EXPERIMENTAL STUDY OF GEOPOLYMER CONCRETE PRODUCE BY USING ALTERNATE AGGREGATE AND CHEMICAL ACTIVATORS

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Civil Engineering

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DECLARATION

I, hereby, declare that the presented work in the thesis entitled "**Experimental Study of Geopolymer Concrete Produce by Using Alternate Aggregate and Chemical Activators**" in fulfillment of the degree of **Doctor of Philosophy (Ph. D)** is the outcome of research work carried out by me under the supervision of Dr. Anshul Garg, working as Associate Professor, in the School of Civil Engineering of Lovely Professional University, Punjab, India. In keeping with the general practice of reporting scientific observations, due acknowledgments have been made whenever work described here has been based on the findings of another investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled "**Experimental Study of Geopolymer Concrete Produce by Using Alternate Aggregate and Chemical Activators**" submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D)** in the School of Civil Engineering, is a research work carried out by M. Anitha, 41800083, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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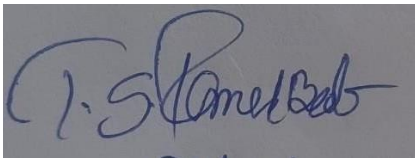

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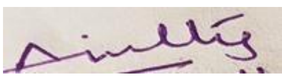

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LIST OF NOTATIONS

%	**----**	**Percentage**
µA	**----**	**Microampere**
µs	**----**	**Microsecond**
ACI	**----**	**American Concrete Institute**
ADP	**----**	**atmospheric depletion**
Al	**----**	**Aluminum**
ASTM	**----**	**American Society for Testing and Materials**
BIS	**----**	**Bureau Indian standards**
Ca	**----**	**Calcium**
CA	**----**	**Coarse Aggregate**
CaO	**----**	**Calcium Oxide**
cm^2	**----**	**Square Centimeter**
CO_2	**----**	**Carbon-di-Oxide**
C-S-H	**----**	**Calcium Silicate Hydrate**
CTM	**----**	**Compression Testing Machine**
E	**----**	**Modulus of elasticity**
EDS	**----**	**Energy-Dispersive X-ray Spectroscopy**
EEC	**----**	**External Exposure Curing**
FA	**----**	**Fine Aggregate**
FLA	**----**	**Fly Ash**
FTM	**----**	**Flexural Testing Machine**
g	**----**	**Gram**
GGBS or GGBFS	**----**	**Ground Granulated Blast Furnace Slag**
GP	**----**	**Geopolymer**

GPC	**----**	**Geo-Polymer Concrete**
GWP	**----**	**global warming potential**
H_2SO_4	**----**	**Sulphuric Acid**
hr	**----**	**Hour**
HTP	**----**	**Human toxicity**
Kg	**----**	**Kilogram**
M	**----**	**Molarity**
M 1	**----**	**Mix/Blend**
m^3	**----**	**Cubic meter**
Max	**----**	**Maximum**
$MgSO_4$	**----**	**Magnesium sulphate**
min	**----**	**Minutes**
mm	**----**	**Millimeter**
MPa	**----**	**Mega Pascal**
N	**----**	**Newton; Normality**
N / mm^2	**----**	**Newton per millimeter square**
Na_2SiO_3	**----**	**Sodium Silicate**
NaOH	**----**	**Sodium Hydroxide**
O	**----**	**Oxygen**
OC	**----**	**Oven Curing**
ODP	**----**	**Ozone depletion**
OPC	**----**	**Ordinary Portland cement**
POF	**----**	**Photochemical oxidants**

QD	**----**	**Quarry Dust**
RCPT	**----**	**Rapid Chloride Penetration Test**
SEM	**----**	**Scanning Electron Microscope**
SF	**----**	**Silica Fume**
TSP	**----**	**Tandur Stone Surry Powder**
UTM	**-----**	**Universal Testing Machine**
WC	**----**	**Water content**

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ABSTRACT

This research investigates the performance of geopolymer Concrete containing Fly Ash, GGBS, and TSP with fractional silica fume replacement as cementitious material and fine aggregate replacement with quarry dust. In the recent past, the importance of geopolymer concrete as an eco-friendly product to replace Portland cement concrete is continuously increasing over time. Yet less research effort has been invested in this area compared with some topical issues in civil engineering. The optimum combination of the above materials has been obtained through trials from the viewpoint of workability and strength. The TSP with SF with three various mixes of GPC as 5%,10% & 15%, and fine aggregate is replaced with quarry dust of GPC as 10%,20%,30%,40%, and 50%. The tests were performed as per the guidelines of "Bureau of Indian Standards." A total of 25 mixes were carried out in this research work with partial replacement of cementitious materials where 150 cubes, 150 cylinders, and 150 beams were cast with different percentages of TSP and fine aggregate. Tests have been performed to assess the mechanical, durability, and micro-structural properties of geopolymer Concrete. Cubes (150 x 150 x 150 mm), cylinders (150X300 mm), and prisms (100 x 100 x 500 mm) were used for determining the compressive strength, flexural strength & split tensile strength of geopolymer Concrete

Cubes (150 x 150 x 150 mm) and disc specimens (100X50 mm) were used for determining the durability properties such as water permeability, RCPT and sorptivity.

Scanning Electron Microscope (SEM) analysis to get the micro-structural properties of the material and Energy Dispersive X-ray Spectroscopy (EDS) analysis to know the material's elemental composition have also been carried out on all concrete mixes.

The experimental investigation gives the idea about the optimal percentage of TSP with SF & recycle aggregates; fine aggregate with quarry dust was used in geopolymer concrete. The compressive strength for the M1S2Q5 mix is 0.46 % higher than that of normal concrete. The flexural strength & split tensile strength of the M1S2Q5 mix were observed to be 1.884% and 0.727%, respectively, compared to normal concrete.

Cost optimization was performed on mixes NC, M1, M1S2, and M1S2Q5, which showed an increase of 23.71% in cost on using optimum mix M1S2Q5; hence, mix M1S2Q5 was used instead of NC.

This work aimed to develop M25 grade GPC mixes under external exposure (EEC) curing conditions utilizing FA, GGBS, SILICA FUME, and TSP.FA, GGBS, and silica fume at 5%, 10%, and 15% of TSP were utilized in the study as the cementitious material to create the GPC. Next, five different percentages of FA were replaced with QD (10%, 20%, 30%, 40%, and 50%).

Tests on water permeability and sorptivity were examined on the performance of GPC combined with FA, GGBS, silica fume, and TSP regarding the durability requirements. The RCPT found that the chloride penetration was increased on the increase of TSP replacement with SF & fine aggregate substituted with quarry dust but comes in a moderate range, which is acceptable.

The SEM & EDS analysis performed on normal concrete, M1, M1S2, and optimized mix M1S2Q5 showed higher strength and composite behavior of optimum mix geopolymer concrete.

The environmental hazards and GPC manufacturing process were recognized, along with potential strategic changes, through a life cycle Assessment. LCA was performed using open LCA software; the production process's environmental effect was assessed in detail, starting with the procurement of source materials and ending with transportation. This work provides a life cycle impact evaluation of recycled aggregate concrete, geopolymer concrete, and OPC concrete using the mid-point approach of the CML 2001 impact-assessment technique. Using OPEN LCA software, the behavior of geopolymer concrete with TSP with silica fume and fine aggregate with quarry dust was examined through software and confirmed for the mixes NC, M1, M1S2, and M1S2Q5. Using the behavior of geopolymer concrete, using OPEN LCA software, TSP with silica fume and fine aggregate with quarry dust was investigated and verified for the mixes NC, M1, M1S2, and M1S2Q5. The GPC's Life Cycle Assessment (LCA) demonstrated a significant decrease in GWP, ADP, and ozone depletion, although the main environmental effects were attributed to using raw materials production. These results emphasized the GPC's environmental benefits and potential to transform sustainable building methods. Proper conclusions have been drawn from the experiment and open-LCA software reliability assessment.

KEYWORDS: Tandur Stone Slurry Powder, Fly Ash, Silica Fume, Quarry Dust, Ground Granulated Blast Furnace Slag.

CHAPTER 1 - INTRODUCTION

1.1 GENERAL

The world's most widely used construction material is concrete. Cement is a major ingredient in concrete. Approximately 7 percent of all greenhouse gases generated globally are thought to be caused by the CO_2 released during the cement-producing process. [12]. Second-largest cement production in the world is India. The production of greenhouse gases during the cement manufacturing process has made it one of the contributors to global warming. Hence, decreasing cement usage is vital, thereby minimizing the carbon footprint [51]. This chapter introduces the thesis, highlighting the issues raised, the necessity for research, and the difficulties encountered while the study was conducted. The study focused on increasing the amount of TSP and recycled aggregate, essentially waste materials whose increased utilization reduces environmental reduction.

Using industry by-products, such as fly ash, GGBS, SF, and Tandur stone slurry powder, as substitutes for cement in concrete production reduces the environmental impact. Incorporating these additional cementitious materials mitigates global warming by decreasing the release of CO_2 into the atmosphere [21]. Fly ash, GGBS, SF, Tandur stone Slurry powder Pozzolanic materials can be directly substituted in blended cement, known as Ordinary Portland Cement. Incorporating fly ash, Ground Granulated Blast Furnace Slag (GGBS), silica fume, and Tandur stone slurry powder pozzolanic materials in geopolymer concrete as cement substitutes deals several benefits, including cost savings, utilization of waste materials to create sustainable concrete, and the preservation of usable land from becoming dumpsites. It also reduces the energy needed for raw material extraction and cement manufacturing.

1.1.1 BACKGROUND OF THE THESIS

Population growth and the increasing need for additional space for living and working are the main causes of the daily increase in construction operations. The growing demand for buildings has resulted in a decreasing daily requirement for construction supplies [1].

1.1.2 GEOPOLYMERS

The geopolymerization cycle is the primary function of a soluble arrangement in geopolymer concrete regularly made of sodium hydroxides and alumina silicates [73], plays a very crucial part in initiating the synthetic reaction between source materials, like flying debris, GGBS, SF, TSP, & an alumina-silicate-rich activator arrangement with this reaction the geopolymer concrete cement results the formation of a three-layered polymeric structure.

The formation of geopolymers includes the formation of binders through a polymerization reaction at high temperatures. In geopolymers, the polymerization cycle develops fewer voids, upgrading the material's mechanical properties and making it more impervious to heat, water penetration, alkali-aggregate reactions, and other forms of chemical degradation [38].

When silica and alumina polymerize in the presence of an alkali-activating solution, an alumino-silicate gel is produced. The binding of loose aggregates in this gel forms three-dimensional amorphous to crystalline polymeric structures, with strong Si-O-Al bonds as the foundation [23]. Source materials include silica and alumina, and the specific technique relies on the types of alkaline activators. Various methods for producing geopolymers have been suggested by diverse research endeavors.

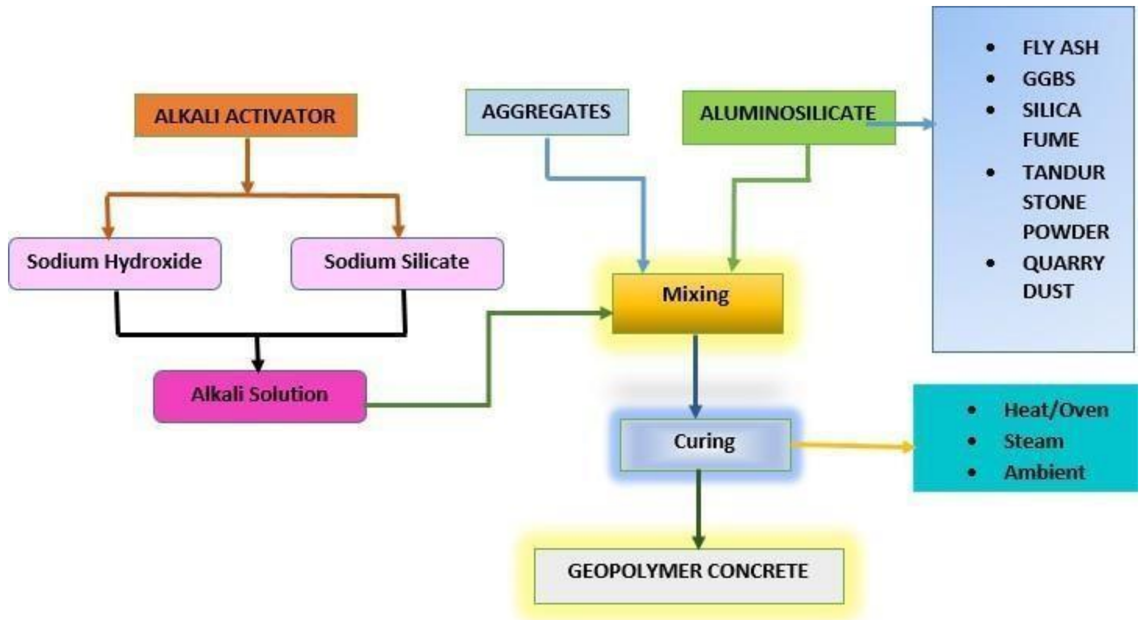

Figure 1.1 Flow Chart of GPC

1.1.3 CURING PROCESS IN GEOPOLYMER CONCRETE

The best methods for producing strength in geopolymer concrete are ambient, oven, and steam curing [92]. During oven and steam curing, geopolymer concrete frequently experiences excessive evaporation. Thus, the specimens are protected with vacuum bagging film. High early-age strength is produced by steam and oven curing; the polymerization process is further accelerated by oven curing. Ambient curing is used for this study to cure the specimens.

Concrete hardening occurs within 24 hours of curing when the room temperature remains below 30°C. Employing ambient curing helps lower construction costs. The use of oven-cured specimens are less common compared to ambient cured specimens due to their higher cost and the challenges they pose during construction.

Research indicates that using TSP and recycled aggregates in geopolymer concrete reduces the material's strength and workability. Hence, the maximum quantity allowed is 25%. It is consequently essential to come up with ways to increase the use of TSP & recycled aggregates. Several constituents that are both cost-effective and capable of enhancing strength have been compared. The ideal combination for “Tandur Stone Slurry Powder” & “quarry dust” is discovered after a thorough investigation into different materials' behavior and suitability for use with Geopolymer concrete. Tandur Stone Slurry Powder and quarry dust are suitable ingredients for Geopolymer concrete, and their combination increases the strength of the concrete, among other things, according to earlier journal research. Thus, a promising way to provide the best strength and economy is to use “Tandur Stone Slurry Powder” & “quarry dust”. The mechanical strengths of “Tandur Stone Slurry Powder” & “quarry dust” in geopolymer concrete with a fracture are examined in this study, including compressive strength, flexural strength & split tensile strength. Optimal blends have been the subject of behavioral and structural investigations. To confirm the optimum Geopolymer concrete mix, software verification is also carried out.

In recent times, recycling waste materials into new construction materials has been a top priority for sustainable building behavior in a number of nations [74]. Several researchers have dedicated their efforts to this task to ensure the qualities of TSP and recycled aggregate, as well as the minimal quantity needed for their usage in Geo polymer concrete. Previous research also demonstrates that TSP and recycled aggregate are effective ingredients in Geopolymer concrete and that using them increases the material's tensile and flexural strengths. The M1S2Q5 mix has the highest compressive, tensile & flexural strength levels compared with other mix types. Maximum strength and efficiency are achieved when using M1S2Q5 mix in geopolymer concrete with TSP and recycled aggregates.

1.1.4 ADVANTAGES OF GEOPOLYMER CONCRETE

Geopolymers are an environmentally friendly replacement for regular Portland cement concrete that shows promise. The production of geopolymer concrete reduces greenhouse gas emissions by almost 80% and decreases energy requirements by 60% [7]. When related to normal cement-based concrete, a number of benefits are there for geopolymer concrete, such as:

1. It has a lower carbon footprint than conventional concrete since less cement is used. Furthermore, it is a more ecologically responsible choice because it frequently includes waste materials or industrial byproducts [38].
2. Geopolymer concrete has better resistance to corrosion, abrasion, and chemical assault, which increases its lifetime and durability.
3. Superior heat resistance is exhibited by geopolymer concrete, rendering it appropriate for use in fire-rated buildings and high-heat settings.
4. Its long-term performance is enhanced, and cracking is often minimized since it exhibits less creep and shrinkage than conventional concrete [30].
5. High early-age and long-term compressive strengths may be achieved by geopolymer concrete, which qualifies it for various structural uses.
6. It provides reduced permeability, enhancing resistance to infiltrating hazardous materials, chemicals, and water.
7. In order to manage trash more effectively and reduce the need for natural resources, geopolymer concrete makes it possible to use a variety of industrial byproducts or waste materials as precursors.
8. It offers more design flexibility and can be customized to meet a given project's needs, enabling the development of creative and environmentally friendly building solutions.

1.1.5 RESEARCH SIGNIFICANCE

A large quantity of energy is needed to produce cement, a major component of concrete, which results in a large consumption of raw materials and a significant emission of greenhouse gases during manufacturing [38]. Therefore, it is essential to use less cement in order to preserve the environment. In this case, fly ash, a thermal power plant by-product; GGBS, a ferrous industry by-product; silica fume, a production of elemental silicon by-product & tandur slurry powder, a polished tandur stone industry by-product, are utilized in the process of developing geopolymer concrete. Fly ash, GGBS, SF & powdered Tandur stone slurry were selected as the main source material because of their easy availability, favorable chemical makeup, and capacity to aid in polymerization.

Ambient curing reduces the requirement for a lot of labor during construction, and geopolymer concrete's quick-setting qualities help shorten construction schedules. Despite its better durability and structural qualities, GPC is not used as much in structural contexts since no mix design process exists.

However, extensive and exhaustive studies must be conducted before introducing novel materials as cement alternatives in the building industry. A thorough evaluation of every aspect of the suggested construction material is required, focusing on in-depth analyses of its durability and structural behavior. The main goal of this study is to create a novel binder from fly ash, GGBS, SF & Tandur stone slurry powder. It also looks at the material's endurance and its structural applications.

1.2 RESEARCH HYPOTHESIS

The M25 grade concrete mix design is the main topic of this study since it is frequently employed in building projects. Thus, the examination of strength requirements for M25-grade concrete is the exclusive focus of this research. Since concrete specimens are intended for structural purposes, they are tested after 28, 56 and 90 days to test their strength.

1.3 RESEARCH OBJECTIVES OF STUDY

This study's primary goal is to investigate the setting behavior & microstructural attributes of geopolymer pastes blended with alkali-activated fly ash (FA), GGBS, SF, and Tandur stone slurry powder. The following tasks were conducted to accomplish this research study, and the following describes the goals of the planned research project:

i) To evaluate the fresh and mechanical properties of geopolymer concrete (GPC) incorporating Tandur Stone Slurry Powder (TSP) and blended quarry dust.

ii) To determine the optimal mix design for durability and conduct a microstructural analysis of GPC produced with TSP and blended quarry dust.

iii) To perform a life cycle assessment (LCA) of GPC utilizing TSP and blended quarry dust as primary materials.

iv) To conduct a cost analysis comparing GPC made with TSP and blended quarry dust to conventional concrete.

1.4 RESEARCH GAP

Research on Geopolymer concrete using natural aggregates is extensively verified and stated, but blended “quarry dust” & “Tandur Stone slurry powder” are not reported.

In recent years, concrete has been required to perform under a wide range of exposure conditions. While standard concrete works well in typical environments, the demands of real-world applications necessitate improved performance. Consequently, engineers have started modifying the properties of concrete to better meet specific needs. Materials such as fly ash, silica fume, alccofine, zeolite, and specialized chemical admixtures have become increasingly popular. Additionally, micro-fillers, including alternatives like quarry dust, Tandur stone powder, and marble dust, are now commonly used in place of traditional aggregates to enhance concrete performance. These fillers improve the density and adhesion at the interfacial transition zone, significantly enhancing the pore structure of the concrete. While most research has focused on standard geopolymer concrete specimens, there has been limited investigation into geopolymer concrete made with alternative aggregates and chemical activators.

1.5 SCOPE

In this study, TSP and recycled aggregates are the two main components. High strength and alkali resistance are among the qualities of TSP and recycled aggregates that may be inserted into a geopolymer concrete matrix. In this configuration, the materials & matrix maintain their individual identities, both physical and chemical, while providing a synergistic quality combination that would be impossible to accomplish with each component functioning alone. Protecting the environment is one of the main issues facing our society today. The utilized waste materials as a consequence of reduced energy & natural raw material consumption are some of the significant characteristics of this technology. Recycled aggregates may be utilized as fine aggregate, and TSP can be used as cementitious materials in part replacement. Influence of the alkali activator on typical geopolymer paste setting & consistency times. Utilizing industrial by-products like FA, GGBS, SF, and TSP to manufacture geopolymer concrete. Experimental studies about fresh, mechanical, and durability characteristics prior to geopolymer concrete and its comparison with traditional concrete. Determining the microstructural properties prior to geopolymer paste & concrete.

This research seeks to examine the setting behavior & microstructural properties prior to geopolymer pastes blended with alkali-activated FA, GGBS, SF, and TSP. various mixes of geopolymer pastes were created by blending different proportions of FA, GGBS, SF, and TSP by sodium hydroxide & sodium silicate serving as per Alkali Activator Solutions. Assessing a hardened property, including compressive strength, split tensile strength & flexural strength, prior to both geopolymer concrete & conventional concrete from different trial mixes. Microstructural analyses using tools like Scanning Electron Microscopy (SEM) & analyses were executed, and the results were presented. Geopolymer Concrete's Life Cycle Assessment is analyzed by using Open LCA software.

1.6 THESIS ORGANISATION

Chapter 1 Introduction deals with the introduction of geopolymers, geopolymerization, geopolymer concrete, and the materials used in this research work. The present study's needs, objectives, Research Gap & scope prior to the study have been documented.

Chapter 2 Literature review contains research-related literature, which is a detailed study of the research done on the two main constituents, TSP and recycled aggregates.

Chapter 3 Research Methodology presents the research flow chart, materials used, instruments, equipment, test methods, preparation of alkali activator solution, and description details of binder combinations. Materials characterization presents a microstructural analysis of source materials, and testing of constituents is presented in detail.

