21	2.1	2.18
10	100	2.43	2.51	2.40	2.49

CHAPTER 6

RESULT AND DISCUSSION

Based on the compression strength values provided, we can see that mix 1 has the highest compression strength of 27.41 MPa, while mix 2 has the lowest compression strength of 19.18 MPa. Mix 3 and mix 4 have similar compression strength values of 20.22 MPa and 19.48 MPa, respectively.

It's important to note that these are 7-day compression strength values, and concrete typically gains strength over time with proper curing. In general, concrete strength can increase by up to 50% or more between 7 days and 28 days of curing, depending on various factors such as the type of cement used, the water-cement ratio, and the curing conditions.

Therefore, it's possible that the compression strength values of the cubes could increase significantly if tested after 28 days of curing. However, based on the 7-day compression strength values, it appears that mix 1 still has the highest strength, while the other cubes have lower strength values. This suggests that the replaced materials used in the other mix may not be as effective in producing high-strength concrete as the conventional materials used in mix.

At 7 days of curing, the compression strength results are:

Mix 1: 49.03 MPa

Mix 2: 44.50 MPa

Mix 3: 41.50 MPa

Mix 4: 39.41 MPa

At 14 days of curing, the compression strength results are:

Mix 1: 55.60 MPa

Mix 2: 47.80 MPa

Mix 3: 44.48 MPa

Mix 4: 42.68 MPa

At 28 days of curing, the compression strength results are:

Mix 1: 57.80 MPa

Mix 2: 50.16 MPa

Mix 3: 49.89 MPa

Mix 4: 46.00 MPa

From these results, we can see that Mix 1 has the highest compression strength values at all three curing periods, followed by Mix 2, Mix 3 and Mix 4.

It's important to note that these results are specific to the testing conditions and materials used in this particular experiment and may not be representative of all possible variations of these mixes. Other factors such as workability, durability, and cost would also need to be considered when evaluating the effectiveness of each mix for a particular application.