Chapter 4 Results and Discussions on geopolymer paste mixes, presents an investigational experiment of "workability, compressive strength, split tensile strength, flexural strength" and" durability Tests like RCPT, Sorptivity, Water Permeability, microstructural test results of EDS and SEM analysis for different mixes were discussed exhaustively.

Chapter 5 Life Cycle Assessment of Geopolymer Concrete by Using Open LCA Software

Chapter 6 Conclusions and Recommendations, presents a detailed summary of conclusions from this research work & scope of further work.

CHAPTER 2 -LITERATURE REVIEW

2.1 GENERAL

A summary of earlier research on the function, emergence, and performance of Geopolymer concrete is given in this chapter. Subsequently, the succeeding section delves into an in-depth examination of the notable research regarding the Fresh, Mechanical, and Durability properties. Additionally, it thoroughly explores the impact of the material and molarity of the activator, and the review of notable studies conducted in the field of geo-polymer concrete is included in this section of the work. A synopsis of a few research studies using various approaches to the relevant topic has been examined.

2.1.1 GEOPOLYMER CONCRETE STUDIES

A. U. Nisa and P. Singh (2023) conducted an investigation into an economical and environmentally beneficial alternative to traditional cement-based concrete, focusing on geopolymer concrete (GPC). The study explored the potential of using basalt and marble dust as partial substitutes for fly ash in the production of GPC. The research aimed to address the growing concern over waste materials while enhancing the performance and sustainability of geopolymer concrete. The author experimented by replacing varying amounts of fly ash with discarded basalt and marble powder in GPC mixtures at ratios of 25%, 50%, and 75%. The study found that samples made solely with fly ash had an average compressive strength of 30 MPa. In contrast, the addition of 25% basalt and marble powder improved the strength to 31 MPa. The highest compressive strength was achieved when basalt and marble powder were added at a 25% ratio. This result suggests that moderate levels of basalt and marble powder can be beneficial for enhancing the mechanical properties of GPC without compromising the overall performance. Additionally, the study revealed that basalt powder performs particularly well when added at a 50% ratio, showing a 15% improvement in compressive strength compared to the control mix. The rise in basalt and marble waste, however, influenced the ductility and energy absorption properties of the GPC. While the sample with 25% basalt showed a ductility value of 1, the sample containing 50% basalt and marble powder exhibited significantly higher ductility, reaching a value of 2.85. This indicates that higher proportions of basalt and marble powder can enhance the material's ability to absorb energy and improve its overall toughness. However, the study also highlighted that the higher-strength samples typically fractured in a brittle manner, which could be a drawback when considering the material's long-term durability in structural applications. Despite this, the use of basalt and marble waste in GPC presents a promising solution to reduce environmental impact while improving certain mechanical properties of the concrete. In conclusion, Ali İhsan's (2023) research demonstrates that basalt and marble dust can serve as effective, sustainable alternatives to fly ash in geopolymer concrete. The study provides valuable insights into optimizing the ratio of basalt and marble powder to achieve enhanced compressive strength and improved ductility. These findings could lead to more sustainable construction practices by utilizing industrial waste while maintaining or even improving the performance of concrete. Further studies could explore the long-term performance and durability of GPC with these alternative materials [14].

S. Paramasivan et al (2023) conducted an in-depth study to investigate the effects of using Ballast Water Sludge Powder (BWSP) as a partial replacement for Ground Granulated Blast Furnace Slag (GGBFS) in geopolymer concrete. The research focused on examining the impact of BWSP on the properties of geopolymer concrete, particularly its strength and overall performance. BWSP was incorporated at varying replacement levels—20%, 40%, and 60%—in place of GGBFS, which is commonly used in geopolymer mixes to enhance their durability and strength. The study employed different molarity levels (8, 10, 12, 14, and 16) of the alkaline activator solution to assess how the concentration of the activator influenced the behavior of the mix. Among these molarity levels, the 16 molarity alkaline solution yielded the most favorable results, demonstrating its potential to facilitate the activation of both the fly ash (FA) and BWSP in the geopolymer matrix. This configuration allowed for the maximum utilization of BWSP while maintaining the overall integrity of the concrete. The findings revealed that the inclusion of BWSP, even at high substitution levels, did not adversely affect the minimum strength (M25 grade) of the concrete. Specifically, the optimal mix composition was found to be 1:1.32:3.1 (GGBFS: FA: Coarse Aggregate), which demonstrated the best performance in terms of strength and workability. These results suggest that BWSP, when used in combination with a suitable alkaline activator, can be effectively incorporated into geopolymer concrete without compromising the material's structural properties. In conclusion, Paramasivan’s study highlights the potential of BWSP as a sustainable and effective alternative to GGBFS in geopolymer concrete. The research provides valuable insights into optimizing the use of BWSP in concrete mixes, particularly in terms of enhancing the strength and performance of geopolymer concrete while reducing the reliance on traditional industrial by-products. Further investigations into the long-term durability and other mechanical properties of BWSP-incorporated geopolymer concrete could further establish its viability in construction applications [95].

A. C. Ganesh and M. Muthukannan (2021) investigated the impact of incorporating GGBS powder and glass fiber into geopolymer concrete cured under specialized alkaline conditions.

The study emphasized the improved mechanical properties and durability of the geopolymer matrix under these unique curing circumstances. A detailed microstructural analysis was performed using Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS), which provided insights into the composition and structure of the geopolymer matrix. These advanced characterization techniques helped in understanding the bonding mechanisms and overall performance of the material [3].

A. L. Almutairi et al (2021) investigated the chloride permeability of geopolymer concrete in comparison to ordinary Portland cement (OPC) concrete. The study reported a significant reduction in pore length and porosity, along with an increase in tortuosity. These improvements were attributed to the dense microstructure of the (C, N)-A-S-H gel and its coexistence within the matrix. Additionally, the chemical stability of geopolymer concrete under marine conditions was found to provide enhanced and sustainable protection for concrete structures, making it a viable option for durability in harsh environments [11].

G. Jayarajan and S. Arivalagan (2021) conducted a study on the polymerization process in geopolymer concrete using sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) as activators. The research focused on developing M40-grade concrete by partially replacing cement with fly ash and GGBS by weight. The findings demonstrated that the hardened concrete exhibited superior mechanical properties, including enhanced tensile strength and compressive resistance, highlighting the effectiveness of these materials in improving the performance of geopolymer concrete [31].

K. Bakthavatchalam and D. Rajendran (2021) explored the potential of using potassium silicate (K_2SiO_3) **and** potassium hydroxide (KOH) solutions as alkali activators in geopolymer concrete (GPC). Their study focused on the incorporation of a combination of metallic and basalt fibers into the geopolymer matrix, with a fiber content of 2% by volume. The choice of potassium-based alkali activators, specifically 12 M KOH solution, is notable for its high reactivity, which enhances the geopolymerization process, allowing for a more efficient activation of the aluminosilicate materials, such as fly ash or slag, used in geopolymer concrete. The use of basalt fibers is significant due to their natural durability, high resistance to chemical attack, and good thermal properties. The research found that the hybridization of basalt and metallic fibers in the geopolymer matrix resulted in a synergistic effect, wherein the combined fibers worked together to significantly enhance the toughness, ductility, and compressive strength of the geopolymer concrete. The fibers not only helped in increasing the flexural strength of the concrete but also improved its impact resistance and ability to withstand cracking under stress. This effect was particularly evident in scenarios involving high tensile stress or dynamic loading conditions, where the fibers played a crucial role in distributing the stress and preventing the formation of large cracks. Authors provides valuable insights into the benefits of combining potassium silicate and KOH as alkali activators, along with hybrid fiber reinforcement, to enhance the mechanical and durability properties of geopolymer concrete. These findings contribute to the ongoing research aimed at making geopolymer concrete a more viable alternative to traditional concrete, especially in applications requiring high-performance materials with improved toughness, durability, and sustainability [53].

K. Singh and P. Thakur (2020) investigated the development and performance of geopolymer concrete incorporating metakaolin and bagasse ash as supplementary materials. The study focused on fly ash-based geopolymer concrete, where bagasse ash and metakaolin were added in varying proportions of 10%, 20%, 30%, and 40% by weight. Key aspects, including the microstructure, mechanical properties, and durability characteristics of the concrete, were examined. The findings highlighted the influence of these additives on the performance of geopolymer concrete, providing insights into optimal material combinations for enhanced strength and durability [60].

M. Wasim et al (2021) study offers a detailed review of GPC's durability and its application in reinforced concrete, providing valuable insights into the material's long-term performance and resilience. The evaluation highlights the potential benefits of using GPC, especially in terms of its enhanced microstructural properties and ability to improve the durability of reinforced concrete structures. In conclusion, Wasim's (2021) research contributes significantly to the understanding of GPC's durability, offering a thorough analysis of its microstructure and its application in reinforced concrete. This study supports the idea that GPC is a promising material for improving the longevity and performance of concrete structures, particularly in demanding environmental conditions [71].

A. Hassan et al (2020) analyzed the behavioural performance of reinforced geopolymer concrete structural elements. The study provided a comprehensive overview of the mechanical properties and performance of enhanced geopolymer concrete components, highlighting their strength, durability, and potential for structural applications. The findings underscored the effectiveness of geopolymer concrete as a sustainable and reliable alternative to traditional construction materials, the study explored the long-term performance of reinforced geopolymer concrete elements, suggesting that these materials offer excellent potential for structural applications in building and infrastructure projects. The authors concluded that geopolymer concrete could be effectively used in a variety of construction scenarios, including high-rise buildings, bridges, and industrial floors, where strength and durability are paramount. The research provided compelling evidence of the effectiveness of geopolymer concrete in reinforcing structural components, offering a reliable alternative to traditional materials while simultaneously addressing environmental concerns [7].

Das et al. (2020) explored the impact of silica fume and lime content on the properties of geopolymer concrete (GPC). The study revealed that an increase in silica fume content led to higher slump and extended setting times, while higher lime content resulted in a decrease in both slump and setting times. The optimal compressive strength was achieved with a mix that included 7.5% lime and 2% silica fume as partial replacements for fly ash. Microstructural analysis demonstrated that the combination of lime and silica fume contributed to a denser microstructure, thereby improving the overall performance of the GPC. The study emphasized the crucial role of these materials in enhancing both the workability and mechanical properties of geopolymer concrete [27].

H. Wang et al (2020) investigated the overall performance of geopolymer concrete (GPC) under triaxial stress conditions. The study examined axial strain and stress, monotonic and cyclic constitutive relationships, failure modes, and mechanical properties. Comprehensive analysis of GPC behavior under triaxial stress states provided valuable insights into its performance and potential applications in various structural scenarios [38].

R. R. Bellum et al (2020) compared the mechanical properties and durability characteristics of graphene-modified fly ash and GGBFS-based geopolymer concrete with conventional control mixes cured at room temperature. The study focused on key properties, including the modulus of elasticity, chloride permeability, and compressive strength. The results demonstrated that the incorporation of graphene into the geopolymer matrix enhanced the compressive strength and reduced chloride permeability, thereby improving the concrete's overall durability. Additionally, the graphene-modified geopolymer concrete exhibited a higher modulus of elasticity compared to the control blends, indicating improved stiffness and structural performance [86].

S. Mesgari et al (2020) compared the properties of Portland cement concrete (PCC) and geopolymer concrete containing varying percentages of recycled coarse geopolymer aggregates (0%, 20%, 50%, and 100% replacement of natural coarse aggregates) to Portland cement concrete with recycled Portland cement concrete aggregates. The study focused on assessing key mechanical properties, such as compressive strength, workability, and durability. The results indicated that geopolymer concrete with recycled geopolymer aggregates showed comparable or improved performance compared to traditional PCC containing recycled Portland cement concrete aggregates. The study highlighted the potential of using recycled geopolymer aggregates as a sustainable alternative in concrete production, contributing to waste reduction and enhancing the environmental footprint of concrete construction [93].

S. Nagajothi and S. Elavenil (2020) conducted a comprehensive review on the experimental and predictive studies that explore the mechanical characteristics of aluminosilicate materials such as fly ash (FA) and ground granulated blast furnace slag (GGBS), which are commonly utilized in the production of geopolymer concrete (GPC). Geopolymer concrete, a sustainable and environmentally friendly alternative to conventional Portland cement concrete, has gained widespread attention for its ability to reduce greenhouse gas emissions, enhance the durability of structures, and utilize industrial by-products. The study presented a thorough investigation into the potential of fly ash and GGBS as key contributors to improving the mechanical performance, durability, and long-term sustainability of geopolymer-based concrete. The findings of the study underscored the effectiveness of these materials in enhancing the overall performance of fully geopolymer-based concrete, contributing to the development of high-strength, durable, and eco-friendly concrete alternatives [94].

W. Prachasaree et al. (2020) conducted an in-depth evaluation of the mechanical properties of geopolymer concrete, particularly focusing on the relationship between compressive strength and modulus of elasticity. Their study reported a strong correlation between the two properties, with an R^2 value of 85%, indicating a high degree of accuracy in predicting strength behavior across different compressive strength levels. This suggests that geopolymer concrete exhibits consistent and reliable mechanical performance, making it suitable for structural applications. The findings from authors reinforce the mechanical reliability of geopolymer concrete, with a strong MOE-compressive strength correlation (R^2 = 85%), making it a viable alternative to OPC concrete in structural applications. Further research is needed to refine prediction models, incorporating additional factors such as long-term durability, creep, and shrinkage behavior to enhance its practical usability [107].

Y. Cui, K. Gao, and P. Zhang (2020) analysed the statistical relationships between the mechanical properties of geopolymer concrete primarily composed of Class F fly ash (CFGPC). The study experimentally examined and presented data on compressive strength, modulus of elasticity, and indirect tensile strength of CFGPC samples. Special emphasis was placed on the tensile strength characteristics of these samples, providing critical insights into the behavior of CFGPC [109].

B. S. Mohammed et al (2019) examined the performance of concrete in meeting diverse requirements, including high strength, the incorporation of secondary materials, reduced carbon footprint, minimal greenhouse gas emissions, and improved frost resistance. The study highlighted the potential of innovative concrete designs to address environmental concerns while maintaining superior mechanical and durability properties, thereby promoting sustainable construction practices. The findings of this research underscore the importance of adopting sustainable construction practices that not only reduce the environmental footprint of concrete but also enhance its mechanical and durability characteristics. By utilizing alternative binders and secondary materials, such as fly ash, slag, and silica fume, concrete can be made more environmentally friendly without compromising its structural performance. This study thus contributes to the growing body of knowledge on sustainable concrete technologies and reinforces the importance of developing concrete mixes that balance both environmental concerns and performance requirements, paving the way for more sustainable construction practices in the future [17].

G. Mallikarjuna Rao et al (2019) conducted a crucial study on the effects of temperature on the mass and compressive strength of concrete. Concrete is one of the most widely used materials in construction, and understanding how it behaves under varying temperature conditions is essential to ensuring its performance and longevity. The study investigated how different temperatures influence the material properties of concrete, particularly focusing on how both mass and compressive strength are affected as the temperature increases [34].

H. Y. Zhang et al (2018) this study focused on the flexural behavior of geopolymer concrete by varying tensile reinforcement percentages and compressive strength while maintaining the same cross-section. The findings reported the formation of initial cracks, service, and ultimate load stages, showcasing improvements in compressive strength and tensile reinforcement. The focus of the study was to understand the interplay between two key parameters—tensile reinforcement and compressive strength—and their combined effect on the flexural behavior of the concrete. Concrete's inherent weakness in tension makes the incorporation of reinforcement essential for improving its load-carrying capacity. The inclusion of steel reinforcement serves to counterbalance the tensile forces, which are a critical consideration for any structural member subjected to bending or flexural loading. However, in the case of geopolymer concrete, the behavior under flexure can be influenced by several factors unique to the material, such as the type of alkali activator used, the degree of polymerization, and the microstructural properties of the geopolymer matrix [39].

U. K. Danda et al (2019) conducted a study on the mechanical properties of geopolymer concrete, focusing on the impact of varying molarity levels of the alkaline solution. The research aimed to understand how changes in molarity influence the material's workability, strength, and resistance to environmental factors. The study revealed that as the molarity of the alkaline solution increased, the workability of the geopolymer concrete decreased proportionally. This reduction in workability was attributed to the higher viscosity of the alkaline solution at increased molarity levels.

In terms of mechanical performance, the study found that the split tensile strength and flexural strength exhibited a proportional relationship with the compressive strength of the geopolymer concrete. As the molarity of the alkaline solution increased, the compressive strength of the concrete also improved, leading to higher split tensile and flexural strengths. This indicates that increasing the molarity of the activator solution positively influences the overall mechanical energy of the material.

Furthermore, the research demonstrated that higher molarity levels enhanced the concrete's resistance to corrosive environments. Geopolymer concrete with higher molarity showed improved resistance to chemical ingress and water penetration, making it more durable in harsh conditions. These findings suggest that increasing the molarity of the alkaline solution not only improves the mechanical properties of geopolymer concrete but also enhances its ability to withstand environmental degradation [102].

C. Gunasekara et al (2018) the study analyzed the penetration characteristics of four distinct FA- GPCs. It was observed that a significant presence of coarse particles in fly ash led to uneven gel distribution, reducing pore-filling capacity. The mesopore quantity (diameter ~1 µm) was found to govern air and water permeability in GPC [18].

C.-K. Ma et al (2018) the research examined the material and structural properties of geopolymer concrete. The findings highlighted superior mechanical qualities, enhanced durability, and better visual performance compared to conventional concrete. The study recommended further structural research to validate the practical implementation of geopolymer concrete [21].

L. N. Assi et al (2018) this study evaluated the impact of fly ash from different sources and particle size distributions on geopolymer concrete. It was concluded that reducing the particle size of fly ash led to decreased permeability, void ratios, and absorption ratios, influenced by the source of the fly ash [65].

P. S. Deb and P. K. Sarker (2017) presented an in-depth analysis of the recent advancements and perspectives on Ultra-High Performance Geopolymer Concrete (UHP-GPC), focusing on both technical and production aspects. The study explored various factors influencing the performance of UHP-GPC, including environmental considerations, mix design, and mechanical properties. It provided a comprehensive review of the fresh and hardened state characteristics of UHP-GPC, along with its dynamic properties, strain- hardening behaviour, and durability.
The research delved into the relationship between the compressive strength of UHP-GPC and its elasticity and splitting tensile strength modules (Modulus of Elasticity - MoE). Qaidi's analysis revealed that the compressive strength is closely linked to both the elasticity and tensile strength of the material, highlighting the importance of optimizing mix design to achieve desired performance outcomes. Furthermore, the study examined the microstructural features of UHP-GPC, emphasizing how these properties contribute to its exceptional mechanical performance and durability. The incorporation of advanced production techniques and materials was identified as key to improving the performance of UHP-GPC, particularly in terms of its resistance to environmental factors and long-term stability. In conclusion, Qaidi's (2022) article provides a comprehensive overview of the latest developments in UHP-GPC, integrating various technical, environmental, and performance-related aspects. The research underscores the potential of UHP-GPC as a high-performance, sustainable material for construction, emphasizing the importance of continued innovation in mix design and production methods to enhance its mechanical and durability properties [82].

V. Keerthy and Y. H. Kumar (2017) investigated the use of ground granulated blast furnace slag (GGBS) as a binding material in reinforced geopolymer concrete columns (RGPC). The study utilized alkali activators, including sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH), to transform GGBS into an effective binder. The findings emphasized the role of chemical activators in enhancing the binding properties of GGBS, demonstrating its suitability for use in RGPC and its potential for sustainable construction applications, the study by Keerthy and Kumar provided compelling evidence that GGBS can be effectively used as a binder in reinforced geopolymer concrete. The findings highlighted the material's mechanical properties**,** sustainability**,** and durability, suggesting that RGPC made with GGBS has significant potential for future construction applications, especially in sustainable and high-performance building projects. This research contributes to the growing body of knowledge on the use of geopolymer concrete as a sustainable alternative to traditional concrete and opens up new avenues for the utilization of industrial by-products in construction [105].

K. T. Nguyen et al (2016) conducted a comprehensive analysis of geopolymer concrete beams, focusing on mechanical properties such as modulus of elasticity, Poisson's ratio, stress-strain relationships, and tensile strength. The study utilized finite element models, elastic theory, and four-point bending tests to assess behavior, concluding that geopolymer concrete exhibited lower elastic modulus but comparable stress-strain behavior to conventional concrete [64].

P. Topark-Ngarm et al (2016) conducted an investigation into the sulfate resistance of ground blast furnace slag (BA) geopolymer mortars with three distinct fineness levels—fine, coarse, and medium. The mortars were immersed in a 5% sodium sulfate solution for a period of 240 days to evaluate their resistance to sulfate attack. The findings of the study revealed that all of the BA geopolymer mortars exhibited superior resistance to sodium sulfate compared to conventional Portland cement (PC) mortars. This enhanced resistance was attributed to the stable cross-linked aluminosilicate polymer structure present in the geopolymer mortars, which is more durable and less susceptible to degradation than the traditional hydration products formed in PC mortars. The study highlighted that the improved stability and chemical resistance of geopolymer mortars make them a viable alternative to conventional concrete, especially in environments prone to sulfate attack [84].

A. Castel and S. J. Foster (2015) the bond strength of geopolymer concrete using smooth and deformed steel bars was examined. Geopolymer concrete made of 14.8% GGBFS and 85.2% low-calcium FA demonstrated improved bond strength under heat-curing conditions. On average, bond strength improved by 10% compared to OPC concrete for the same compressive strength [4].

G. Lavanya and J. Jegan (2015) conducted a study on the structural behavior of Geopolymer Concrete (GPC) beams, investigating key characteristics such as fresh properties, elastic modulus, flexural strength, splitting tensile strength, and compressive strength. The research aimed to assess the overall performance of GPC beams and compare them with traditional concrete composites.

The findings from the study concluded that GPC outperforms conventional concrete in both mechanical and fresh properties. GPC demonstrated superior strength characteristics, including higher flexural and splitting tensile strengths, as well as a comparable or better elastic modulus and compressive strength when compared to standard concrete. This suggests that GPC beams are not only effective but also have enhanced structural properties, making them a viable alternative in construction. Lavan also emphasized that GPC can be safely utilized in the production of concrete members, meeting recognized professional standards for physical strength. The study highlighted the potential for GPC to be used in various structural applications, providing a more sustainable and efficient solution without compromising safety or performance. In conclusion, Lavan's (2022) study reinforces the advantages of Geopolymer Concrete in terms of both mechanical properties and structural behavior. The research indicates that GPC beams offer significant improvements over traditional concrete composites and can be used reliably in structural applications, further supporting the case for GPC as a viable material for sustainable construction [32].