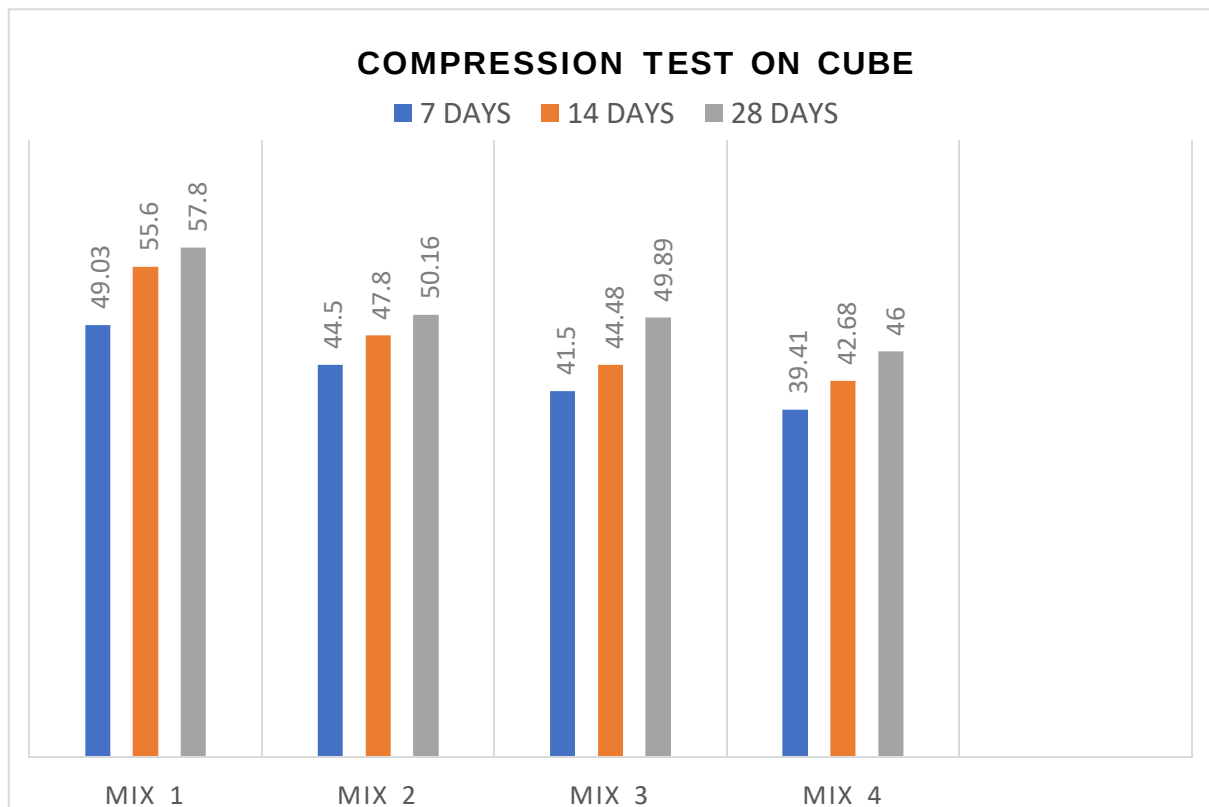


FIG 6.1 GRAPH OF COMPRESSION TEST RESULTS ON CUBE

At 7 days of curing:

Mix 1 (represented by Cylinder 1): 2.87 MPa

Mix 2 (represented by Cylinder 2): 2.66 MPa

Mix 3 (represented by Cylinder 3): 2.43 MPa

Mix 4 (represented by Cylinder 4): 2.34 MPa

At 14 days of curing:

Mix 1: 3.01 MPa

Mix 2: 2.90 MPa

Mix 3: 2.65 MPa

Mix 4: 2.48 MPa

At 28 days of curing:

Mix 1: 3.67 MPa

Mix 2: 3.14 MPa

Mix 3: 2.86 MPa

Mix 4: 2.68 MPa

Based on these results, we can see that Mix 1 has the highest tensile strength values at all three curing periods, followed by Mix 2, Mix 4, and Mix 3.

It's important to note that the tensile strength values are significantly lower than the corresponding compressive strength values, and that concrete is typically stronger in compression than in tension. Therefore, it's important to carefully evaluate the tensile strength values in the context of the specific application and conditions in which the concrete will be used.

Four concrete beams were casted using Mix 1, Mix 2, Mix 3, and Mix 4, respectively. Each beam had a size of 1.5m x 0.23m x 0.23m.

After casting, the beams were cured for 28 days to ensure that the concrete reached its maximum strength potential. Proper curing involves keeping the concrete moist and at a stable temperature to allow for optimal chemical reactions and hydration.