M. W. Hussin et al (2015) Aamer Rafique Ariffin's study investigated the performance of Unified Ash Geopolymer (BAG) concrete, which utilized palm oil fuel ash and lignite pulverized exposed fuel ash. The study exposed the concrete samples to a 2% sulfuric acid solution for over a year to assess their durability and compared the results with traditional Ordinary Portland Cement (OPC) concrete. The findings revealed that the geopolymer concrete exhibited superior stability due to the formation of a cross-linked aluminosilicate polymer structure during the geopolymerization process. This structure enhanced the overall durability of the concrete, making BAG-based geopolymer concrete more stable and preferable to OPC concrete under sulfuric acid exposure [70].

P. Topark-Ngarm et al (2015) this research explored the bonding, strength, and setting time of high-calcium FA geopolymer concrete. Using 15 M NaOH, the study achieved a high-strength geopolymer concrete with a 28-day compressive strength of 54.4 MPa. The modulus of elasticity was comparable to PC concrete, with the study emphasizing the potential of high-calcium FA in producing high-strength GPC [84].

J.-S. Kim and J. Park (2014) Kim conducted an investigation utilizing pullout tests to evaluate the bond strength and growth duration of steel reinforcements embedded in geopolymer concrete (GPC). The study involved testing 27 specimens, which comprised three different types of GPC, reinforcing bars with diameters of 10 mm, 16 mm, and 35 mm, and compressive strengths of 20 MPa, 30 MPa, and 40 MPa. The experiments adhered to the EN 10080 standard. The results revealed that bond stresses in GPC decreased as the diameter of the embedded reinforcement increased, regardless of the compressive strength of the concrete. This study provided insights into the performance of reinforced GPC under varying conditions [50].

P. Chindaprasirt and W. Chalee (2014) conducted a study to investigate the strength characteristics of geopolymer concrete with the combined effect of fly ash (FA), focusing on how the properties of the mix were influenced by the type and concentration of alkaline activators, such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The research specifically explored the impact of these activators on the workability and strength of geopolymer mortar, particularly in mixes incorporating high-calcium lignite fly ash. The study revealed that the concentrations of sodium hydroxide and sodium silicate played a crucial role in affecting the flow of the coarse fraction in geopolymer mortar. An increase in the concentrations of NaOH and sodium silicate led to a decrease in the flowability of the mortar. This suggested that higher concentrations of alkaline activators resulted in a more viscous mixture, which negatively impacted workability. To counteract this reduction in flow, superplasticizers (SP) or additional water were introduced to improve the workability of the mix. However, the addition of a superplasticizer, although it enhanced the flow properties, was found to negatively affect the strength of the geopolymer. The strength reduction could be attributed to the interaction between the superplasticizer and the geopolymer matrix, which may have interfered with the proper geopolymerization process or reduced the bonding strength of the material. Overall, the findings of Chindaprasirt highlight the delicate balance between improving workability and maintaining the desired strength in geopolymer concrete. The study provides valuable insight into the effects of alkaline activators and additives such as superplasticizers on the properties of geopolymer mortar, guiding future mix design strategies for optimizing both performance and ease of handling in practical applications [78].

S. Luhar (2014) investigated the acid resistance of fly ash-based geopolymer concrete in comparison to OPC concrete. Their study revealed that OPC concrete exhibited a 3.4% higher weight lo**ss** when exposed to acidic environments, accompanied by strength losses of 4.51% and 2.74% more than FA-based activated concrete. These findings highlight the superior durability of geopolymer concrete in acidic conditions. The enhanced resistance was attributed to the low calcium content and the formation of a dense aluminosilicate gel (N-A-S-H or C-A-S-H), which provides a more stable and impermeable microstructure. The findings from author, along with supporting studies, establish FA-based geopolymer concrete as a durable and sustainable alternative to OPC concrete in acid-prone environments. The superior acid resistance, stemming from its calcium-deficient composition and dense geopolymer matrix, makes it a promising material for enhancing the longevity of concrete structures [92].

S. K. Nath et al (2014) the study focused on the early-age properties of FA-based geopolymers with the incorporation of GGBS up to 30% of the total binder. The research demonstrated that increasing the GGBS content reduced the workability and setting time of the geopolymer mixtures. The optimal performance was observed in combinations containing 10% slag, 40% chemical activator, and a Na_2SiO_3/NaOH ratio between 1.5 and 2.5, without the addition of extra water. These conditions produced the most effective geopolymer formulations in terms of early-age characteristics [90].

T. Ostwal and M. V. Chitawadagi (2014) the study examined the influence of the alkaline solution-to-binder ratio at an 8M molarity on the properties of geopolymer concrete. The findings indicated that geopolymer concrete blocks exhibited higher strength under ambient curing conditions. Additionally, the research extended to evaluate the economic and sustainability impacts of using geopolymer concrete blocks, highlighting their potential as a sustainable alternative to traditional concrete [100].

A. Nazari et al (2012) conducted a study to examine the water absorption characteristics of geopolymers produced from rice husk-bark ash and seeded fly ash (FA). The study focused on understanding how various factors, including the particle size distribution of the ash, the baking duration of the ashes, and the exposure time of the samples at room temperature, influenced the water absorption and pore volume of the geopolymer specimens. The findings revealed that the particle size of the ash played a significant role in the material's density, with smaller ash particles leading to denser specimens. This densification resulted in reduced pore volume and enhanced resistance to water permeability. Additionally, the study identified that the specimens exhibiting the best resistance to water permeability had a SiO_2/Al_2O_3 ratio of 2.99. This ratio was found to be a key factor in improving the geopolymer's overall performance in terms of water absorption and permeability resistance [13].

D. V. Dao and J. P. Forth (2013) developed a geopolymer material derived from waste sources rich in aluminum (Al) and silicon (Si) to serve as a sustainable alternative to conventional concrete. Geopolymers, identified as eco-friendly and durable synthetic composite polymers, were created by replacing traditional Portland cement with materials such as fly ash, ground granulated blast furnace slag (GGBS), silica fume, metakaolin (MK), rice husk ash (RHA), and other alumino-siliceous compounds. These materials were activated under alkaline conditions using solutions like NaOH, KOH, Ba(OH) , and LiOH. GGBS, MK, and RHA were utilized as supplementary cementitious materials (SCMs) in the geopolymer concrete to enhance its binding properties and environmental sustainability [26].

S. Kumaravel and S. Thirugnanasambandam (2013) conducted an experimental study to evaluate the resistance of Geopolymer Concrete (GPC) to sulfuric acid attack. The study involved preparing GPC specimens with different sodium hydroxide (NaOH) molarity levels, specifically 8, 10, 12, and 14 M, to assess their behaviour under sulfuric acid exposure. The specimens were exposed to 0.5%, 1%, and 2% concentrations of H_2SO_4, and their weight reduction was monitored. The results indicated a slight weight reduction in the GPC samples, with 0.91%, 1.21%, and 1.36% reductions observed for the 0.5%, 1%, and 2% H_2SO_4 concentrations, respectively. In terms of compressive strength, the study revealed that GPC specimens with 12 M NaOH showed reductions of 3.7%, 8.59%, and 16.7% under the same acid concentrations. These findings suggest that while GPC exhibits some resistance to sulfuric acid, the strength and durability of the material decrease progressively with increasing acid concentration [91].

Sreevidya et al (2012) investigated the resistance of geopolymer concrete (GPC) to acidic environments by exposing specimens to 5% hydrochloric acid (HCl) and 5% sulfuric acid (H_2SO_4) for a period of 14 weeks. The study observed a gradual decrease in weight loss in all specimens as the water-to-binder ratio increased. This suggests that higher water content in the binder improved the GPC's resistance to acid attack, likely by enhancing the material's structural integrity and reducing the rate of degradation. The results highlighted the importance of the water-binder ratio in enhancing the durability of GPC when exposed to aggressive chemical environments, particularly sulfuric and hydrochloric acids [99].

B. Li et al. (2011) investigated the significance of Methylene Blue Value (MBV) as an important indicator of the quality of manufactured sand (MS). The study explored the relationship between the MBV of manufactured sand and its clay content, fine stone content, and the properties of the clay. The authors concluded that the MBV of MS was primarily influenced by the amount of clay present, rather than the concentration of fine limestone particles. The findings indicated that as the clay content in MS increased, the MBV value also increased, which negatively impacted the material's workability and compressive strength at 7 days. However, it was observed that the flexural strength of the MS decreased when the MBV increased. Despite the reduction in early compressive strength, the 28-day compressive strength remained largely unaffected. Furthermore, the study also explored the use of manufactured sand (MS) in the production of micro-expansive Self-Compacting Concrete (SCC) with a C60 grade, aiming to meet the specifications required for the construction of steel tube arches filled with concrete. The research involved incorporating varying concentrations of lime quarry fines (3%, 7%, and

10%) into MS-SCC mixes. These mixes were compared with a conventional natural sand (NS)-based SCC mix. The results revealed that the MS-SCC mix with 7% lime quarry fines performed exceptionally well, surpassing the performance of the NS-SCC mix in terms of workability, compressive and splitting strength, modulus of elasticity, restrained expansion, chloride ion permeability, and freeze-thaw resistance. This study highlighted the potential of MS as a viable alternative to natural sand, particularly for specialized concrete applications where high-performance characteristics are required [16].

G. Liu, Z. Chen, and X. Chen (2011) conducted a study investigating the performance of C30 concrete containing synthetic sand under freeze-thaw cycle conditions. The study aimed to assess the impact of different environmental stresses, such as acid corrosion, alkali corrosion, and freeze-thaw cycles, on the properties of concrete. The investigation specifically focused on evaluating the bulk properties, strength, and dynamic relative elastic modulus of the concrete mixtures during exposure to these harsh conditions. The experimental procedure involved subjecting concrete samples to freeze-thaw cycles in conjunction with acid and alkali corrosion. The findings revealed a significant deterioration in the concrete's properties as the number of freeze-thaw cycles increased. Specifically, the concrete's bulk, strength, and elastic modulus decreased notably as the number of freeze-thaw cycles increased. Additionally, the study highlighted a pronounced decline in the acid and alkali resistance of the concrete containing synthetic sand. The deterioration was more severe in terms of acid resistance, with the anti-acid capability showing a more rapid decline compared to alkali resistance. The research concluded that the presence of synthetic sand in concrete had a detrimental effect on its performance under freeze-thaw conditions, particularly in terms of durability against acid and alkali attacks. This finding underscores the need to carefully consider the use of synthetic sand in concrete mixes for applications exposed to aggressive environmental conditions, as freeze-thaw cycles can significantly reduce the longevity and durability of the material [33].

K. Ramujee and M. Potharaju (2011) conducted an investigation into the mechanical properties of Geopolymer Concrete Composites (GPCC), which incorporate alkaline liquids, 10% Ordinary Portland Cement (OPC), and 90% Fly Ash (FA). The study primarily aimed to understand the effects of replacing a portion of fly ash with OPC in the geopolymer mix and its influence on various mechanical properties, including density, split tensile strength, compressive strength, flexural strength, and the behavior under heat-cured conditions (specifically 60°C for 24 hours in a hot air oven).The author found that the inclusion of 10% OPC in the mix, replacing a corresponding amount of fly ash, had a noticeable impact on the mechanical characteristics of the geopolymer concrete. The tests revealed that the composite's compressive strength, flexural strength, and split tensile strength were significantly improved by the addition of OPC. In particular, the heat curing process enhanced the mechanical properties of the GPCC, as the elevated temperature facilitated the geopolymerization reaction, leading to better consolidation and stronger bonding of the materials. Moreover, empirical formulas were developed from the experimental data to predict the split tensile and flexural strengths of GPC and GPCC based on the measured compressive strength. These formulas offered a valuable tool for understanding the relationship between the different mechanical properties of the composite concrete and could be used to optimize the mix design for specific applications. Overall, the study concluded that the partial replacement of fly ash with OPC in geopolymer concrete can enhance its mechanical performance, especially under heat curing, and provided useful predictive models for the design and assessment of GPCC in engineering applications [58].

N. P. Rajamane et al (2011) conducted a study comparing the chloride penetration characteristics of concrete specimens made with standard Portland cement (OPC) and geopolymer concrete (GPC). The study involved performing the Rapid Chloride Permeability Test (RCPT) on both types of concrete, with the aim of evaluating their resistance to chloride ion penetration, which is a critical factor in the durability of concrete exposed to aggressive environments, such as those containing de-icing salts or seawater. The results of the RCPT indicated that the GPC specimens demonstrated chloride penetration grades ranging from "low" to "very low," with the charge passed through the concrete over six hours varying between 722 and 1222 coulombs. These values were significantly lower compared to typical OPC concrete, which generally exhibits higher chloride penetration. Despite the difference in material composition, the study found that the chloride penetration and diffusion coefficient values of GPC were comparable to those of OPC concrete. Based on these findings, Rajamane concluded that geopolymer concrete (GPC) exhibited similar or even superior resistance to chloride ion penetration when compared to traditional OPC concrete. This suggests that GPC may offer a viable alternative to OPC in applications where enhanced durability against chloride-induced corrosion is a priority, such as in marine structures and reinforced concrete exposed to aggressive environmental conditions [74].

S. Thokchom et al (2010) conducted an experimental investigation to explore the mechanical and microstructural properties of geopolymer concrete (GPC). The primary focus of the study was on the compressive strength of geopolymer paste and mortar derived from Indian fly ash (FA) activated using a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). The investigation also involved the analysis of the microstructural development of FA-based GPC and its relationship to various factors, including synthesis characteristics such as alkali concentration, water/geopolymer solid ratio, silica content, and sand/FA ratio, as well as processing parameters like curing temperature and curing time. The study aimed to establish the key factors that influenced the compressive strength of GPC, with particular attention given to the effect of curing conditions. Thakur's research concluded that a geopolymer mixture subjected to thermal activation for 48 hours at a curing temperature of 85°C, with a silica value of 4.0 and an alkali content of 0.62, achieved a compressive strength of 48.20 MPa. This highlighted the significance of curing temperature and the alkali content in determining the mechanical strength of the geopolymer concrete. Furthermore, the study also explored the effects of various mix ratios, such as the sand-to-fly ash ratio, on the microstructure of the geopolymer. The results revealed that the proper balance between the alkali concentration, silica content, and water/geopolymer solid ratio was crucial for optimizing the material's performance, especially in terms of compressive strength. His work demonstrated that FA-based GPC, when treated under controlled thermal conditions and with precise mixture ratios, could exhibit high compressive strength, making it a viable alternative to traditional cement-based concrete. The study also provided valuable insights into the microstructural development of GPC, emphasizing the importance of key synthesis and processing parameters in achieving desired mechanical properties. He contributed to the understanding of how different synthesis and processing parameters, particularly curing temperature, alkali concentration, and silica content, influence the compressive strength and microstructure of FA-based geopolymer concrete. The findings of this study help guide the optimization of GPC formulations for improved performance in construction applications [98].

V V. Bhikshma et al (2010) investigated the performance of geopolymer concrete (GPC) using five distinct fly ash mix proportions combined with different ratios of alkaline solution. The study involved casting 30 cubes, 30 cylinders, and 15 prisms to evaluate key mechanical properties, including modulus of elasticity, splitting tensile strength, flexural strength, and compressive strength, along with workability parameters such as slump and compacting ability in the fresh state. The results from the experimental study indicated that a mix with a ratio of 0.50 between the alkaline solution and fly ash, activated with a 16 molarity of sodium hydroxide ($NaOH$), resulted in GPC exhibiting a compressive strength of 30 MPa. This finding highlights the significant influence of the alkaline solution to fly ash ratio on the mechanical properties of the geopolymer concrete. Additionally, the workability and compaction characteristics were also assessed, showing that these factors were closely linked to the specific mix proportions and the molarity of the activating solution. The study concluded that the optimization of the alkaline activator concentration and the fly ash ratio plays a critical role in achieving desired strength and workability in geopolymer concrete [103].

D. S. Cheema et al (2009) conducted a study to assess the durability and feasibility of geopolymer concrete (GPC) in the production of pre-cast concrete goods, specifically focusing on box culverts measuring 1200 x 600 x 1200 mm. The study aimed to evaluate whether GPC could provide a viable alternative to traditional concrete for use in precast structures that require durability and long-term performance. The investigation found that GPC exhibited promising results, particularly in terms of its robustness and ability to withstand the conditions typically faced by pre-cast structures. The study concluded that GPC could offer a durable and strong alternative to conventional Portland cement-based concrete in the production of precast goods, such as box culverts. One of the key advantages highlighted by the study was the enhanced durability of GPC compared to traditional concrete, particularly under aggressive environmental conditions. The research demonstrated that GPC could maintain its structural integrity and performance over extended periods, making it suitable for infrastructure applications where durability is critical. Cheema's findings suggest that GPC is a feasible material for producing precast goods like box culverts, offering improved durability and potentially reducing the environmental impact associated with conventional concrete. The study laid the groundwork for further research into the use of GPC in large-scale infrastructure projects, indicating its potential as a sustainable alternative to traditional concrete in various construction applications. He demonstrated that GPC is a durable and robust material for the production of precast concrete items, such as box culverts. The study affirmed the feasibility of using GPC in infrastructure projects, highlighting its potential as a strong and sustainable alternative to conventional concrete [25].

P. K. Sarker (2009) investigated the suitability of applying a constitutive model, initially proposed by Popovics for Ordinary Portland Cement (OPC), to Geopolymer Concrete (GPC). The study focused on adapting the Popovics equation, specifically its curve-fitting factor, to evaluate the stress-strain behavior of GPC under different conditions. The research found that when the Popovics equation was modified for GPC, it provided a better correlation between experimental results and computed stress-strain curves, particularly for GPC with 8M and 14M sodium hydroxide (NaOH) concentrations. This improved correlation indicated that the modified Popovics model could more accurately represent the mechanical behavior of geopolymer concrete under various loading conditions. Furthermore, Sarker extended his study by conducting a non-linear analysis of reinforced concrete columns made from GPC. The results revealed a strong relationship between the experimental final loads, corresponding deflections, and the analytical predictions for twelve thin test columns. The findings demonstrated that the modified constitutive model could be effectively used for evaluating the performance of structural members made from GPC. He study affirmed that the modified Popovics model could be successfully applied to GPC for predicting the stress- strain behavior and the performance of structural components, such as reinforced concrete columns. This work contributes to the ongoing development of reliable analytical tools for the design and assessment of GPC-based structures, offering an acceptable method for evaluating the mechanical properties of GPC in structural applications [80].

A. Mishra et al (2008) conducted an investigation to examine the strength and water absorption properties of Geopolymer Concrete (GPC) by varying the curing period and sodium hydroxide (NaOH) concentration. The study focused on three different curing durations—24, 48, and 72 hours—and three NaOH concentrations—8M, 12M, and 16M.
The results of the study revealed a notable relationship between the curing time, NaOH concentration, and the water absorption of the geopolymer concrete. Specifically, it was observed that as the curing time and NaOH concentration increased, the water absorption of the GPC decreased. This suggests that both factors contribute to the densification of the geopolymer matrix, thereby reducing its porosity and enhancing its resistance to water penetration. Furthermore, the study indicated that longer curing periods allowed for a more complete geopolymerization process, resulting in a more robust and impermeable structure. Higher NaOH concentrations also played a key role in improving the chemical bonding within the geopolymer, leading to a lower water absorption rate. She concluded that increasing the curing time and NaOH concentration in GPC mixes can significantly reduce water absorption, which in turn enhances the material's durability. These findings emphasize the importance of optimizing both curing conditions and chemical activators to improve the performance of GPC in practical applications [12].

D. D. Cortes et al (2008) conducted a study on the increasing use of angular manufactured sands (MS) as a fine aggregate in Portland cement concrete. The study aimed to evaluate the mechanical performance of synthetic and natural sands in concrete, given that traditional methods for selecting fine aggregates for concrete mixes were based on the performance of round natural sand. The research compared two natural sands and two synthetic sands, examining their mechanical performance at various ratios of cement to fine aggregate and water to cement. Three key tests were conducted: stiffness, flowability, and strength. The study found that, for the same standard gradation, the angular manufactured sands exhibited different performance characteristics when compared to natural sands. A significant finding from the study was that the quantity of paste (the binder material) in the concrete mixture was more than the available space in the loosely packed aggregate, which could influence the overall mix's performance. Despite this, the results showed that sufficient flowability and compressive strength could still be achieved when using angular manufactured sands as fine aggregate. Cortes concluded that angular manufactured sands, when used in proper mix proportions, could provide adequate flowability and compressive strength, making them a viable alternative to natural sand in concrete production. This work highlighted the potential of manufactured sands for improving the sustainability and performance of concrete, as well as the need for more detailed consideration of aggregate properties in mix design [23].

2.2 SUMMARY

Geopolymer Concrete (GPC) is an innovative and sustainable alternative to traditional Portland cement concrete. Its composition primarily includes industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), and other supplementary cementitious materials (SCMs). As a result, GPC not only helps in the efficient disposal of industrial waste but also conserves finite natural resources, addressing key environmental concerns.

Industrial Waste in Geopolymer Concrete Production

One of the key aspects of GPC is the use of industrial waste materials, such as fly ash, GGBS, and other industrial by-products. This incorporation of waste products serves a dual purpose: it helps in the effective disposal of effluents from industries while providing a sustainable building material. The replacement of conventional cement with industrial by-products reduces the environmental impact associated with cement production, such as carbon dioxide emissions. Studies have shown that the use of industrial waste in GPC production not only mitigates waste disposal challenges but also reduces the consumption of virgin natural resources, leading to significant ecological benefits.

Advantages of Geopolymer Concrete

GPC has shown remarkable technical properties that make it an attractive alternative to conventional concrete. Research indicates that GPC exhibits superior compressive strength, nhanced durability, and better resistance to chemical attacks compared to ordinary Portland cement (OPC) concrete. These properties are due to the unique chemical reactions that occur when the alkaline activators (such as sodium hydroxide and sodium silicate) interact with the alumino-silicate precursors like fly ash or GGBS.

Additionally, GPC has been found to be highly resistant to aggressive environmental conditions, such as sulfate and acid attacks, which makes it particularly suitable for use in harsh environments, such as wastewater treatment plants, sewage systems, and coastal constructions. The solidification process of GPC, where the industrial waste is transformed into a stable, hardened structure, is a critical factor in ensuring its strength and longevity.

Performance of GPC with Fly Ash, GGBS, TSP, and SF

A significant portion of the research into GPC focuses on understanding the performance of different mix combinations of fly ash, GGBS, and other supplementary materials like thermally activated slag powder (TSP) and silica fume (SF). Various studies have examined the mechanical properties and durability characteristics of GPC produced with different combinations of these materials.

- **Fly Ash:** Fly ash is one of the most widely used precursors in GPC. It has been found that GPC made with fly ash as the primary alumino-silicate source exhibits good workability, high compressive strength, and excellent resistance to acid and sulfate attacks.

- **GGBS:** Ground Granulated Blast Furnace Slag (GGBS) is another common material used in GPC production. When combined with fly ash, GGBS improves the mechanical properties and durability of the concrete, making it more suitable for heavy-duty applications.

- **TSP and SF:** The inclusion of TSP and SF has been studied to further enhance the performance of GPC. Silica fume, for instance, improves the densification of the microstructure, resulting in better durability and strength. Thermally activated slag powder (TSP) contributes to a more stable geopolymer structure, which enhances the overall properties of GPC.

Impact of Alkali Content on GPC Properties

The alkali content in GPC plays a significant role in determining its final mechanical strength and durability. Studies have shown that as the alkali content (measured as Na_2O %) increases, the porosity, water absorption, and water sorptivity of the geopolymer mortar decrease. For example, alkali concentrations in the range of 5% to 8% have been used to investigate the effects on GPC properties. Higher alkali concentrations result in a more solidified matrix, thereby reducing water penetration and enhancing the durability of the material.

Conclusion

In conclusion, Geopolymer Concrete (GPC) stands out as an innovative, sustainable, and environmentally friendly construction material. By incorporating industrial by-products such as fly ash and GGBS, GPC addresses the critical issues of waste disposal and resource depletion. The results of numerous studies demonstrate that GPC exhibits superior mechanical properties, excellent durability, and resistance to harsh environmental conditions, making it a promising alternative to traditional concrete. Furthermore, the optimization of alkali content and the careful selection of supplementary materials can further enhance its performance, positioning GPC as a viable option for a wide range of construction applications.

Techniques and Methodology

To study the behavior and properties of GPC, several techniques have been employed, including the investigation of compressive strength, durability under chemical attacks, and permeability tests. The use of different alkali activators and varying curing conditions are also key parameters that influence the final properties of GPC. Additionally, studies often utilize various testing methods, such as the RCPT (Rapid Chloride Permeability Test) and acid resistance tests, to assess the material's ability to withstand aggressive environmental conditions.

Importance of the Research

The research into Geopolymer Concrete is of paramount importance in the current context of environmental sustainability and waste management. By developing a construction material that not only performs at par with traditional concrete but also utilizes industrial waste, GPC represents a significant step toward reducing the carbon footprint of the construction industry. The findings from studies like the one presented are crucial for advancing the practical applications of GPC in the construction industry, especially in environmentally sensitive areas.

CHAPTER 3 -MATERIALS AND METHODS

3.1 GENERAL

This chapter discusses the materials utilized in experimental investigation and testing methods employed for the proposed research, aiming to identify the engineering properties of the Ternary blends and Binary in Geopolymer concrete. Fig 3.1 demonstrates the research work's flow chart.

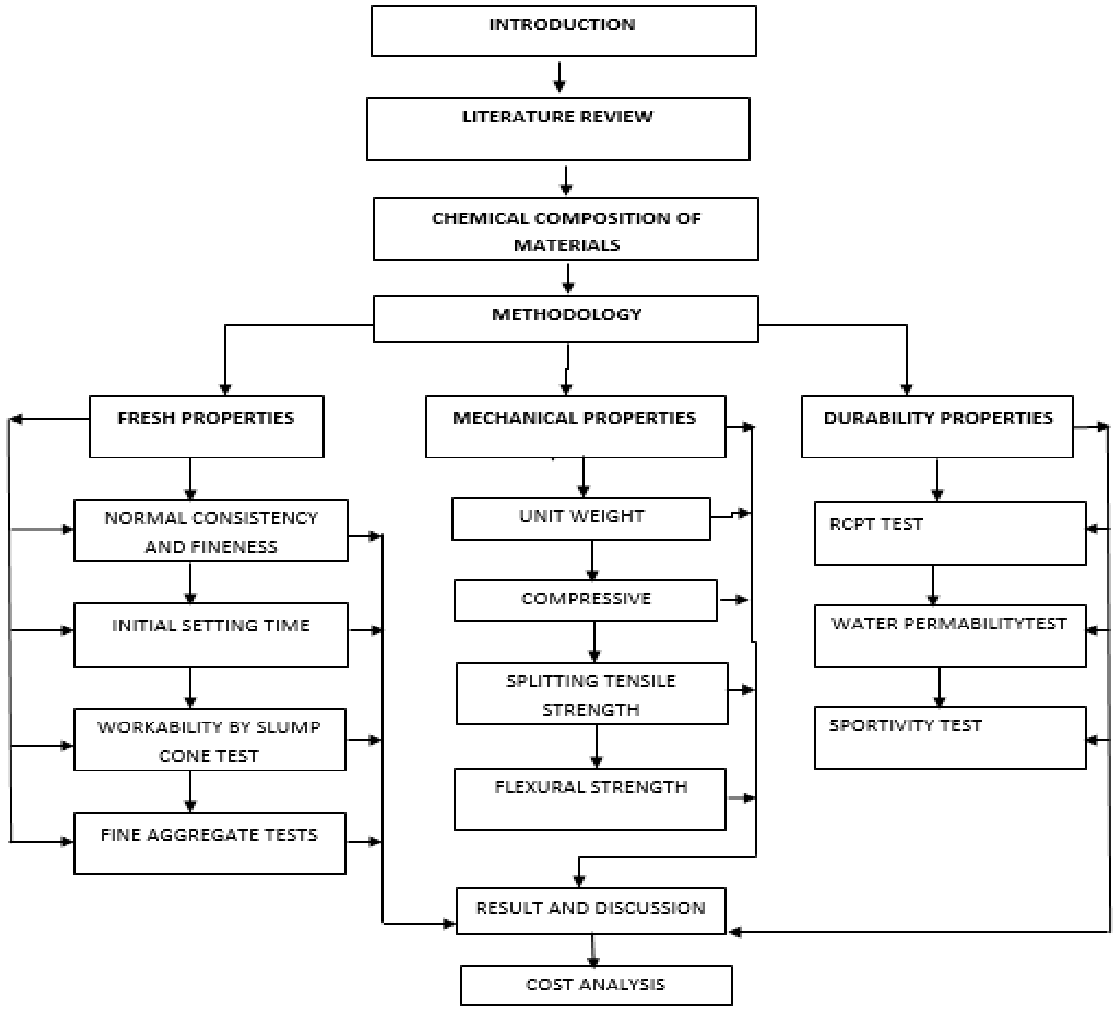

Figure 3.1 Flow Chart of Research Methodology

3.2 EXPERIMENTAL WORK PLAN

The experimental investigation was divided into 4 stages. The material properties and concrete mix design have been investigated in the first stage. All the constituents for manufacturing geopolymer concrete were collected from the local market.

In the second stage, GPC mixtures are manufactured with various percentage replacements of TSP with silica fume @ 5%, 10%15%, & “Fine aggregate with Quarry dust” @ 10%, 20%, 30%, 40% &50% and tested to assess their strength characteristics like flexural strength, split tensile strength, and compressive strength. They are also tested for workability and density to examine their behavior both in their fresh and hardened states were found for the geopolymer mixes.

The third stage consists of studying the durability characteristics of the control and optimized mixtures of GPC. The studies are carried out by conducting tests like water permeability test, sorptivity test, & rapid chloride resistance test. Development of strength in GPC was studied with the assistance of “Scanning Electron Microscope (SEM) & Energy-Dispersive X-ray (EDS) spectroscopy” analyses.

The last fourth stage, the analysis of the applicability of the optimized mixture to the main structural element, has been discussed. An investigation of flexural behavior was carried out on Geopolymer Concrete (GPC). The experimental results are validated by using open LCA software.

3.3 FLYASH

Fly ash is a cementitious substance that is produced by burning coal at a high temperature” [43]. Motkur Thermal Power unit located in Telangana, India, provided the fly ash (Class-F) (MTTP) is shown in Figure-3.2.

Figure 3.2 Fly Ash

An experimental program in this research, low calcium fly ash (“ASTM type F”), was utilized as a cementitious material. The properties and chemical composition are tabulated in Table.3.1 & 3.2.

Table 3.1 Physical Properties of Fly Ash

Properties	Nature or Value
Appearance	Gray
Form	Powder
Apparent Density	1.78 g/cm^3
Specific Gravity	2.3
Specific Surface Area	75 m^2/g
Finesses modulus	7.86

The Motkur Thermal Power Station FA falls under class F, or low-calcium FA, based on its chemical composition. BIS 3812 (Part 1): 2013 states that the lowest and maximum amounts of chemical substances found in the FA were examined.

Table 3.2 Fly Ash Chemical Composition

Components	Specification (%) as per BIS 3812	Fly Ash (%)
SiO_2+Al2O_3+Fe2O_3	70Min	93.93
SiO_2(Alone)	35 Min	53.97
MgO	5 Max	1.28
SO_3	3Max	0.25
Na_2O	1.5Max	0.13
LOI	12Max	2.6

3.3.1 APPLICATIONS AND USES OF FLY ASH

"Fly ash" has several applications, and its beneficial use can help reduce waste and promote sustainability. Some common uses of fly ash include:

Concrete manufacturing: Workability, durability, and the carbon footprint of concrete production are all enhanced when fly ash is substituted for part of the Portland cement in concrete mixes. [87].

Building supplies: It has advantages similar to those of concrete and is utilized in manufacturing bricks, blocks, and other building materials.

Soil stabilization: To enhance the engineering qualities of soil, such as compaction and load-bearing ability, fly ash can be added.

Road construction: Fly ash's stabilizing qualities are advantageous for roads and sub-bases.

Agriculture: In some cases, fly ash can increase soil fertility & as a liming agent to balance acidic soils.

Utilizing fly ash for various purposes can be environmentally beneficial, as it reduces the demand for traditional raw materials like cement and conserves landfill space by reusing a waste product [35].

3.4 GGBS

GGBS as shown in Figure 3.3 used in the present study was procured from Polestar Marketing, Ranigunj, Hyderabad, India. GGBS stands for Ground Granulated Blast Furnace Slag. The properties and chemical composition of GGBS are presented in Tables 3.3 & 3.4.

Figure 3.3 GGBS

Table 3.3 Physical Properties of GGBS

Properties	Nature or Value
Appearance	White
Form	Powder
Apparent Density	2.56 g/cm^3
Particle Size	40microns
Specific Gravity	2.85
Specific Surface Area	40 m^2/g

Table 3.4 GGBS chemical composition

Chemical Composition	Percentage by weight
SiO_2	33.69%

CaO	35.20%
Al_2O_3	16.78%
Fe_2O_3	0.735%
SO_3	1.62%
MgO	6.21%
Ignition Loss	2.1%

3.4.1 APPLICATIONS OF GGBS

Like fly ash, GGBS has a number of uses in the building sector:

Concrete production: GGBS is used in concrete mixtures instead of Portland cement. When blended with cement, it enhances the characteristics of concrete, including enhanced workability, decreased hydration heat, and increased durability, & lower permeability [111].

Cementitious binder: GGBS can also be used as a standalone binder or combined with other cementitious materials to produce specialized construction products like precast concrete elements.

Soil stabilization: GGBS can be mixed with soil to improve its engineering properties, similar to how fly ash is used [82].

Grouting and backfilling: It is used in grouting applications to fill voids and stabilize the ground in construction projects.

Utilizing GGBS in geopolymer concrete & production materials can suggestively reduce the carbon footprint of construction activities and enhance the long-term performance of structures [28]. It's an environmentally- amicable substitute for conventional cement; It is a significant source of greenhouse gas prduction in cement manufacturing [100].

3.5 SILICA FUME

The research study used silica fume from Polestar Marketing, Ranigunj, and Hyderabad, India. Figure 3.4 shows silica fume, which is grey in color. Micro silica, this residue, commonly known as silica fume, is produced in electric arc furnaces while silicon and ferrosilicon alloys are being made [87]. It’s a highly reactive, amorphous, fine-grain material with tiny silicon dioxide (SiO_2) particles. Silica fumes are typically composed of flue fumes produced during the smelting process and are then processed into a powdered form. The properties and chemical composition of Silica fume are presented in Tables 3.5 & 3.6.

Figure 3.4 Silica Fume

Table 3.5 Physical Properties of Silica Fume

Properties	Nature or Value
Appearance	Dark grey
Form	Powder
Apparent Density	7.6 g/cm^3
Specific Gravity	2.2

Table 3.6 Silica Fume chemical composition

Chemical Composition	Percentage by weight
SiO_2	92.03
CaO	0.70
Al_2O_3	0.18
Fe_2O_3	1.10
SO_3	0.85
MgO	2.10
L.O. I	3.78

3.5.1 USES OF SILICA FUME

Because of its special qualities, silica fume has several valuable solicitations in various industries, especially in the construction sector. Some of the key uses of silica fume include: High pozzolanic activity: Silica fume is a highly pozzolanic material; it responds chemically with lime or calcium hydroxide when water is present and forms extra gel made of C-S-H gel [87]. This response results in increased strength together with the concrete matrix's densification.

Concrete production: Silica fumes are often used in concrete as an additional cementitious ingredient mix. After being incorporated into concrete, it enhances unique characteristics, including resistance to chloride penetration, abrasion resistance, durability, and compressive strength. It also decreases concrete's permeability, making it less vulnerable to chemical attacks & enhancing its conflict to freeze-thaw cycles.

Refractory materials: High-performance is made from silica fume in which refractory materials are capable of withstanding high temperatures and harsh environments, making them suitable for various industrial applications.

Silica fume is frequently utilized in the manufacturing of high-strength & high-performance concrete for specialty construction applications projects where superior mechanical properties and durability are required.

Shot Crete: Silica fume is added to shot Crete (sprayed concrete) mixes to improve strength and reduce rebound during application.

Oil well grouts: It is used in oil well grouts to enhance their compressive strength & durability.

Repair, and rehabilitation of structures: Silica fume is utilized in the repair of mortars and grouts for rehabilitating deteriorated structures, providing enhanced mechanical properties and durability.

The addition of silica fume to various construction materials improves their performance and reduces their effects on the environment, which results in more sustainable and durable infrastructure [17]. It is a valuable and versatile material that has found widespread use in the construction and engineering industries.

3.6 QUARRY DUST

Quarry dust utilized in this investigation is sourced from Tandur region, Hyderabad, Telangana, India. Figure 3.5 shows quarry dust in the Tandur site. Quarry dust, also known as stone dust or rock dust, is the residue left over after rocks are crushed at quarries. A fine, powdery material with particles that range in size from fines to small gravel-like pieces [72]. Quarry dust-specific composition can change based on the rock type being crushed and the quarrying process. Some common rock types from which quarry dust is generated include granite, limestone, and basalt [86]. The properties and chemical composition of quarry dust are presented in Tables 3.7 & 3.8.

Figure 3.5 Quarry Dust

Table 3.7 Physical Properties of Quarry Dust

Properties	Value observed in Investigation
Specific gravity	3.37
Bulk density (kg/m3)	1720
Absorption (%)	1.50
Moisture Content (%)	NIL
Fine particles less than 0.075 mm (%)	14
Sieve analysis	Zone-II

Table 3.8 Quarry dust chemical composition

Chemical Composition	Percentage by weight
SiO_2	65.73
CaO	3.64
Al_2O_3	19.31
Fe_2O_3	5.72
K_2O	2.26

MgO	2.16
L.O. I	0.35
TiO_2	1.28

3.6.1 USES AND APPLICATIONS - QUARRY DUST

Quarry dust can be used in place of some natural sand that is utilized in the construction of concrete. In concrete mixtures, it's frequently utilized to take the place of some sand or fine aggregate. This usage can help reduce the demand for natural sand, which is often overexploited from riverbeds.

Stabilization of soils: Quarry dust can be mixed with soils to improve their engineering properties. It is commonly used in road construction, embankments, and landfills to enhance the stability and strength of the soil.

Pavement sub-base material: When building a road, quarry dust can be utilized as a sub-base material. When compacted and properly graded, it provides a stable foundation for the upper layers of the pavement [41].

Manufactured sand: In some cases, In the process of creating manufactured sand, in place of natural sand (M-sand), quarry dust is employed. River sand can be substituted with M-sand and is used in construction activities like plastering and concrete production [72].

Ground improvement: Quarry dust can be used in ground improvement techniques, such as stone column construction, to lessen settling in weak areas and boost bearing capacity soils.

3.6.2 ADVANTAGES OF EXPENDING QUARRY DUST

Cost-effective: Quarry dust is often a cheaper alternative to natural sand, making it an economically viable option for various construction applications.

Environmentally friendly: Utilizing quarry dust in buildings decreases the need for natural properties like sand, leading to a greener and more sustainable approach.

Improves workability: Quarry dust can enhance the workability of concrete mixes, allowing for easier placement and compaction.

Reduces shrinkage: In concrete, the use using quarry dust in place of some of the sand can help lower shrinkage cracks, contributing to more durable concrete structures.

It's important to note that while quarry dust has its benefits, there are also potential drawbacks to its usage, such as its fineness and potential to increase the water demand in concrete mixes. Therefore, proper mix design and testing should be conducted to ensure the optimal use of quarry dust in specific applications while maintaining the desired performance of the construction materials [107]. Additionally, environmental considerations and local regulations should be considered when using quarry dust to ensure responsible and sustainable practices in quarrying activities.

Good attempts have recently been made to reduce environmental pollution by the effective use of a variety of industrial waste (fly ash, silica fume, rice husk ash, and foundry garbage, for example). Furthermore, there has been a significant focus on another source as a possible alternative to concrete's natural aggregates. Reasonable research has thus been done to determine if granite quarry dust is appropriate for use in regular concrete.

According to IS-383-1987, the fundamental tests on quarry dust revealed a specific gravity of about 1.95. The quarry dust's wet sieving percentage of 78% was determined by passing it through a 90-micron sieve; the dust's matching bulking value was 34.13%.

Industries involved in road construction and the manufacturing of building materials, such as autoclaved blocks, lightweight aggregates, tiles, and bricks, have been a key focus of research on the incorporation of quarry dust into concrete. Studies on this topic have been conducted worldwide [108], exploring the effects of replacing sand with varying amounts of quarry dust (20%, 30%) on the properties of both fresh and cured concrete.

3.7 TANDUR STONE POWDER (TSP)

Tandur stone slurry powder taken from the tandur region, Hyderabad, Telangana, India, refers to a byproduct obtained during the processing of Tandur stones, and its chemical composition is presented in Table 3.9. Type of sedimentary rock commonly used in construction and landscaping. During the processing of Tandur stones, water is often used to cool the cutting blades and to wash away debris and sediment generated during cutting and polishing. Tandur stone slurry powder is dried and processed form of the slurry obtained during the stone processing operations. Limestone is used to make TSP. The main constituents of limestone, a sedimentary rock, are the crystal forms of calcium carbonate called aragonite and calcite. A large portion of limestone is made up of the skeletal remains of marine creatures like foraminifera and coral.

Table 3.9 Tandur Stone Slurry Powder Chemical Composition

Chemical Composition	Percentage by weight
CO_3	85.22
$MgCO_3$	3.34

Al_2O_3	1.12
Fe_2O_3	1.60
L.O.I	36.98
TiO_2	1.28

Approximately 10% of sedimentary rocks are composed of limestone. Karst landscapes result from limestone's solubility in water and mild acid solutions, which allows water to dissolve the limestone over thousands to millions of years. The bedrock of most cave systems is limestone. Among its many uses are as a construction material, as an aggregate for road bases, as a white pigment or filler for goods like paint or toothpaste, and as a feedstock for chemicals.

Particularly in North America and Europe, limestone is frequently used in architectural design. Limestone is used to construct a number of famous structures worldwide, such as the Great Pyramid and the complex around it at Giza, Egypt. Kingston, Ontario, Canada is known as the "Limestone City" as so many of its buildings were made of it. Globigerina limestone is a form of limestone that is still widely utilized on all kinds of structures and sculptures on the island of Malta. For a very long time, it was the only material accessible for construction. Limestone is easily obtained and may be carved or broken into blocks with ease. It is also resilient to exposure and long-lasting: 1. However, because it is such a heavy material, towering buildings cannot use it. Figures 3.6, 3.7, 3.8, and 3.9 show the tandur stone polishing machine, tandur stone slurry storage tank, tandur site, and tandur stone powder used in research work.

Certain limestones, such as travertine, are entirely composed of calcite or aragonite that has precipitated chemically. These stones have no grains at all. Supersaturated meteoric fluids, or groundwater that precipitates the material in caves, have the potential to deposit secondary calcite. Speleothems like stalactites and stalagmites are created as a result. Oolitic limestone is another form that calcite may take; it is distinguished by its granular (oolite) look.

Marine life is often the main source of calcite found in limestone. Building on previous generations, some of these creatures are able to create reefs, which are mounds of rock. Limestone normally does not develop in deeper waters below approximately 3,000 meters because of nonlinear increases in calcite dissolving caused by temperature and water pressure (lysocline). Moreover, lacustrine and evaporite depositional settings can produce limestone. Many limestones have diverse hues because of impurities, including clay, sand, organic remnants, iron oxide, and other elements, especially on worn surfaces.