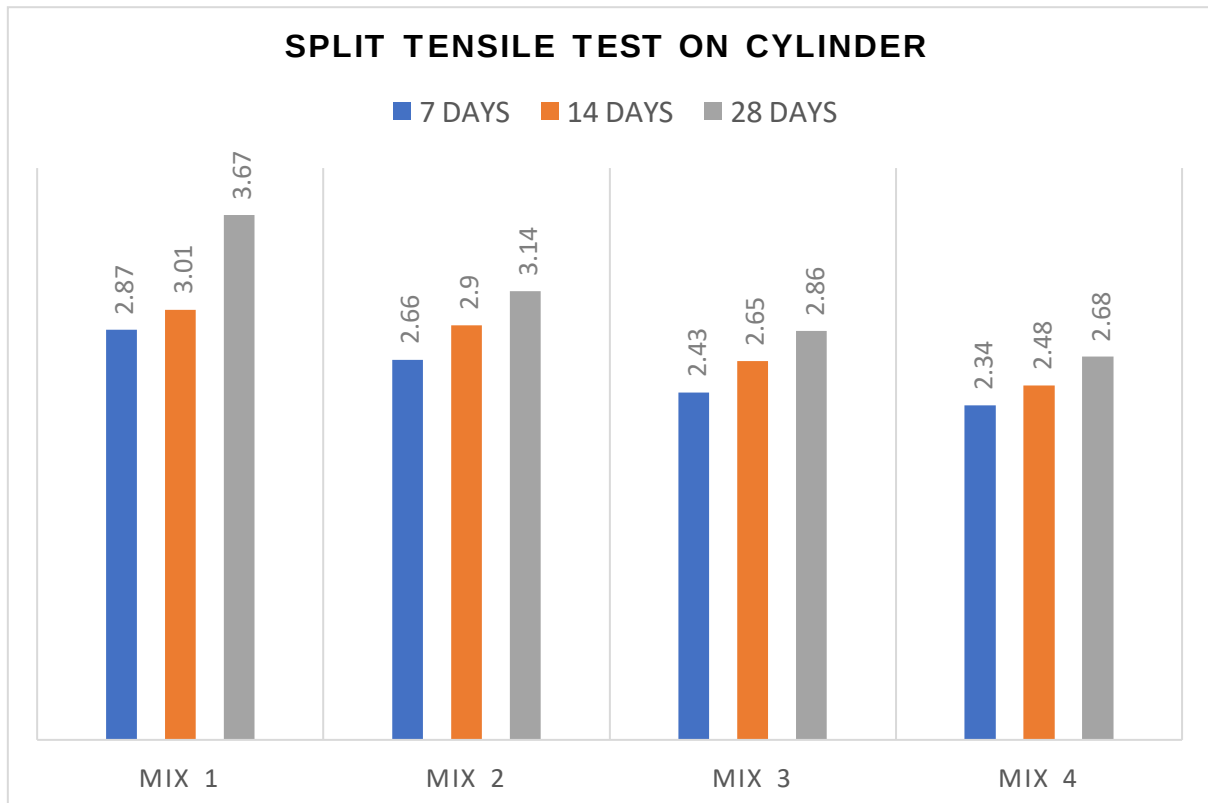


FIG 6.2 GRAPH OF SPLIT TENSILE TEST RESULTS ON CYLINDER

Following the curing period, the beams were subjected to a loading frame test to measure their deflection. During the test, a load was applied to the centre of the beam using a loading frame, causing it to bend or deflect. The deflection of the beam was measured at different load levels, and this data was used to calculate the flexural strength and stiffness of the beam.

It's important to note that the results of the loading frame test can provide valuable information about the performance of the concrete beams under different loading conditions, and can be used to assess their suitability for various structural applications. However, it's also important to consider other factors, such as the type and quality of materials used, the dimensions and shape of the beam, and the curing conditions, when evaluating the strength and durability of a concrete structure.

In summary, the concrete beams were casted using different mixes and cured for 28 days before being tested in a loading frame to measure their deflection. The results of the test can provide valuable information about the flexural strength and stiffness of the beams, which can be used to evaluate their suitability for various structural applications.

The experimental vs analytical rest are represented below.