Figure 3.6 Tandur Stone Polishing Machine

Figure 3.7 Tandur Stone Slurry Storage Tank

Figure 3.8 Tandur Stone Dried Slurry at Site

Figure 3.9 TSP Powder

3.8 FINE AGGREGATE

Locally accessible from Hyderabad, river sand was utilized, as shown in Figure 3.10. Natural river sand conforming to grading zone-II with specific gravity 2.37 of IS 383:2016 was used as fine aggregate, and it was discovered to have bulk densities of 1455 Kg/m^3 and 1726 Kg/m^3, respectively. The aggregates were tested as per IS: 2386:2016. Table 3.10, 3.11 shows the fine aggregate sieve analysis and properties of fine aggregates.

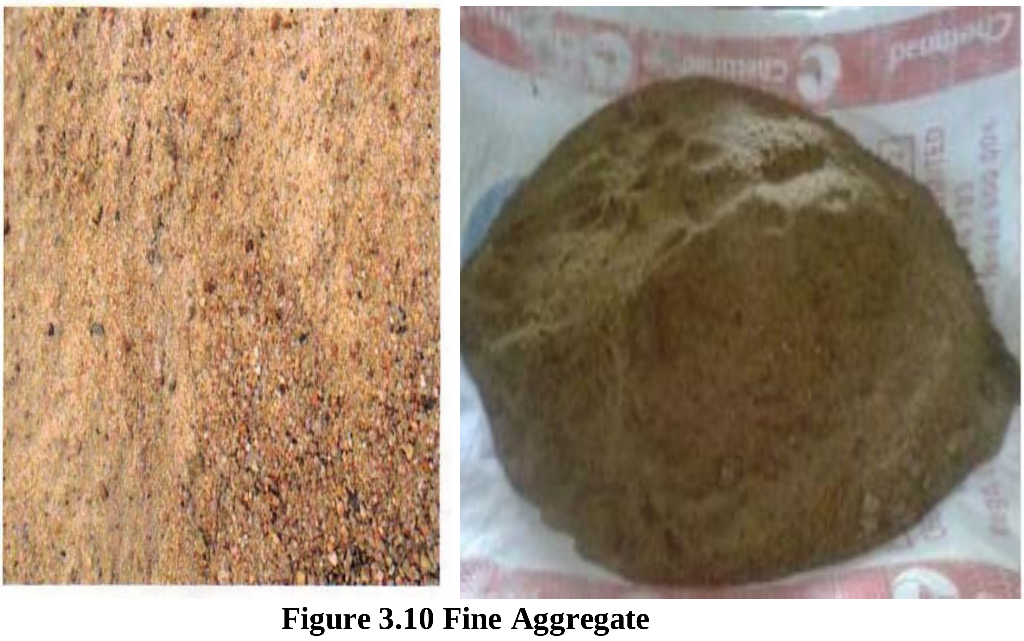

Figure 3.10 Fine Aggregate

Table 3.10 Fine Aggregate Sieve Analysis

S. No.	Sieve No.	Retained Mass (gm)	percentage of retained weight	Total percentage of retained weight	Percentage of Passing
1	4.750	0	0	0	0
2	2.360	0	0	0	0
3	1.180	4.6	0.46	24.8	99.54
4	600µm	57.2	5.72	6.18	93.82
5	425µm	548	54.8	60.98	39.02
6	300µm	347.6	34.7	95.68	4.32
7	150µm	35	3.5	99.18	0.18
8	75 µm	5.0	0.50	99.68	0.32
9	Pan	3.0	0.30	99.98	0.02
	∑F=237.20				

∑F/100=237.2/100=2.372 is the fineness modulus of fine aggregate.

Table 3.11Properties of Fine Aggregate

Properties	Value observed in Investigation
Specific gravity	2.37
Bulk density (kg/m^3)	1455
Water Absorption (%)	0.9
Moisture Content (%)	1.50
Wet density (kg/m^3)	1982
Dry density (kg/m^3)	1602
Fine particles less than 0.075 mm (%)	6
Sieve analysis	Zone-II

3.9 COARSE AGGREGATE

Crushed granite of maximum size 20 mm conforming to IS 383:2016 has been used as coarse aggregate with specific gravity 2.67. In the present research locally available from Hyderabad, Ranigunj area, crushed granite stone aggregate of Coarse aggregate used in geopolymer concrete refers to the larger-sized particles, such as gravel or crushed stone, incorporated into the mixture to provide strength and stability to the final concrete structure shown in figure 3.11.Table 3.12, 3.13 shows fineness and characteristics of coarse aggregates

Figure 3.11 Coarse Aggregate

Table 3.12Modulus of Fineness of Coarse Aggregate

I.S.Sieve Size	Aggregate weight maintained in grams	Weight kept cumulatively in grams	Total percentage of weight maintained in grams	percentage of passing
40 mm	0	0	0	100
20 mm	0	0	0	100
10 mm	270	750	15	85
4.75 mm	4250	5000	100	0
2.36 mm	0	5000	100	0
1.18 mm	0	5000	100	0
600 µm	0	5000	100	0

300 µm	0	5000	100	0
150 µm	0	5000	100	0

The fineness modulus of coarse aggregate is 615/100, or 6.15.

Table 3.13 Characteristics of Coarse Aggregate

Property	**Result**
Modulus of fineness	6.15
Specific gravity	2.67
Bulk density (kg/m^3)	1475
Loose compact	1690

CHEMICAL ACTIVATORS USED IN GEOPOLYMER CONCRETE

In this present research work, chemical Activators such as Sodium Hydroxide, Sodium silicate were utilized.

3.10 SODIUM HYDROXIDE

Figure 3.12 shows the Sodium hydroxide pellets are offered as flakes and pellets in a solid condition. The primary factor influencing sodium hydroxide pricing is the material's purity. In this study, sodium hydroxide is utilized to activate the homogenous substance known as Geopolymer concrete. It is thus advised to choose pure and reasonably priced sodium hydroxide. The physical and chemical parameters of the sodium hydroxide pellets utilized in this experiment were supplied by the producer, as displayed in Table 3.14.

Figure 3.12 Sodium Hydroxide

Table 3.14Sodium Hydroxide Chemical Composition

Appearance	White Crystalline Substance
Color	White
Specific Gravity	1.52
Assay	99%
Carbonate (Na_2CO_3)	1%
Chloride (Cl)	0.01%
Sulfate (SO_2)	0.01%
Lead (Pb)	0.002%
Iron (Fe)	0.002%
Aluminium	0.002%

3.11 SODIUM SILICATE

Sodium silicate is commonly referred to as water glass or liquid glass since it is available in liquid (gel) form. In the current investigation, sodium silicate 2.0 (ratio of Na_2O to SiO_2) is used and shown in Figure 3.13. According to the manufacturer, silicates were supplied as bonding agents to the textile sector and detergent companies [47]. Geopolymer concrete is made using the same sodium silicate. Based on information provided by the manufacturer, Table 3.15 displays the chemical and physical characteristics of the silicates.

Figure 3.13 Sodium Silicate

Table 3.15 Chemical Composition of Sodium Silicate

Appearance	Liquid(gel)
Color	Light yellow liquid (gel)
Boiling Point	100^{o} C
Specific gravity	1.53
Assay Na_2O	8.58%
Assay SiO_2	28%
H_2O	63.5%

3.12 ALKALINE LIQUID

Mixing sodium silicate with sodium hydroxide solution at ambient temperature is the usual method for creating alkaline liquids [87]. After mixing the solutions, the alkaline liquid becomes ready to act as a binding agent since both solutions begin to react or polymerize and release a substantial quantity of heat. For around one day, it is advised to leave the mixture, and while preparing the solution, it is advised to wear gloves on your hands.

3.12.1 ALKALINE LIQUIDS PREPARATION

The alkaline liquid preparation is shown in Figure 3.14, and the appropriate security precautions were followed, including donning masks and gloves.

3.13 SODIUM HYDROXIDE

In the current investigation, sodium hydroxide pellets were dissolved at a rate of 12 molar concentrations. Before usage, sodium hydroxide solution should be made 24 hours before. If leftover 36 hours, it will turn into a semi-solid liquid form. Thus, this is the period of time in which to employ the produced solution. A long steel rod was employed to continuously stir both solutions for a few seconds in order to avoid heterogeneity in the combination.

3.13.1 CALCULATION OF MOLARITY

A solution with the necessary concentration can only be created by dissolving the solids in water. Sodium hydroxide solution concentrations might change throughout various moles. The solution's concentration affects how much NaOH solids exist in a given volume [44].

To create a 12M sodium hydroxide solution, the weighted solid sodium hydroxide pellets were submerged in the necessary amount of drinkable water. Without delay, the plastic lid was closed to avoid breathing in hot gas fumes that may cause discomfort. A 12-molar concentration of

NaOH solution is equivalent to 12 x 40 = 480 grams of solid NaOH per liter of water, where 40 is the molecular weight of NaOH. One may observe that the primary element in both of the alkaline solutions is water mass. 444 grams of NaOH solids per kilogram of NaOH solution, with a concentration of 12 molar, was the mass of the solids. Figure 3.15 shows the alkaline liquid used in the present research work.

Figure 3.14 Preparation of NaOH Solution

Figure 3.15 Alkaline Liquid

3.14 EXPERIMENTAL WORK

3.14.1 SIEVES FOR FINE AGGREGATE AND COARSE AGGREGATE TEST

The current study uses a series of sieves with the following sizes: 4.75 mm, 2.36 mm, 1.180 mm, 600 microns, 425 microns, 300 microns, 150 microns, and 75 microns. This is done to determine the fineness modulus of the fine aggregates. Additionally, 40mm, 20mm, 10mm, 4.75mm, 2.36mm, 1.18mm, 600 microns, 300 microns, and 150-micron sieves are used to measure the fineness modulus of coarse aggregates. Figure 3.16 shows the set of sieves used for the present research work.

Figure 3.16 Fine and Coarse Aggregates Set of Sieves

CUBES

In accordance with BIS 10086: 1982, the dimensions of the GPC cubes cast for this study were 150 mm × 150 mm × 150 mm, figure 3.17 shows the cubes molds used for the present research work.

CYLINDERS

In compliance with BIS 5816: 1999, GPC cylindrical specimen dimensions of 150 mm in diameter and 300 mm in height were cast to quantify the concrete's Young's modulus [35]. For the purpose of evaluating split tensile strength, these cylinders were cast, figure 3.17 shows the cylindrical molds used for the present research work.

BEAMS / PRISMS

To investigate GPC flexural strength, plain GPC beams within standard dimensions of 100 X 100 X 500 mm long and in compliance with BIS 516: 1959 were cast. Figure 3.17 shows the beam molds used for the present research work, figure 3.17 shows the beams/prisms used for the present research work.

Figure 3.17 Moulds, Beams, Cylinders

WEIGHING BALANCE

Weight was taken by using an electronic weighing balance for the whole research project. There are two weighing balances available; one can weigh up to 100 Kg, while the other can weigh up to 10 Kg. Figure 3.18 displays the weighing balance.

Figure 3.18 Weighing Balance

A PAN MIXER FOR MIXING

A 150 Kg rotating pan mixer with two revolving wheels was used for mixing; the setup is seen in Figure 3.19. First, the Fly ash, GGBS, Silica Fume, TSP and aggregates were combined for about three minutes in the lab pan mixer. The mixture was finally mixed with the alkaline liquid added & maintained a wet mixing for an additional four minutes to start the polymerization process.

Figure 3.19 Concrete Mixer

3.14.2 CASTING OF GEOPOLYMER CONCRETE

First, a determined amount of water was added to dissolve the flakes of sodium hydroxide. After that, sodium silicate & sodium hydroxide solution were combined to create an alkaline activator. In a concrete pan mixer, dry components like fly ash, GGBS, TSP, silica fume, various-sized coarse & fine aggregates, & quarry dust were added. The mixture was thoroughly stirred for five minutes. After that, the components in the pan mixer were mixed for a further five minutes with the additionally added alkaline activator to make workable geopolymer concrete mix. Figure 3.20 shows the fresh geopolymer concrete which is used for the present study. After that, three layers of the produced geopolymer mix were poured into the molds, and they were compressed with a table vibrator machine for 2 minutes, as shown in Figures 3.21 and 3.22. After being taken out of the molds, the hardened geopolymer specimens were kept in room temperature storage for 30±2°C. (Figure 3.23). For the cast geopolymer specimens, different mix IDs have been assigned, namely, M1, M1S1, M1S2, M1S3, M1Q1, M1Q2, M1Q3, M1Q4, M1Q5, M1S1Q1, M1S1Q2, M1S1Q3, M1S1Q4, M1S1Q5, M1S2Q1, M1S2Q2, M1S2Q3, M1S2Q4, M1S2Q5, M1S3Q1, M1S3Q2, M1S3Q3, M1S3Q4 and M1S3Q5.

Figure 3.20 Fresh Geopolymer Concrete

Figure 3.21 Casted Specimens

Figure 3.22 Vibrating Machine

Figure 3.23 Casted Geopolymer Concrete Specimens

3.14.3 WORKABILITY DETERMINATION

Workability was carried out by slump cone test, V-funnel, and L-box as described for geopolymer concrete as shown in figure 3.24,3.25,3.26 as per BIS 1199-1959; in Abram's cone [111], three layers of freshly mixed geopolymer concrete were added, and each layer received 25 strokes from a steel tamping rod. The slump value was measured when the cone was raised and filled with the compressed new mix.

Figure 3.24 Slump Cone Test

V-Funnel and L Box TEST

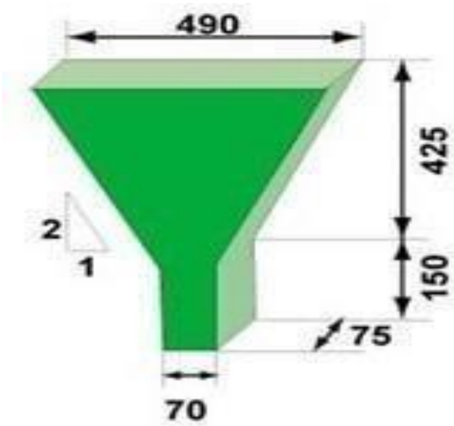

Figure 3.25 V-Funnel Test

https://theconstructor.org/practical-guide/v-funnel-test-on-self-mpacting-concrete/6034/

Figure 3.26 L-Box Test

3.15 COMPRESSIVE STRENGTH

A 150 x 150 x 150 mm cubic cube was used to evaluate the compressive strength of geopolymer concrete in compliance with IS 516-1959 [86]. The compressive test depicted in Figures 3.27 and 3.28 was carried out using a typical compression testing machine with a 2000 KN capacity. The specimens' test results are displayed in Table 4.2.of all mixes and the optimal mix obtained for mix M1S2Q5, which has a compressive strength of 42.85 N/mm^2. For casting compression elements of buildings, this optimal mixture can be employed in construction practices.

Figure 3.27 Compression Machine Test Setup

Figure 3.28 Compression Testing Machine

3.16 SPLIT TENSILE STRENGTH

In this research work, a test of the split tensile strength (ft) was conducted on concrete cylinder samples having 150 mm diameter & 300 mm length, and the capacity of the tensile testing machine is 40 Tones. As per the procedure given in IS 5816:1999 [104], Fig. 3.29 shows the experimental setup for evaluating the geopolymer concrete split tensile strength. The load was increased until the specimen failed by splitting along the diameter shown in Figure 3.30. From the expression split tensile strength of the concrete is calculated [53].

$$f_t = \frac{2P}{\pi D L}$$

Where P denotes split tensile load, D and L are the diameter and length of the specimen.

In this research, geopolymer concrete's tensile strength varies in compressive strength between 5% and 20%. The obtained strength values were considered for analysis as shown in table 5.3. It's important to remember, nevertheless, that despite continuous study and advancement in the field of geopolymer concrete, tensile strength remains a challenge. Compared to traditional concrete, geopolymer concrete's tensile strength is relatively increased, which limits its use in certain structural applications.

Figure 3.29 Split Tensile Test Setup

Figure 3.30 Split Tensile Test Specimen Failure

3.17 FLEXURAL STRENGTH

In this research work, the tests are conducted on beams under a two-point flexural strength test on a tensile testing machine Capacity of 40 Tones with a flexural Strength test setup displayed in Figure 3.31. Utilizing the two-point loading method on beams 100 mm by 100 mm by 500 mm, the flexural strength (f_{cr}) was determined, following the guidelines provided in IS 516:1959 [40]. The loading rate was maintained at 4 KN/min. P represents the maximum load, which was increased until the beam cracked and failed.

Figure 3.31 Flexural Testing Test Setup

Table 3.16 Specifics of the carried out experimental testing

Sl.no	Details of Test	Code book used	Detailsof specimens	No. of samples
a) Slump cone tests for workability in accordance with BIS 1199-1959[69]				
b) Tests pertaining to strength				
1.	Compressive Strength test @7, 28, 56 and 90 days	BIS 516:1959	Cube Size (150x150 mm)	116
2	Splitting tensile strength @ 7, 28, 56 and 90 days	BIS 5816:1999	Cylinder 100 X 200 mm	116

3	Flexural strength@ 28, 56 and 90 days	BIS 516:1959	Prism 100 X100X500 mm	116
c) Tests pertaining to durability				
1	RCPT Test	Modified RCPT by McGrath - 1999	Cylindrical disk 100X50mm	45
2	Water Permeability Test	ASTM C 642-06	Cube Size (150x150 mm)	45
3	Sorptivity Test	ASTM C 1585-04	Cylindrical disk 100X50mm	45
d) SEM and EDX studies are used to analyze the microstructure of the tested				
Total number of cast specimens used in the investigation				**483**

3.18 COST ANALYSIS OF GPC

The cost of cement is Rs 10/Kg., the price of fine aggregate is Rs 0.65/ kg, the price of coarse aggregate is Rs 0.7/ Kg, the price of fly ash is Rs.2/Kg, the cost of GGBS is Rs.1.5/Kg, the cost of TSP is RS 0/Kg, the cost of Silica fume is Rs.5/Kg, the cost of Alkaline activators is Rs.20/Kg. The cost required to cast 1 cubic meter of concrete of mix designations NC, M1, M1S2, and M1S2Q5 is discussed in Chapter 4 and shown in Tables 4.5, 4.6, 4.7, and 4.8. Hence for M1, M1S2, and M1S2Q5, the rate of the GPC concrete is Rs 5365.96/- per m^3, Rs 5431.625 per m^3, Rs 5412.295 per m^3 which is lower than conventional mix but 50 % substitute of fine aggregate through quarry dust, the addition of 10 % of silica fume by TSP shows economical as well as optimum results. The savings in cost in Rs through conventional concrete for the mixes M1, M1S2, and M1S2Q5 are shown in the table, and the figure 4.6, 4.7 shows the savings graph and is useful for the construction works.

3.19 DURABILITY TESTS

3.19.1 PERMEABILITY TEST FOR RAPID CHLORIDE (RCPT)

Chloride Penetration of optimum mixes of concrete is checked using Rapid Chloride Penetration Test which is performed in accordance to standard ASTM C1202 [6] Figure 3.32 indicates the RCPT setup, and the plan was to put an electrical potential over the geopolymer concrete in order to compel the chloride ions to permeate it. On one side of the specimen, a reservoir with a negative terminal holds the negatively charged chloride ions, while on the other side, a reservoir with a positive terminal holds the positively charged chloride ions.

In civil engineering, the Rapid Chloride Permeability Test (RCPT) is an essential evaluation technique that is used to ascertain the concrete permeability and other building constituents. This test offers important information on the strength and caliber of concrete constructions [105].

Figure 3.32 Rapid Chloride Permeability Test Setup

Table 3.17 Concrete Permeability Values Based on RCPT

Charge Passed (Coulombs)	Chloride Ion Penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

When a potential is supplied, Chloride ions are directed toward the positive terminal located across the specimen from the reservoir [8]. The whole current/charge passed during a six-hour period is recorded. After that, this charge passed is compared to the concrete's permeability rating in Table 3.20.

Chloride Penetration of optimum mixes of GCP concrete is checked using The Rapid Chloride Penetration Test, which is carried out in compliance with the standard “ASTM C1202” [107]. The specimens of NC, M1, M1S2, and M1S2Q5 are prepared as cylinders 100 mm in diameter & 200 mm in depth, which are further spliced in samples of depth 50 mm. The McGrath approach was used to conduct modified RCPT. For this test, concrete disks having a 50 mm thickness and a 100 mm diameter were employed, which had been cast 28 days earlier. The specimen was mounted such that one end was attached to a cell containing 3% sodium chloride solution (which was linked to the power supply's negative terminal) and the other end was attached to a cell containing 0.3 N sodium hydroxide solution (which was connected to the positive terminal of the power supply). Figure 3.33 illustrates how a potential difference of 60 V was maintained across the specimen's ends during the test. The current passing through the material was monitored for a maximum of thirty minutes at one- minute intervals. Using the existing values, a total charge that flowed by specimens was determined in coulombs (current multiplied by time) from the current in amperes and the duration in seconds. This value was connected to the specimen's resistance to the chloride ions' penetration.

3.19.2 APPLICATION

Multiple reasons are served by the outcomes of RCPT tests conducted on geopolymer concrete samples or cores. There exists a correlation between the fundamental durability characteristics of concrete and the findings of the RCPT, namely the chloride diffusion coefficient [79]. The long-term integrity of geopolymer concrete buildings is ensured by this connection, which helps with service life design [92].

Quality control and assurance of geopolymer concrete in building projects are made possible by the use of RCPT data in performance-based assessment. Engineers can improve the quality of a material by making well-informed judgments based on an analysis of its permeability properties. [14].

Figure 3.33 RCPT Specimen Testing

3.20 WATER PERMEABILITY TEST

Cubes measuring 150 mm were the test specimens. According to ASTM C642, the water absorption values of GPC concrete specimens were tested 28 days following the date of casting. The water permeability of optimum mixes of GCP concrete is checked using the test for water absorption, which is carried out in compliance with standard “ASTM C642” as shown in figure 3.34. The specimens of NC, M1, M1S2, and M1S2Q5 are prepared, and a known hydrostatic pressure is applied from one side to a mortar as part of the test. The specimen is then allowed to percolate through for a specified period of time, after which the amount of water that does so is measured, and the coefficient of permeability is computed, which is shown in Figure 3.35. The test specimen will be installed in a machine so that it may be submerged under pressure in water at pressures of up to 7 bars. One bar of pressure is first administered for 48 hours, then three bars during the following 24 hours, and finally seven bars for the last 24 hours. Following the aforementioned time, the sample is removed & divided in half using compression to two round bars on the opposing sides, above and below. The maximum allowable limit for water penetration in an outline construction specification is 25 mm, and for an outline design specification, it is 10 mm [79]. A scale is used to measure the water penetration in the cracked core, and millimeters are used to determine the penetration depth at three locations of maximum penetration; then, the values are determined as the water penetration.

Figure 3.34 Water Permeability Testing Machine

Figure 3.35 Water Permeability Specimen Testing

3.21 TEST OF SORPTIVITY

In compliance with ASTM C1585-04, the sorptivity test was performed. In the first absorption measurements, a maximum coefficient changes of 6% was permitted. The pore structure of the geopolymer concrete's capillary force to attract fluids into the geopolymer concrete's body is measured by a property called sorptivity.

The sorptivity of optimum mixes of GCP concrete is checked using the sorptivity Test, which is performed in accordance with standard ASTM C1585-04. The specimens of NC, M1, M1S2, and M1S2Q5 were prepared, and for the test, 100 mm diameter by 50 mm thick chunks of GPC concrete were employed. The specimen's sides were sealed with epoxy glue and waxed, and the specimen's original mass was then calculated. The specimen was then stored in a tray that was submerged in water to a depth of three to five millimeters, as seen in Figures 3.36, 3.37, 3.38, 3.39, and 3.40. After the extra surface water was removed and bloated off, the specimen's mass was measured at every one, two, three, four, five, and six hours at intervals of one, five, ten, twenty, and thirty minutes.

The sorptivity test illustrates the water flow restriction on concrete specimen surfaces brought on by capillary suction. The curing time and geopolymer concrete's pore structure often have an impact on this attribute. Sorptivity is a geopolymer concrete durability attribute [78].

The following equation can be used to model, water penetration caused by capillary action:

$$\boxed{I = A + St^{1/2}}$$

Where I=volume of water absorbed, A= Area, S= Sorptivity, t = Exposed time. The weight increase, cross-sectional area, and water density, respectively, and I is the cumulative absorbed volume after time t per unit area of inflow surface.

Figure 3.36 Hydraulic Drilling for Specimens

Figure 3.37 Drilled Samples for Sorptivity Test

Figure 3.38 Disc Samples for RCPT Test

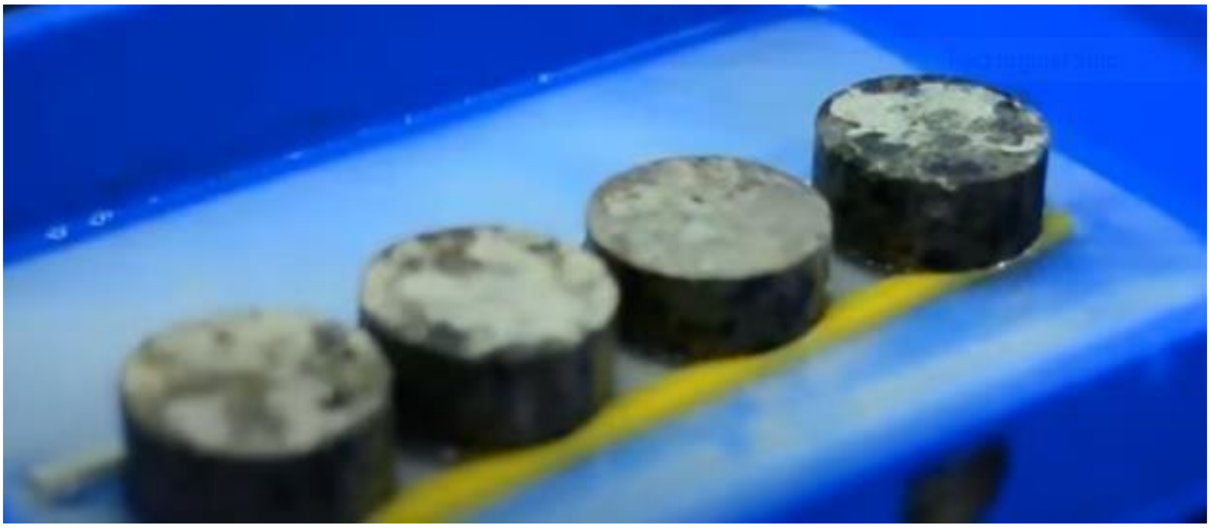

Figure 3.39 Sorptivity Samples in Water

Figure 3.40 Sorptivity Samples Testing Machine

3.22 MICRO STRUCTURAL STUDY OF GEOPOLYMER CONCRETE-SEM, EDS

A tool used to examine the microstructure of materials by capturing magnified pictures is the scanning electron microscope [60]. The crushed mix identification powder samples are gold-coated and subjected to a 20000x magnification electron microscope scan.

This device, which has two numbers of magnetic lenses and an electron cannon with anode, is seen in Figure 3.41. When the specimen is bombarded with electrons, its electrons become excited and release X-rays, which are then picked up by the detector and used to determine the EDS values of the material compositions and the crystalline behavior of the scanned zoom picture. Geopolymer concrete's microstructure may be better understood by using SEM (Scanning Electron Microscopy) examination, which provides microscopic information on the material's composition, texture, and bonding properties [26]. The following is how SEM analysis advances our knowledge about geopolymer concrete:

Microstructure Examination

Cementitious Matrix: SEM enables the analysis of the matrix made of aluminosilicate gel that is normally generated by geopolymer binders. It facilitates the evaluation of the gel's homogeneity, porosity, and dispersion inside the concrete matrix [18].

Aggregate-Binder Interface: The geopolymer binder and aggregates' interfacial transition zone (ITZ) may be seen by SEM. Evaluating the bond strength and endurance of geopolymer concrete requires an understanding of the ITZ.

Pore Distribution and Structure: SEM offers details on the distribution and structure of the pores in the geopolymer concrete. This comprises bigger holes between aggregate particles as well as gel pores inside the binder matrix. The permeability of concrete's pore characteristics affects its strength and longevity.

Chemical Composition Analysis

Phase Identification: Different crystalline and amorphous phases found in geopolymer concrete may be identified with the combination of energy-dispersive X-ray spectroscopy (EDS) & SEM. Phases such as unreacted precursors of aluminosilicate, reaction products like geo-polymeric gels, and any crystalline phases generated during curing are all included in this. We can see the spatial distribution of elements like silicon, aluminum, calcium, and sodium inside the microstructure of concrete by using elemental mapping, which is made possible by EDS. This facilitates comprehension of the components' distribution and response processes in geopolymer concrete.

Figure 3.41 SEM & EDS Analysis Equipment http://cif.lpu.in/

3.23 MECHANICAL PERFORMANCE CORRELATION

Microstructural aspects and Mechanical Properties: SEM investigation can establish a connection between the mechanical characteristics of geopolymer concrete and microstructural aspects such as porosity, pore size distribution, and aggregate-binder interface characteristics. This aids in improving concrete performance and mix design optimization.

Evaluation of Defects: SEM aids in the detection of flaws in the concrete microstructure, such as voids, fractures, and interfacial debonding. Enhancing the longevity and structural integrity of geopolymer concrete requires an understanding of the kind and amount of faults.

3.24 RESEARCH AND DEVELOPMENT

Optimization of Mix Designs: SEM analysis provides feedback for refining geopolymer concrete formulations by evaluating the results of various raw materials, curing conditions, and additives on the microstructure & performance of the concrete.

Innovation and Material Characterization: SEM is an essential tool for researching new geopolymers, including substitute raw materials and synthesis techniques, which helps to create high-performing and environmentally friendly concrete materials.

3.25 SUMMARY

SEM analysis is essential for thoroughly describing the composition, microstructure, and characteristics of geopolymer concrete. This helps to develop material research, building methods, and the sustainability of infrastructure.

3.26 ENERGY DISPERSIVE X-RAY SPECTROSCOPY (EDS)

Energy Dispersive X-ray Spectroscopy (EDS), also known as Energy Dispersive X-ray Analysis (EDX), is used in conjunction with scanning electron microscopy (SEM) to analyze the elemental composition of materials. The energy dispersive spectroscopy analysis (EDS) is executed on specimens this is how it operates:

PRINCIPLE

X-ray Emission: A material in the SEM that has been subjected to an electron beam will release distinctive X-rays as a result of the electrons' interactions with the sample's atomic structure.

Energy Levels: The atomic structure of every element is linked to a specific set of energy levels. Upon excitation and subsequent relaxation to lower energy levels, the sample's electrons release X-rays that are unique to the elements found in the sample.

Energy Dispersive Detection (EDS): EDS systems measure the energy of the X-rays that are released using semiconductor detectors. These detectors distinguish between the distinctive X-ray energy linked to the various elements present in the specimen.

Spectral Analysis: The EDS analysis yields a spectrum that shows the energies and intensities of the X-rays that the sample emits. Researchers can ascertain the elemental makeup of the substance they are examining by examining this spectrum.

3.27 WORKFLOW

Sample Preparation: To improve conductivity and lessen charging effects during SEM imaging and EDS analysis, the sample is usually coated with a thin conductive coating (such as carbon or gold).

Electron Beam Excitation: A concentrated electron beam is directed onto the sample surface by the SEM. X-rays are produced by the electrons' interaction with the sample.

X-ray Detection: The sample's X-rays are collected and analyzed by the EDS detector. To determine which elements are present in the sample, the energy and intensity of the X-rays are measured.

Data Analysis: An elemental spectrum, which shows peaks corresponding to the distinctive X-rays released by the elements in the sample, is produced by processing and analyzing the acquired data.

EDS may be used for elemental mapping, which is a technique that visualizes the distribution of certain elements across a sample surface, in addition to qualitative analysis. This gives spatial details on the sample's elemental makeup.

3.28 APPLICATIONS

Material Characterization: In disciplines including materials science, metallurgy, geology, and biology, the elemental composition of materials is frequently ascertained by the use of EDS.

Quality Control: EDS analysis is used in industries to confirm the uniformity and quality of products, as well as to detect impurities and confirm the composition and purity of materials.

Research and Development: By analyzing the composition of new materials, examining chemical reactions, and refining material qualities for a range of uses, researchers use EDS.

Forensic Science: EDS is used in forensic science to identify materials at crime scenes, analyze samples in criminal investigations, and perform elemental analysis of trace evidence.

All things considered, EDS is a potent analytical method that offers insightful information on the distribution and elemental makeup of materials, opening up a variety of commercial and research uses.

CHAPTER 4 -RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

A detailed program was experimentally implemented to assess various attributes of GPC concrete, generating a substantial volume of data. This data was subjected to thorough analysis to clarify the behavior exhibited by different geopolymer concrete mixes across various tests. A number of 483 specimens were cast & tested in order to investigate the strength, resilience, & structural behavior of GPC manufactured with FA, GGBS, and TSP with silica fume and fine aggregate with quarry dust replacement. Experiments were performed on GPC using different dosages of cementitious materials, such as 5%, 10%, and 15% silica fume in lieu of TSP and 10%, 20%, 30%, 40%, and 50% substitute for fine aggregate with quarry dust. Findings demonstrate compressive strength of GPC at 7, 14, 28, 56, & 90 days of testing. Additionally, the GPC specimens' flexural strengths and split tensile were examined. Sorptivity, Water permeability, & rapid chloride penetration were among the criteria evaluated for durability. The aforementioned strength and durability properties of GPC specimens were shown in charts at various ratios of silica fume with TSP and fine aggregate with substitution of quarry dust. The structural behavior of TSP- TSP- containing geopolymer concrete was compared to that of GPC under ambient curing conditions. Following is a discussion of the test findings. The mix design of M25 grade concrete has been adopted for normal concrete and the mix details are shown in Table 4.0.

4.1.1 COMPOSITION OF MATERIALS USED IN EXPERIMENTAL RESEARCH

Table 4.0 Design Mix Proportion

Sample Mix I'd	Cement (Kg/m^3)	Fly Ash (Kg/m^3)	GGBS (Kg/m^3)	Tandur Stone (Kg/m^3)	Silica Fumes (Kg/m^3)	Fine Aggregate (Kg/m^3)	Quary Dust (Kg/m^3)	Coarse Aggregate (Kg/m^3)
Control	394	-	-	-	-	791.000	-	1068
M1	-	131.33	131.33	131.330	-	791.000	-	1068
M1S1	-	131.33	131.33	124.764	6.567	791.000	-	1068
M1S2	-	131.33	131.33	118.197	13.133	791.000	-	1068
M1S3	-	131.33	131.33	111.631	19.700	791.000	-	1068

M1Q1	-	131.33	131.33	131.330	-	711.900	79.100	1068
M1Q2	-	131.33	131.33	131.330	-	632.800	158.200	1068
M1Q3	-	131.33	131.33	131.330	-	553.700	237.300	1068
M1Q4	-	131.33	131.33	131.330	-	474.600	316.400	1068
M1Q5	-	131.33	131.33	131.330	-	395.500	395.500	1068
M1S1Q1	-	131.33	131.33	124.764	6.567	711.900	79.100	1068
M1S1Q2	-	131.33	131.33	124.764	6.567	632.800	158.200	1068
M1S1Q3	-	131.33	131.33	124.764	6.567	553.700	237.300	1068
M1S1Q4	-	131.33	131.33	124.764	6.567	474.600	316.400	1068
M1S1Q5	-	131.33	131.33	124.764	6.567	395.500	395.500	1068
M1S2Q1	-	131.33	131.33	118.197	13.133	711.900	79.100	1068
M1S2Q2	-	131.33	131.33	118.197	13.133	632.800	158.200	1068
M1S23Q3	-	131.33	131.33	118.197	13.133	553.700	237.300	1068
M1S2Q4	-	131.33	131.33	118.197	13.133	474.600	316.400	1068
M1S2Q5	-	131.33	131.33	118.197	13.133	395.500	395.500	1068
M1S3Q1	-	131.33	131.33	111.631	19.700	711.900	79.100	1068
M1S3Q2	-	131.33	131.33	111.631	19.700	632.800	158.200	1068
M1S3Q3	-	131.33	131.33	111.631	19.700	553.700	237.300	1068
M1S3Q4	-	131.33	131.33	111.631	19.700	474.600	316.400	1068
M1S3Q5	-	131.33	131.33	111.631	19.700	395.500	395.500	1068

4.2 GPC WORKABILITY

The workability was tested using the slump cone and compaction factor method, and outcomes were listed in Table 4.1. Research has been performed to determine the workability of GPC, with the replacement of quarry dust with fine aggregate and cementitious materials FA, GGBS, and TSP with Silica fume. Table 4.1 shows the slump values of all 25 mixtures. Specimens made with GPC combination observed with slump values between 55 and 69.55 mm, which were presented in figure 4.1; the amount of TSP used with different dosages of silica fume & quarry dust with partial replacement of fine aggregate was used to determine the workability of the GPC. The slump value of GPC gradually increased with the inclusion of different dosages of cementitious materials. The primary may be due to the larger specific surface area, which results in a greater water requirement.

Table 4.1 Test Results of Workability

Sample Mix I'd	Slump Flow		V-funnel	L-box
	mm	T50(sec)	T50(sec)	H2/H1
M1	55.00	14	16	1
M1S1	56.00	10	7	1.32
M1S2	56.50	9	7	1.32
M1S3	57.00	10	7	1.28
M1Q1	58.00	15	16	1.25
M1Q2	59.00	10	15	1.28
M1Q3	61.00	10	15	1.35
M1Q4	62.00	11	15	1.34
M1Q5	63.50	12	15	1.26
M1S1Q1	64.00	10	12	1.28
M1S1Q2	64.50	9	12	1.36
M1S1Q3	65.00	12	12	1.25
M1S1Q4	65.90	11	13	1.24
M1S1Q5	67.00	12	12	1.22
M1S2Q1	67.15	11	12	1.35
M1S2Q2	67.95	12	12	1.36
M1S23Q3	68.25	12	12	1.34
M1S2Q4	69.00	12	12	1.32

M1S2Q5	69.55	13	12	1.26
M1S3Q1	69.15	11	11	1.22
M1S3Q2	69.00	11	12	1.23
M1S3Q3	68.85	12	12	1.24
M1S3Q4	68.00	11	12	1.28
M1S3Q5	67.90	12	11	1.25
M1S4Q1	66.25	11	11	1.31

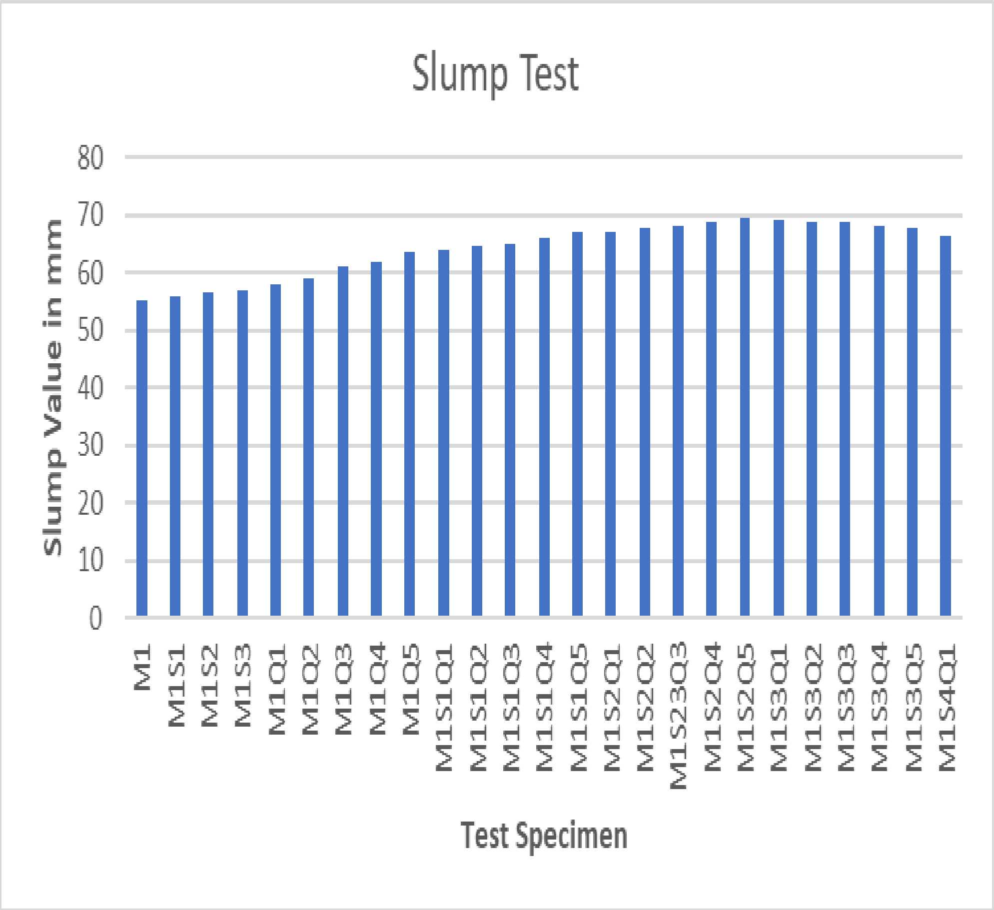

Figure 4.1 Test Results of Slump Value on GPC

4.3 RESULTS OF STRENGTH TEST

Experimental investigation has been done on the mechanical characteristics of GPC under ambient curing circumstances, including mechanical and durability properties.

4.3.1 COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE

The development of compressive strength in the hardened GPC is the primary measure used to assess the efficacy of the substitute source material since it offers an essential description of the properties of the geopolymerization products.

Compressive strength results of all the specimens were cured at 7, 28, 56 and 90 days and were presented in Table 4.2. Compressive strength results after 7, 28, 56 and 90 days in ambient curing of geopolymer concrete cubes depicted a Geopolymer concrete increased in strength on additionally higher percentage of TSP with Silica fume @ 5%, 10%, 15% and recycled aggregates with quarry dust @10%, 20%, 30%, 40%, 50% but the mixes M1, M1S2 and M1S2Q5 shown better results when compared to normal concrete. The compressive strength for the specimens of NC 29.145 MPa, M1 31.60 MPa, M1S2 35.69 MPa and M1S2Q5 38.19 MPa were noted at 28 days, NC 30.15 MPa, M1 32.30 MPa, M1S2 36.10 MPa and M1S2Q5 40.15 MPa were noted at 56 days, NC 31.26 MPa, M1 34.50 MPa, M1S2 38.10 MPa, M1S2Q5 42.15 MPa were noted at 90 days respectively. The enhanced compressive strength of 0.084% for mix M1, 0.225% for mix M1S2, and 0.335% for mix M1S2Q5 at 28 days when compared to normal concrete (NC). An increase in compressive strength of 0.071% for mix M1, 0.197% for mix M1S2, and 0.332% for mix M1S2Q5 at 56 days compared to normal concrete (NC). An increase of compressive strength of 0.104% for mix M1, 0.219% for mix M1S2, and 0.348% for mix M1S2Q5 at 90 days compared to normal concrete (NC). The specimen M1S2Q5 at 28, 56 and 90 days strength was nearly equal to the target strength, which is 38.25MPa. Compressive strengths for all themixes areshown in Figure 4.2.

Calcium compounds in the geopolymer mix, together with cementitious ingredients FA, GGBS, silica fume, and TSP, enhanced the sample's mechanical strength. The pozzolanic reaction, which intensifies when TSP is employed in calcium compounds, might be the cause of the GPC increased compressive strength with the inclusion of TSP. Al and Si become much more soluble in calcium compounds, and with an increase in concrete age, the strength has been enhanced. The concrete containing Geopolymer has been observed

Comparable pattern of strength increased with function of age when compared to normal concrete. The presence of more calcium silicate hydrate gel in addition to the predominate aluminosilicate gel in geopolymer concrete may be responsible for the overall trend of greater strengths in GPC, including TSP.