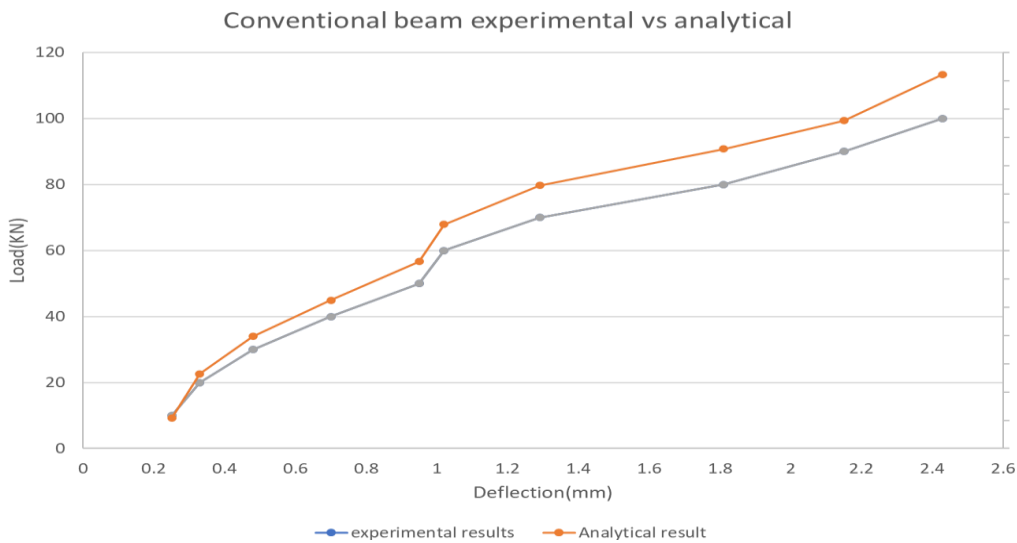


FIG 6.3 GEOPOLYMER M40 EXPERIMENTAL VS ANALYTICAL RESULTS

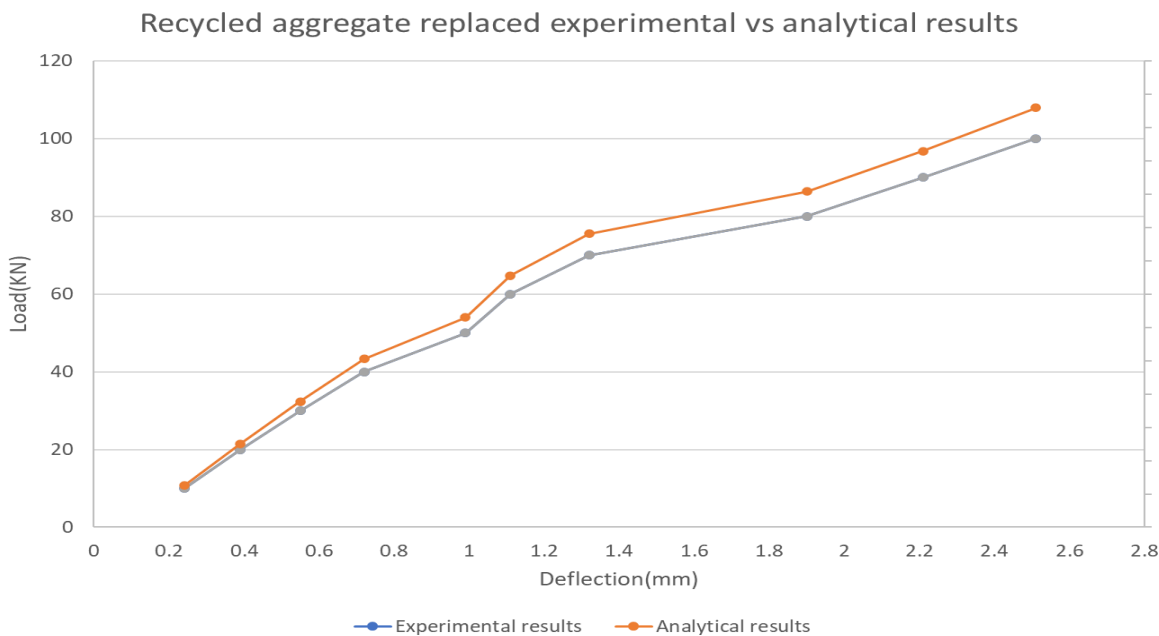


FIG 6.4 GEOPOLYMER M40(20% STEEL SLAG AND 25% FOUNDRY SAND) BEAM EXPERIMENTAL VS ANALYTICAL RESULTS

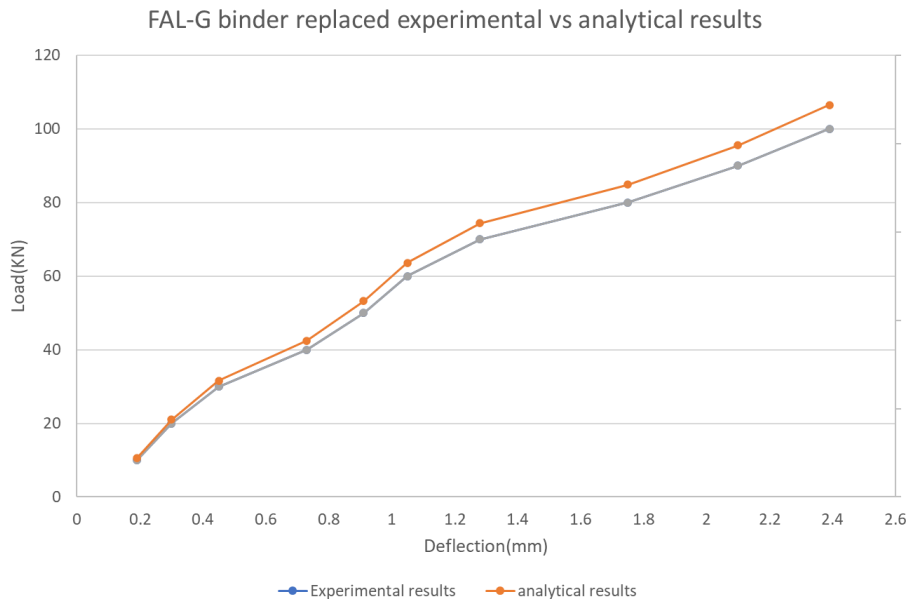


FIG 6.5 GEOPOLYMER M40(30% STEEL SLAG AND 35% FOUNDRY SAND) BEAM EXPERIMENTAL VS ANALYTICAL RESULTS

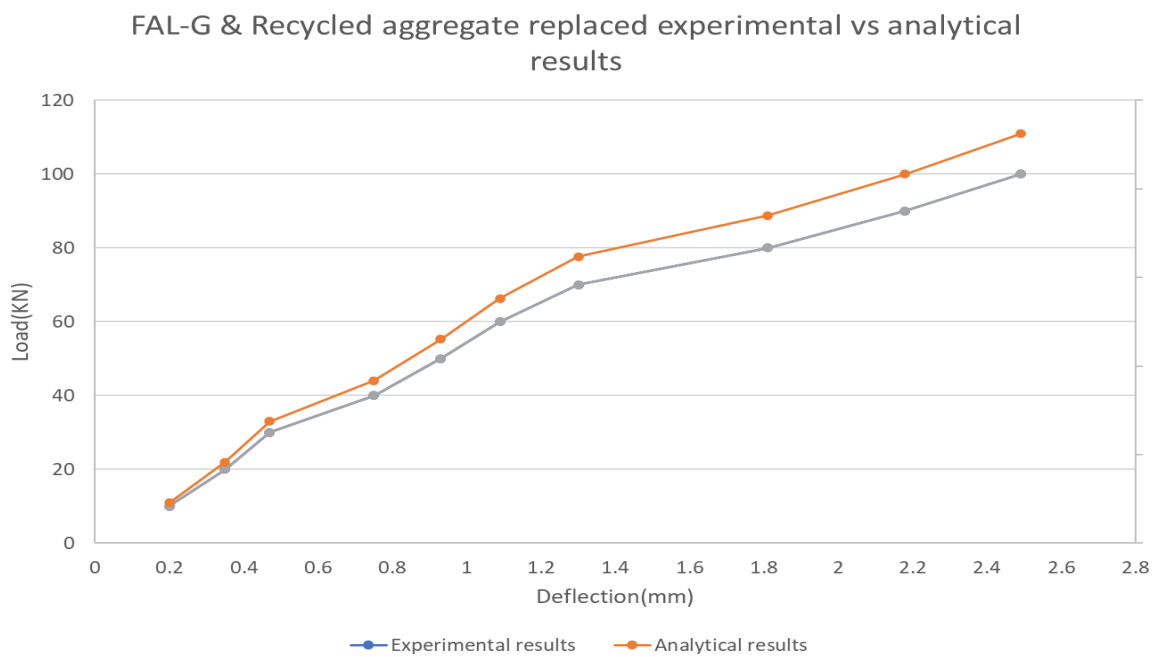


FIG 6.6 GEOPOLYMER M40(35% STEEL SLAG AND 40% FOUNDRY SAND) BEAM EXPERIMENTAL VS ANALYTICAL RESULTS

CHAPTER 7

SUMMARY AND CONCLUSION

7.1 SUMMARY

The study on geopolymer concrete with partial replacement of scrap steel slag as coarse aggregate and foundry sand as fine aggregate is focused on finding an alternative and sustainable solution for the construction industry, as it reduces the amount of waste materials in landfills and decreases the carbon footprint associated with traditional concrete production.

The study focuses on the use of geopolymer concrete, a sustainable alternative to traditional concrete, with partial replacement of scrap steel slag as coarse aggregate and foundry sand as fine aggregate.

The study was conducted by replacing a percentage of coarse aggregate (steel slag) and fine aggregate (foundry sand) with geopolymers, which are materials that have similar properties to traditional concrete but are made from industrial waste materials.

The goal was to investigate the effect of these replacements on the compressive strength and durability of the resulting concrete.