Table 4.2 Compressive Strength of Geopolymer Concrete Specimen

Samples Mix I'd	**COMPRESSIVE STRENGTH (MPa)**			
	7 Days	**28 Days**	**56 Days**	**90 Days**
Control	---	33.27	33.45	32.26
M1	23.25	31.60	32.30	34.50
M1S1	30.37	34.44	35.90	36.70
M1S2	32.32	35.69	36.10	38.10
M1S3	33.10	36.06	37.50	39.20
M1Q1	20.25	21.15	32.5	34.65
M1Q2	23.37	23.45	36.2	36.95
M1Q3	25.32	25.90	36.95	38.75
M1Q4	26.70	26.95	37.95	40.1
M1Q5	28.85	29.01	38.2	41.35
M1S1Q1	25.05	32.12	32.9	35.25
M1S1Q2	30.80	35.56	36.95	37.85
M1S1Q3	32.95	36.15	37.45	39.15
M1S1Q4	33.05	36.98	38.15	40.05
M1S1Q5	34.35	37.5	38.95	41.85
M1S2Q1	28.20	33.25	33.5	35.85
M1S2Q2	31.65	36.45	37.15	38.2
M1S23Q3	33.5	37.32	38.4	40.15
M1S2Q4	34.82	38	38.95	41.65
M1S2Q5	35.45	38.91	40.15	42.15
M1S3Q1	30.35	30.95	31.25	33.25
M1S3Q2	31.23	35.15	36.15	37
M1S3Q3	32.56	36.1	37.45	38.15
M1S3Q4	32.25	36.99	37.99	38.9
M1S3Q5	32	37.15	39	40.05

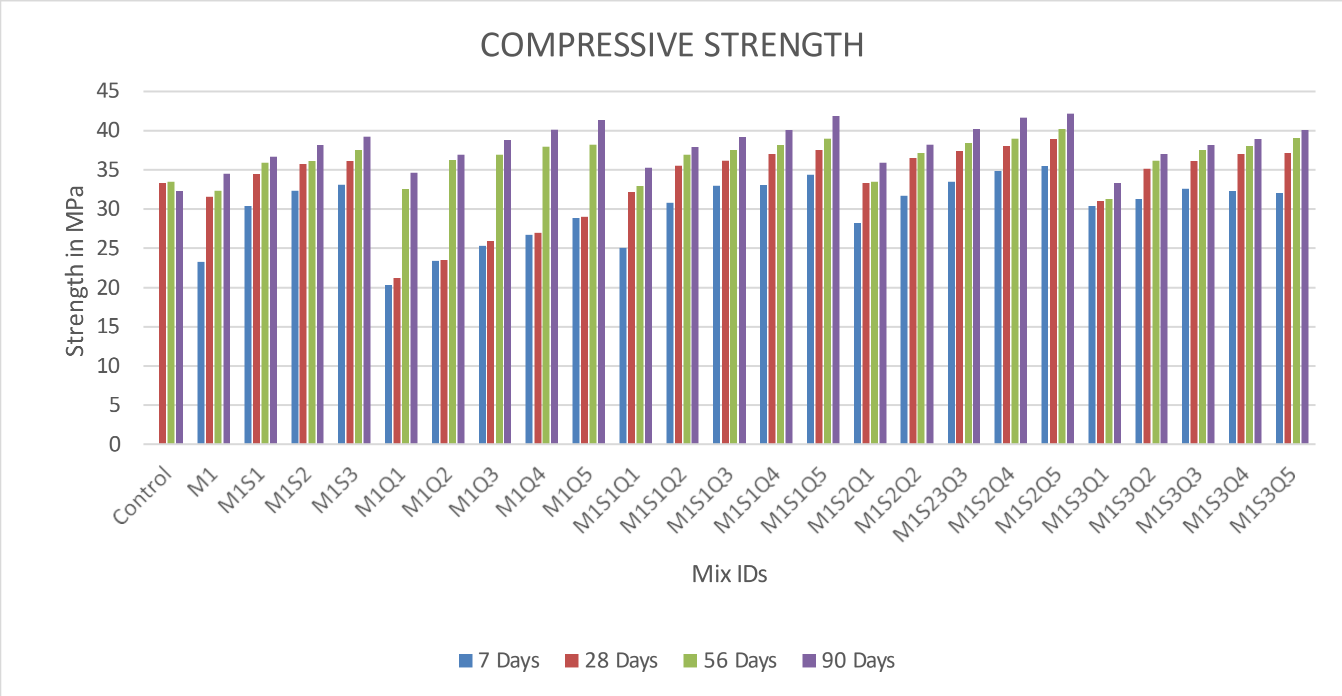

Figure 4.2 Effect of Geopolymer on Compressive Strength

4.3.2 TENSILE STRENGTH OF GEOPOLYMER CONCRETE

The resultant split tensile strength of the specimens at 7, 28, 56 and 90 days are provided in Table 4.3. The split tensile strength showed an increasing trend when concrete made with TSP, Silica fume, and Quarry dust in GPC concrete as shown in Fig.4.3. An increased Split tensile strength was observed for concrete mix with varying dosages 5,%,10% and 15% of Silica fume in TSP and 10%,20%,30%,40% and 50% of quarry dust in Fine aggregate for the mixes N.C, M1, M12 and M1S2Q5. The Tensile strength results subsequent to 28 days, 56 and 90 days of EEC curing of geopolymer concrete cubes depicted an increase in the strength of geopolymer concrete on addition of a higher percentage of TSP with Silica fume at 5%, 10%, and 15% and recycled aggregates with quarry dust at 10%, 20%, 30%, 40% and 50% but the mixes M1, M1S2 and M1S2Q5 shows better results when compared to results obtained of other mixes. The tensile strength of 2.6 MPa, 2.78 MPa, 2.93 MPa, and 5.25 MPa results were observed for normal concrete-NC, M1, M1S2 and M1S2Q5 samples at 28 days, 2.85 MPa,

2.90 MPa, 2.98 MPa, and 6.95 MPa results were observed for normal concrete-NC, M1, M1S2, and M1S2Q5 at 56 days, 2.92 MPa, 3.10 MPa, 4.20 MPa, 7.35 MPa results were observed for normal concrete-NC, M1, M1S2, and M1S2Q5 at 90 days respectively. An increase of tensile strength at 28 days was observed for samples M1 was 0.069%, M1S2 was 0.127%, M1S2Q5 was1.019%, the tensile strength at 56 days was observed for samples M1 was 0.018%, M1S2 was 0.046%, M1S2Q5 was 1.439%, and the tensile strength at 90 days was observed for samples M1 was 0.060%, M1S2 was 0.0436%, M1S2Q5 was 1.513% with respect to normal concrete (NC). In the mix M1S2Q5 cylindrical tested under split tensile loading, the tensile strength was observed at 7.93 MPa, which was noted to be 1.884% higher than the tensile strength of normal concrete, which was 5.25 MPa. This may be probably because of the TSP which led to the interfacial transition zone densification and micro filler action of the concrete matrix. The addition of TSP, Silica fume, and quarry dust to the GPC concrete improved the interfacial bond, which significantly enhanced the split Tensile Strength, as shown in Fig.4.3.

Table 4.3 Tensile Strength of Geopolymer Concrete Specimen

Sample Mix I'd	**SPLIT TENSILE STRENGTH (MPa)**			
	7 Days	**28 Days**	**56 Days**	**90 Days**
Control	---	2.6	2.85	2.925
M1	1.94	2.78	2.90	3.10
M1S1	2.35	2.85	2.99	3.80
M1S2	2.27	2.93	2.98	4.20
M1S3	2.35	2.99	3.10	4.60
M1Q1	1.24	1.55	3.15	3.85
M1Q2	1.65	1.90	3.99	4.15
M1Q3	2.07	2.50	4.1	4.95
M1Q4	2.35	2.85	4.95	5.01
M1Q5	2.89	2.95	5.15	5.55
M1S1Q1	2.01	2.5	3.55	4.01
M1S1Q2	2.65	2.95	4.1	4.85
M1S1Q3	2.78	3.15	5.25	5.55
M1S1Q4	3.15	3.55	5.9	6.15
M1S1Q5	3.95	4.15	6.25	6.95
M1S2Q1	2.85	3.01	4.01	4.65
M1S2Q2	3.1	3.55	4.85	5.25
M1S23Q3	3.75	4.05	5.55	6.15

M1S2Q4	4.25	4.99	6.02	6.9
M1S2Q5	5.01	5.25	6.95	7.35
M1S3Q1	2.75	2.99	3.85	4.01
M1S3Q2	2.99	3.25	4.15	4.95
M1S3Q3	3.55	3.85	5.15	5.35
M1S3Q4	4.15	4.25	5.85	6.35
M1S3Q5	4.99	5.15	5.55	6.75

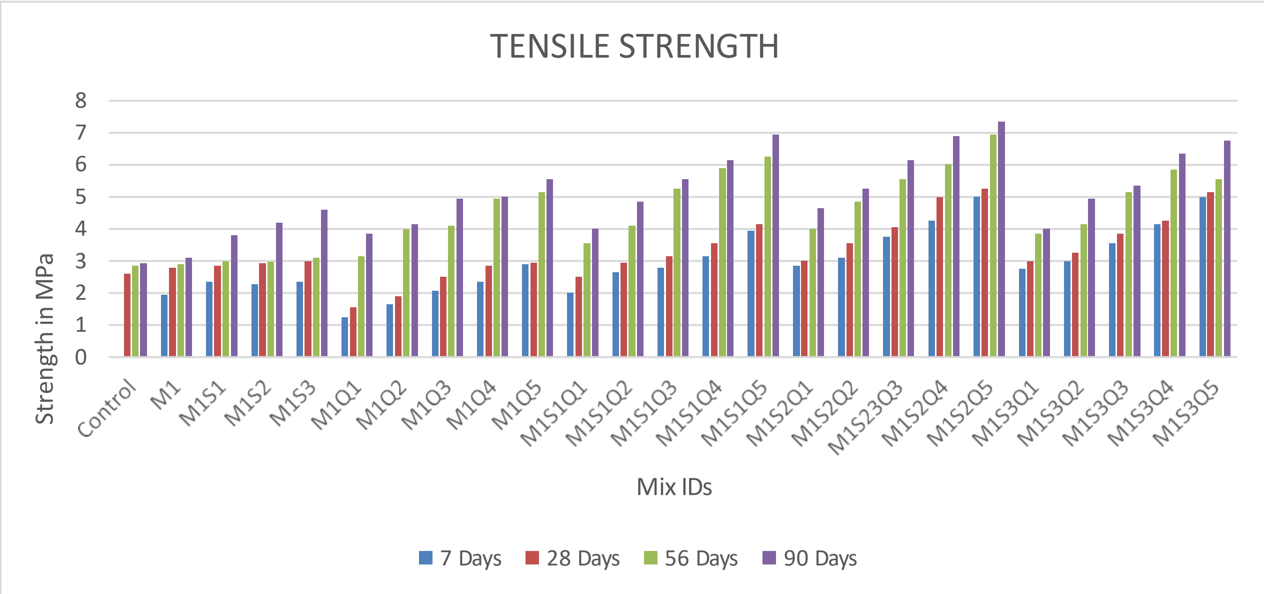

Figure 4.3 Effect of Geopolymer on Tensile Strength

4.3.3 FLEXURAL STRENGTH OF GEOPOLYMER CONCRETE

The outcomes of flexural strength specimens at 28, 56 and 90 days are presented in Table 4.4. flexural strength showed an increased trend when TSP with Silica fume and Fine aggregate with quarry dust were included in GPC concrete as shown in Fig.4.4 A considerable increase in flexural strength was observed by concrete mixes involving 5%, 10% and 15% of Silica fume in TSP and 10%, 20%, 30%, 40% and 50% of quarry dust in Fine aggregate for the mixes N.C, M1, M12, and M1S2Q5. The flexural strength results after 28 days, 56 and 90 days of EEC curing of geopolymer concrete cubes depicted an increased in the strength of geopolymer concrete.

In addition, a higher percentage of TSP with Silica fume at 5%, 10%, and 15% and recycled Aggregates with quarry dust at 10%, 20%, 30%, 40%, and 50% but the mixes M1, M1S2, and

M1S2Q5 shown better results as compared to results obtained of other mixes. The flexural strength at 28 days was observed for samples NC 2.35 MPa, M1 3.89 MPa, M1S2 4.79 MPa, and M1S2Q57.15 MPa, samples at 56 days of NC 2.65 MPa, M1 4.05 MPa, M1S2 4.79 MPa and M1S2Q5 8.35 MPa, samples and at 90 days of NC 3.25 MPa, M1 5.20 MPa, M1S2 7.90 MPa, M1S2Q5 10.85 MPa test results were observed. Flexural strength was shown to increase 0.655% for mix M1, 0.528% for mix M1S2, and 0.600 % for mix M1S2Q5 at 28 days when compared to normal concrete (NC). An increase of flexural strength of 1.038% for mix M1, 0.808% for mix M1S2, 1.431% for mix M1S2Q5 at 56 days when compared to normal concrete (NC). Normal concrete (NC). An increase of flexural strength of 2.043% for mix M1, 2.151% for mix M1S2, and 2.338% for mix M1S2Q5 at 90 days when compared to normal concrete (NC). The mix M1S2Q5 beams tested under flexural loading showed a flexural strength of 11.35 MPa, which was 2.331% higher than the split tensile strength of normal concrete, which was noted to be 2.35MPa. This may be probably due to the addition of TSP, which led to the interfacial transition zone's densification and micro filler action. The addition of TSP with Silica fume and Fine aggregate with quarry dust to the GPC concrete mixture improved the interfacial bond, which significantly increased the flexural strength, as Fig. 4.4 illustrates.

Table 4.4 Flexural Strength of Geopolymer Concrete Specimen

Sample Mix I'd	**FLEXURAL STRENGTH (MPa)**		
	28 Days	**56 Days**	**90 Days**
Control	2.35	2.65	3.25
M1	3.89	4.05	5.2
M1S1	4.26	4.68	6.25
M1S2	4.79	4.79	7.90
M1S3	5.13	5.63	8.65
M1Q1	4.01	4.75	5.5
M1Q2	4.50	4.95	6.9
M1Q3	4.85	5.01	8.1
M1Q4	5.25	5.99	9.25
M1Q5	5.62	6.01	9.35
M1S1Q1	4.15	5	6.15

M1S1Q2	4.95	5.35	7.5
M1S1Q3	5.25	5.85	8.5
M1S1Q4	5.99	6.35	9.65
M1S1Q5	6.25	6.85	10.5
M1S2Q1	4.85	5.85	6.25
M1S2Q2	5.25	6.45	7.55
M1S23Q3	6.25	6.95	8.85
M1S2Q4	6.86	7.5	10.15
M1S2Q5	7.15	8.35	10.85
M1S3Q1	4.25	5	5.55
M1S3Q2	4.85	5.35	6.1
M1S3Q3	5.75	5.75	7.45
M1S3Q4	6.15	6.99	8.15
M1S3Q5	7	7.45	9.35

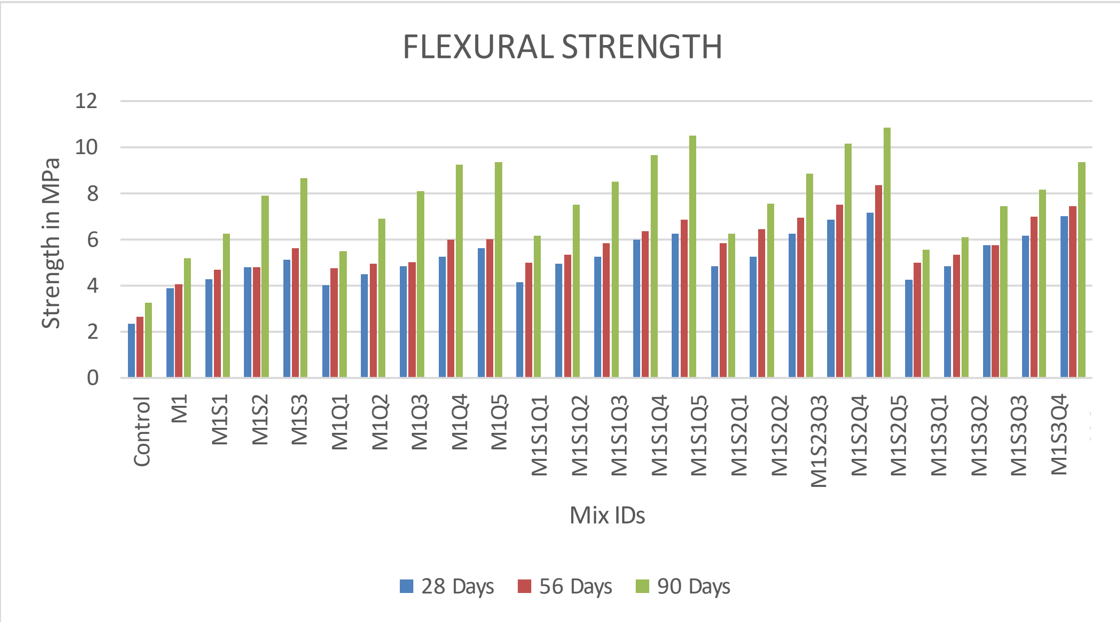

Figure 4.4 Effect of Geopolymer on Flexural Strength

4.4 COST ANALYSIS

Table 4.9 shows the savings in cost in contrast to regular concrete. The outcomes obtained were analyzed in depth, and cost optimization was carried out by finding the cost required in materials used for preparing 1 cubic meter of concrete for all the mixes NC, M1, M1S2, and M1S2Q5. The cost required for materials for the casting of 1 cubic meter of concrete for all the NC, M1, M1S2, and M1S2Q5 were 5797.02/-, 4423.4/-, 4444.07/- and 4422.29/- in
Indian Rupees respectively. The cost required for optimum mix M1S2Q5 was 23.71% lower when compared to normal concrete (NC). Geopolymer concrete offers potential long-term benefits such as reduced carbon footprint and improved durability, which could offset low expenses over the lifespan of a structure in determining the cost-effectiveness of geopolymer concrete when compared to normal concrete. Figure 4.5 and 4.6 displays the cost analysis.

Table 4.5 Cost Analysis of Conventional Mix of M25 Grade Concrete

Description	Quantity	Rate in Rs per kg.	Total Amount in Rs
Cement	394 kg/m^3	10	3940.00
Fine aggregate	791 kg/m^3	0.65	514.15
Coarse Aggregate	1068 kg/m^3	0.7	747.6
Mason (for 2hrs)	1 No	75 Rs/hour	150.00
Labor (for 2hrs)	3 Nos	50 Rs/hour	300.00
Miscellaneous	Lumpsum	45 Rs	45.00
Total of Materials and Labor			5696.75
Add 1.5% water charges			100.27
Total cost for 1 cubic meter of concrete			5797.02

Table 4.6 Cost Analysis for Mix M1 Concrete

Description	Quantity	Rate in Rs per kg.	Total Amount in Rs
Fly Ash (0.33 kg/m^3)	131.33	2	262.66
GGBS (0.33 kg/m^3)	131.33	1.5	196.99
TSP (0.33 kg/m^3)	131.33	0	0
fine aggregate (2 kg/m^3)	791	0.65	514.15
coarse aggregate (2.71 kg/m^3)	1068	0.7	747.6
NaOH flakes (20Rs/kg)	7.1	20	142
Na2SiO3 solution (20Rs/kg)	101	20	2020

Mason (for 2hrs)	1 No	75 Rs/hour	150.00
Labor (for 2hrs)	3 Nos	50 Rs/hour	300.00
Miscellaneous	Lumpsum	45 Rs	45.00
The total cost of Materials and Labor for 1 cubic meter GP concrete			4423.4

Table 4.7 Cost Analysis for Mix M1S2 Concrete

Description	Quantity	Rate in Rs per kg.	Total Amount in Rs
Fly Ash (0.33 kg/m^3)	131.33	2	262.66
GGBS (0.33 kg/m^3)	131.33	1.5	196.99
TSP (0.297 kg/m^3)	118.19	0	0
Silica fume(0.033 kg/m^3)	13.13	5	65.66
fine aggregate (2 kg/m^3)	791	0.65	514.15
coarse aggregate (2.71 kg/m^3)	1068	0.7	747.6
NaOH flakes (20Rs/kg)	7.1	20	142
Na2SiO3 solution (20Rs/kg)	101	20	2020
Mason (for 2hrs)	1 No	75 Rs/hour	150.00
Labor (for 2hrs)	3 Nos	50 Rs/hour	300.00
Miscellaneous	Lumpsum	45 Rs	45.00
The total cost of Materials and Labor for 1 cubic meter GP concrete			4444.07

Table 4.8 Cost Analysis for Mix M1S2Q5 Concrete

Description	Quantity	Rate in Rs per kg.	Total Amount in Rs
Fly Ash (0.33 kg/m^3)	131.33	2	262.66
GGBS (0.33 kg/m^3)	131.33	1.5	196.99
TSP (0.297 kg/m^3)	18.19	0	0
Silica fume(0.033 kg/m^3)	13.13	5	65.66
fine aggregate (1 kg/m^3)	395.5	0.65	257.07
quarry dust(1 kg/m^3)	395.5	0.6	237.3
coarse aggregate (2.71 kg/m^3)	1068	0.7	747.6
NaOH flakes (20Rs/kg)	7.1	20	142
Na2SiO3 solution (20Rs/kg)	101	20	2020
Mason (for 2hrs)	1 No	75 Rs/hour	150.00

Labor (for 2hrs)	3 Nos	50 Rs/hour	300.00
Miscellaneous	Lumpsum	45 Rs	45.00
The total cost of Materials and Labor for 1 cubic meter GP concrete			4422.29

Table 4.9 Savings in Cost in Rs through Normal Concrete

Sample Name	Cost Production of 1 Cubic Meter i n Rs	Savings In Cost in Rs Through Normal Concrete	Savings in %
NC	5797.02	---	---
M1	4423.4	1373.62	23.69
M1S2	4444.07	1352.95	23.38
M1S2Q5	4422.29	1374.73	23.71

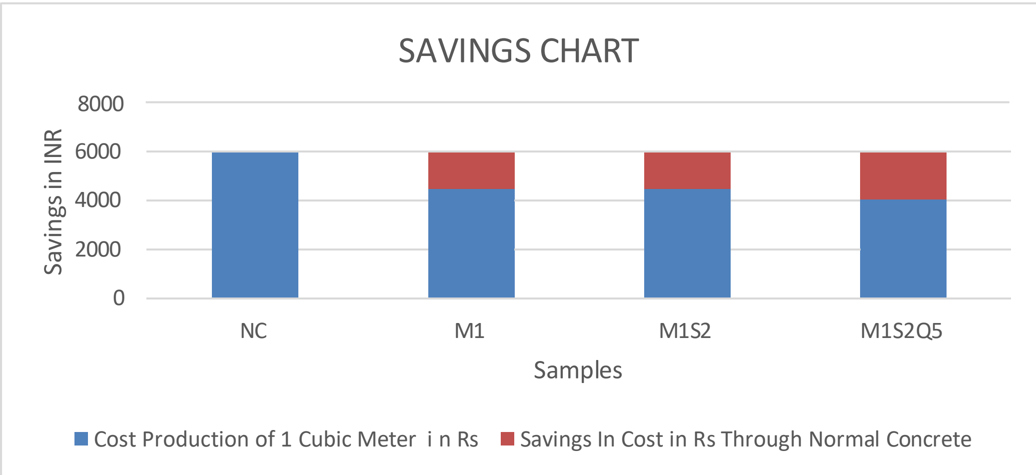

Figure 4.5 Cost Analysis

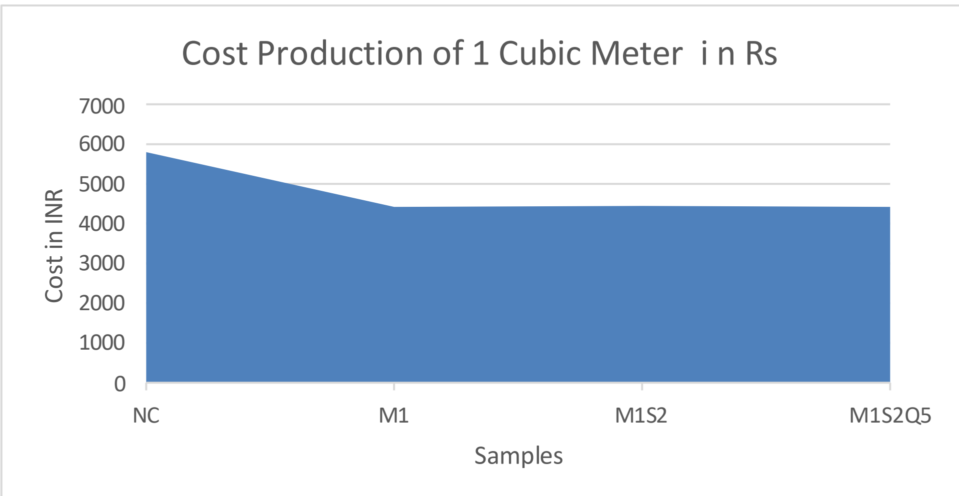

Figure 4.6 Cost Comparison of GPC

4.5 DURABILITY TESTS RESULTS

The durability test was conducted on four different mix proportions and the mix details were shown in Table 4.10.