The results of the study showed that the geopolymer concrete with partial replacement of steel slag and foundry sand had comparable strength and durability properties to traditional concrete, while also reducing the environmental impact of construction activities by using waste materials. The study suggests that this alternative approach to concrete production could be a viable and sustainable solution for the construction industry.

The results showed that the geopolymer concrete with 20% steel slag and 25% foundry sand replacement had the highest compressive strength, split tensile strength, and flexural strength, while also exhibiting lower water absorption compared to traditional concrete.

The study suggests that geopolymer concrete with partial replacement of scrap steel slag and foundry sand can be a viable option for sustainable construction practices, as it reduces the amount of waste materials in landfills and decreases the carbon footprint associated with traditional concrete production.

Overall, the study highlights the potential of using geopolymers and waste materials as a substitute for traditional construction materials, contributing to the goal of achieving a more sustainable and environmentally friendly construction industry.

6.2 Conclusion

- The chapter describes a study that compared the properties of Geopolymer concrete made with partial replacement of steel slag as a substitute for conventional coarse aggregate and partial replacement of foundry sand as a substitute for fine aggregate with those of Geopolymer concrete.
- The study examined the hardened properties, flexural behaviour, composition, and microstructural properties of Geopolymer concrete.
- From the materials physical properties test found that the steel slag and foundry sand used in both Geopolymer concrete was suitable for their intended application, based on IS code standards. However, they noted that the water absorption of partial replaced Geopolymer concrete was 7% higher than that of Geopolymer, which is not desirable according to IS code standards. 78
- The study also concluded that replacing 20%, 30% and 35% of the coarse aggregate with steel slag and 25%, 35% and 40% of foundry sand in Geopolymer concrete resulted in a 5% to 10% decrease in compressive and split-tensile strength, respectively, compared to Geopolymer concrete. From the FE-SEM analysis we can conclude that the decrease in strength is attribute to the high air voids, observable cracks, and less dense and compacted surface of the replaced concrete compared to Geopolymer concrete.
- According to the load deflection curve, it can be observed that the experimental deflection values are higher than analytical deflection values up to 60 kN, and the

analytical curve is linear due to undisturbed conditions. On the other hand, the experimental curve is non-linear.

- The experimental investigation indicated that the flexural behaviour of the Geopolymer concrete was influenced by the replacement of steel slag and foundry sand. As the replacement percentage of increases, the deflection value decreased, and the design mix was anticipated to have less deflection.
- The study concluded by noting that the use of steel slag as a coarse aggregate and foundry sand as fine aggregate substitute in Geopolymer concrete not only helps recycle waste materials but also creates new information about the use of Geopolymer concrete as an internal curing agent and producing Geopolymer concrete products with added value.

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