Table 4.10 Mix Proportion of Concrete for Durability Test

Sample Mix I'd	Cement (Kg/m^3)	Fly Ash (Kg/m^3)	GGBS (Kg/m^3)	Tandur Stone (Kg/m^3)	Silica Fumes (Kg/m^3)	Fine aggregate (Kg/m^3)	Quary dust (Kg/m^3)	Coarse aggregate (Kg/m^3)
Control	394	-	-	-	-	791.000	-	1068
M1	-	131.33	131.33	131.330	-	791.000	-	1068
M1S2	-	131.33	131.33	118.197	13.133	791.000	-	1068
M1S2Q5	-	131.33	131.33	118.197	13.133	395.500	395.500	1068

4.5.1 RCPT TEST

The findings of the Rapid Chloride Permeability Test (RCPT) for GPC specimens are depicted in Figure 4.7. The total charge passed through various GPC mixes in the modified RCPT, as per McGrath (1999), at 28 days, was provided in Table 4.11 & Figure 4.7.The chloride penetration test (RCPT) was performed on mixes NC, M1, M1S2, and M1S2Q5. The results showed that the charge passed in coulombs to be 2737, 2768, 2775, and 2815, respectively. The results are below 4000 Coulombs charge pass, which was the moderate limit, but it indicates an increase in chloride penetration with an increase in TSP and recycled aggregates. The pore structure stands out as a pivotal parameter influencing chloride penetration.

Table 4.11 Test Results of RCPT

Sample	Types of Concrete	Charge Passed in Coulombs
N.C	Conventional Concrete	2737
M1	Geopolymer concrete (33.33% of Fly Ash, @33.33% of GGBS @33.33% of TSP @0% of QD	2768
M1S2	Geopolymer concrete (33.33% of Fly Ash, @33.33% of GGBS @23.33% of TSP @10% of SF @ 0% of QD	2775

M1S2Q5	Geopolymer Concrete (33.33% of Fly Ash, @33.33% of GGBS @23.33% of TSP @10% of SF@50% Fine Aggregte@50% of QD	2815

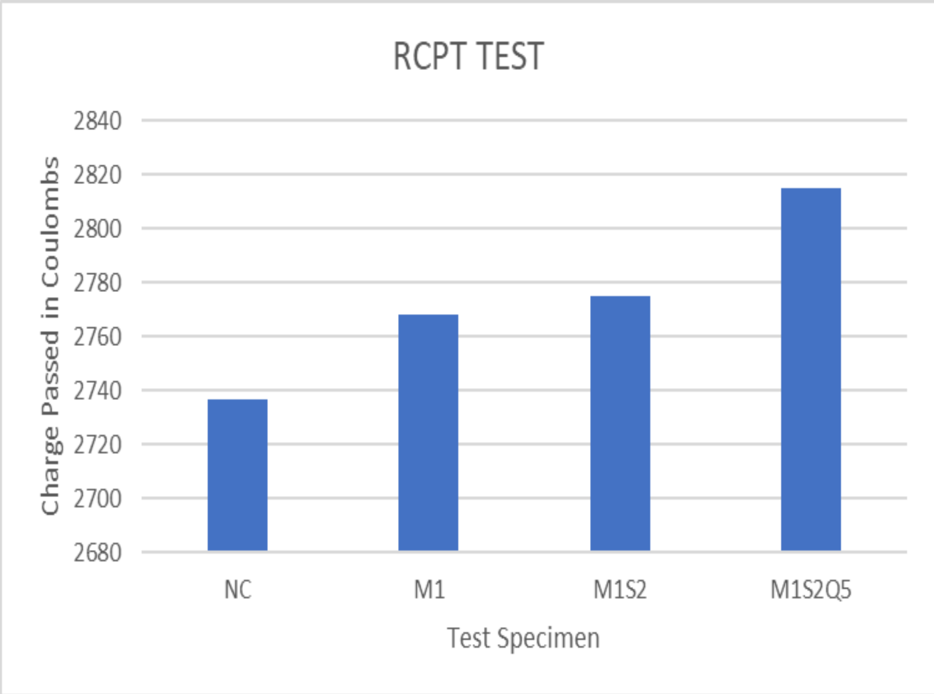

Figure 4.7 Effects of Geopolymer on RCPT.

4.5.2 SORPTIVITY TEST

The capillary rise was calculated for GPC specimens NC, M1, M1S2, and M1S2Q5 after 28 days of curing, presented in Table 4.12 and Figure 4.8. The sorptivity of all four spectrums progressively decreased with the addition of TSP with Silica fume and Fine aggregate with quarry dust content under ambient curing conditions. The inclusion of TSP with Silica fume and Fine aggregate with quarry dust increases the sorptivity value to 55.84% compared to NC- GPC specimens. The presence of calcium oxide content improves the microstructural property by the formation of Ca–Al-Si gel, which in turn strengthens the final product by filling up the pores. Also, the finer TSP particles produced the pores, creating a micro-filler effect. The sorptivity value decreased with an increase in age.

Table 4.12 Test Results of Sorptivity

Sample No	Sample Name	Volume of Water Absorb /Area of Surface Exposure (cm)				Sorptivity x 10^{-3}
		30 min	60 min	90 min	120 min	(cm/min$^{0.5}$)
NC	Conventional Concrete	0.03	0.04	0.06	0.06	4.4
M1	Geopolymer Concrete (33.33% of Fly Ash, @33.33% of GGBS @33.33% of TSP @@0% of QD	0.06	0.07	0.08	0.10	8.3
M1S2	Geopolymer Concrete (33.33% of Fly Ash, @33.33% of GGBS @23.33% of TSP @10% of SF @ 0% of QD	0.08	0.08	0.10	0.11	8.3
M1S2Q5	Geopolymer Concrete (33.33% of Fly Ash, @33.33% of GGBS @23.33% of TSP @10% of SF@50% Fine Aggregte@50% of QD	0.08	0.09	0.10	0.11	8.3

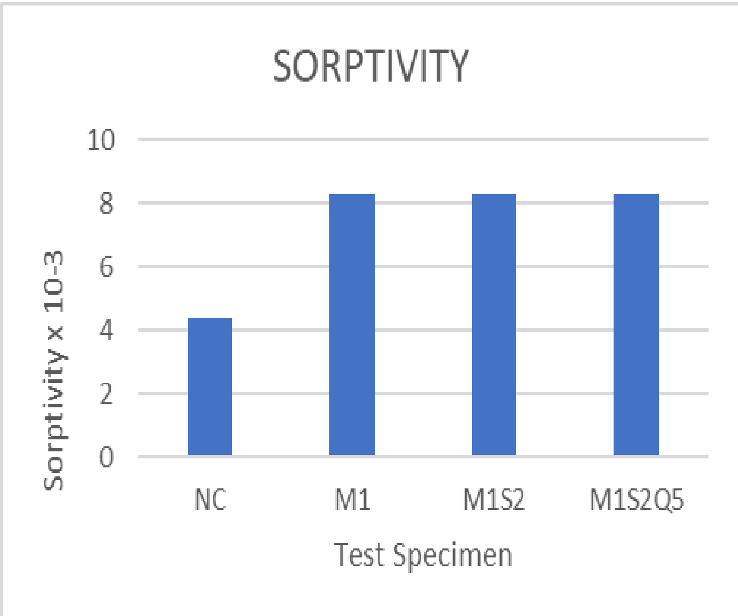

Figure 4.8 Effects of Geopolymer on Sorptivity

4.5.3 WATER PERMEABILITY TEST

The saturated water permeability of GPC specimens NC, M1, M1S2, and M1S2Q5 after 28 days are given in Table 4.13. Saturated water permeability of GPC increased with additional TSP with Silica fume and Fine aggregate with quarry dust under ambient curing conditions, as the TSP is finer and hygroscopic in nature. Water absorption values of NC, M1, M1S2, and M1S2Q5 GPC concrete specimens were found to fall within the range of 4.51% & 5.13% at 28 days of curing, correspondingly. The water absorption values for all GPC mixes are presented in Figure 4.9.

Table 4.13 Test Results of Water Permeability

Sample No	Sample Name	Water Permeability Coefficient (X 10^{-11} m/s)	Void Content (%)
N.C	Conventional Concrete	4.01	10.5
M1	Geopolymer Concrete (33.33% of Fly Ash, @33.33% of GGBS @33.33% of TSP @@0% of QD	3.85	13
M1S2	Geopolymer Concrete (33.33% of Fly Ash, @33.33% of GGBS @23.33% of TSP @10% of SF @ 0% of QD	3.15	10.8
M1S2Q5	Geopolymer Concrete (33.33% of Fly Ash, @33.33% of GGBS @23.33% of TSP @10% of SF@50% FINE AGGREGTE@50% of QD	2.61	10

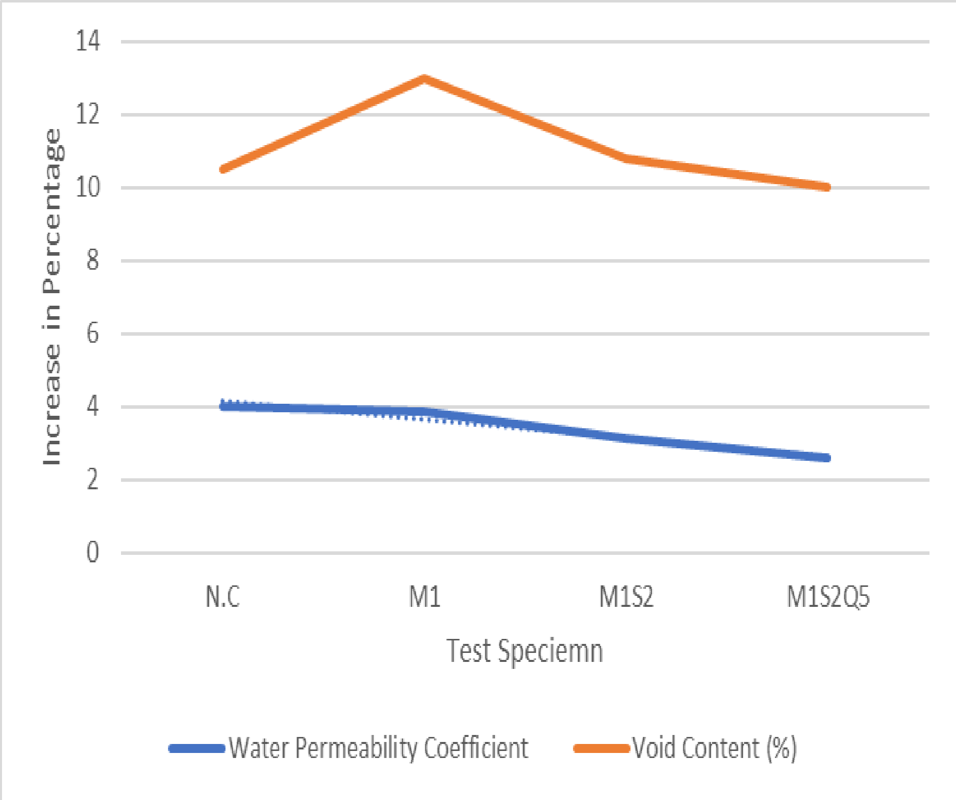

Figure 4.9 Effects of Geopolymer on Water Permeability

4.6 EDS TEST

The energy dispersive spectroscopy analysis (EDS) was conducted on four specimens was convention concrete, M1, M1S2, and M1S2Q5 were shown in figures 5.10, 5.11, 5.12, 5.13, and 4.14. The atomic percentages of all four spectrums NC, M1, M1S2 & M1S2Q5 were been tabulated in Table 4.14. And same was expressed by graphical representation in graph 4.14. The percentage of calcium silicates for spectrum NC is found more when compared to spectrum M1 and spectrum M1S2 and the percentage of calcium silicates for spectrum NC was found less compared to M1S2Q5 which was an optimum mix and maximum which represents more strength and elastic behavior of the mix and hence verifies experimental behavior of M1S2Q5 use for the constructional works.

Table 4.14 EDS - Chemical Composition

Chemical Name	Spectrum NC		Spectrum M1		Spectrum M1S2		Spectrum M1S2Q5	
	Wt%	Atomic %	Wt%	Atomic %	Wt%	Atomic %	Wt%	Atomic %
C- Carbon	6.85	15.68	4.33	7.38	24.52	35.08	10.08	18.72
O - Oxygen	28.39	48.81	45.10	57.73	41.55	44.62	31.77	44.30
Na -Sodium	---	---	0.79	0.70	0.25	0.19	0.95	0.92
Mg -Magnesium	---	---	0.00	0.00	0.06	0.04	1.60	1.47
Al - Aluminium	0.37	0.38	9.43	7.16	0.41	0.26	5.07	4.20
Si – Silicon	0.92	0.90	28.69	20.92	31.31	19.15	13.23	10.51
K -Potassium	---	---	11.43	5.99	0.09	0.04	0.82	0.47
Ca -Calcium	2.75	1.89	0.23	0.12	0.72	0.31	31.20	17.37
Ti -Titanium	29.86	17.15	0.00	0.00	0.09	0.03	0.99	0.46
Fe -Iron	30.85	15.19	0.00	0.00	0.19	0.06	0.72	0.29
Cu -Copper	---	---	---	---	0.80	0.22	2.66	0.93
Mn -Manganese	----	---	---	---	---	---	0.93	0.38
TOTAL	100	100	100	100	100	100	100	100

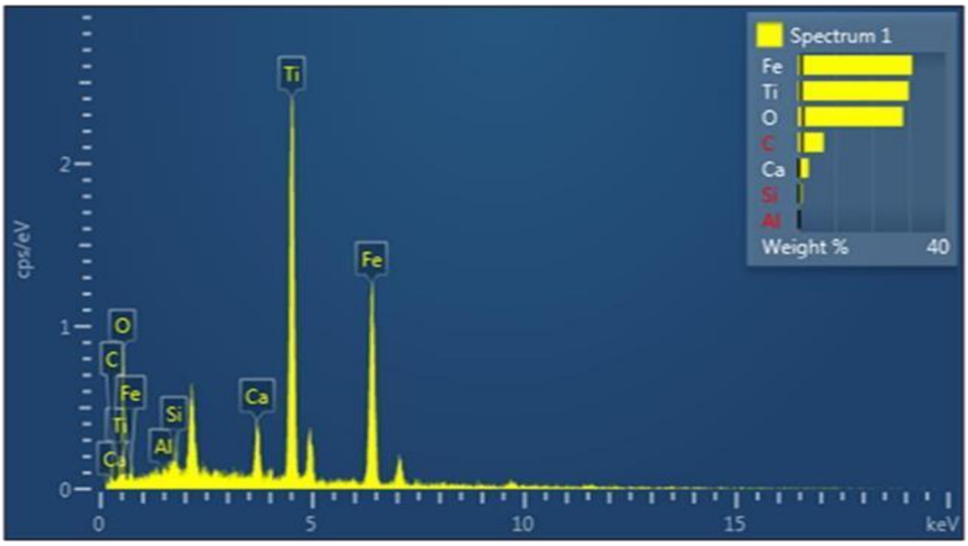

Figure 4.10 EDS Image for Normal Concrete Sample

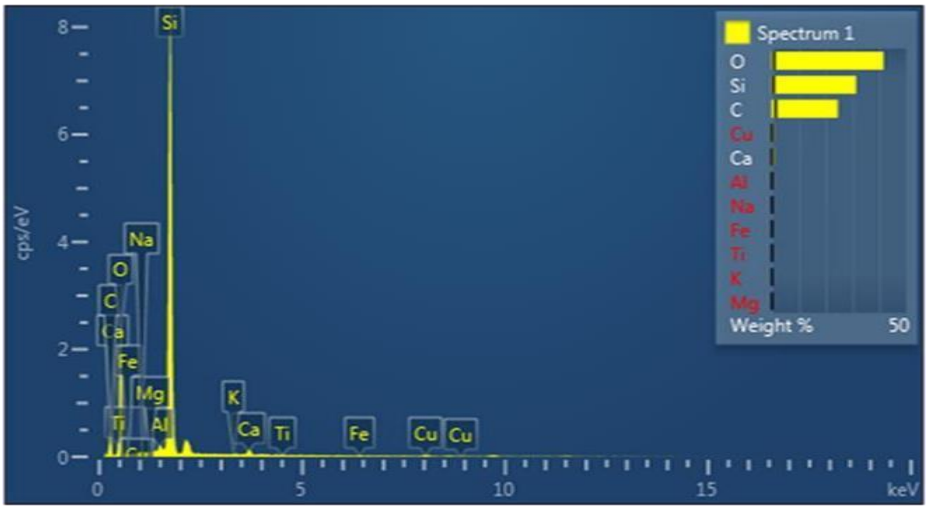

Figure 4.11 EDS Image for M1 Sample

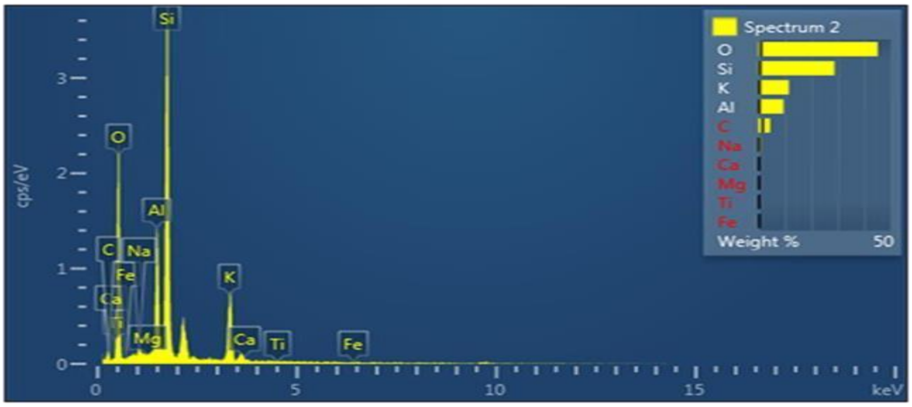

Figure 4.12 EDS Image for M1S2 Sample

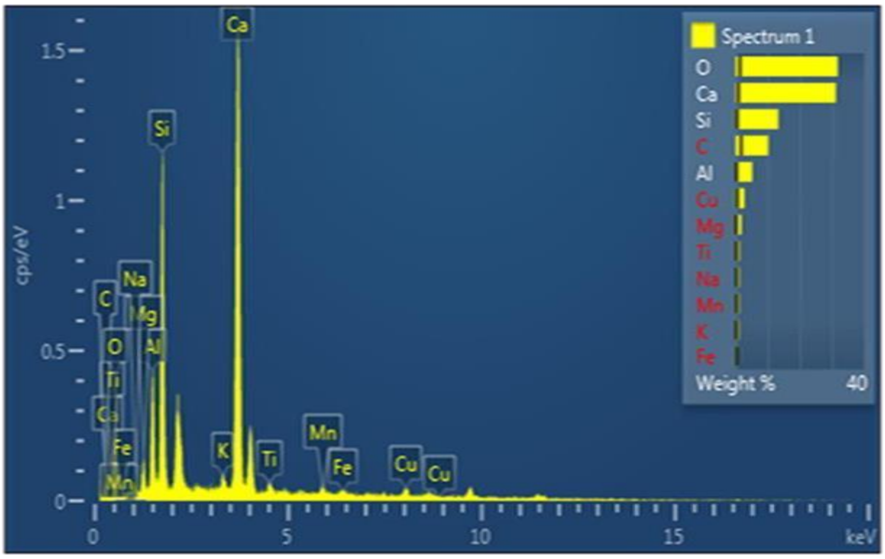

Figure 4.13 EDS Image for M1S2Q5 Sample

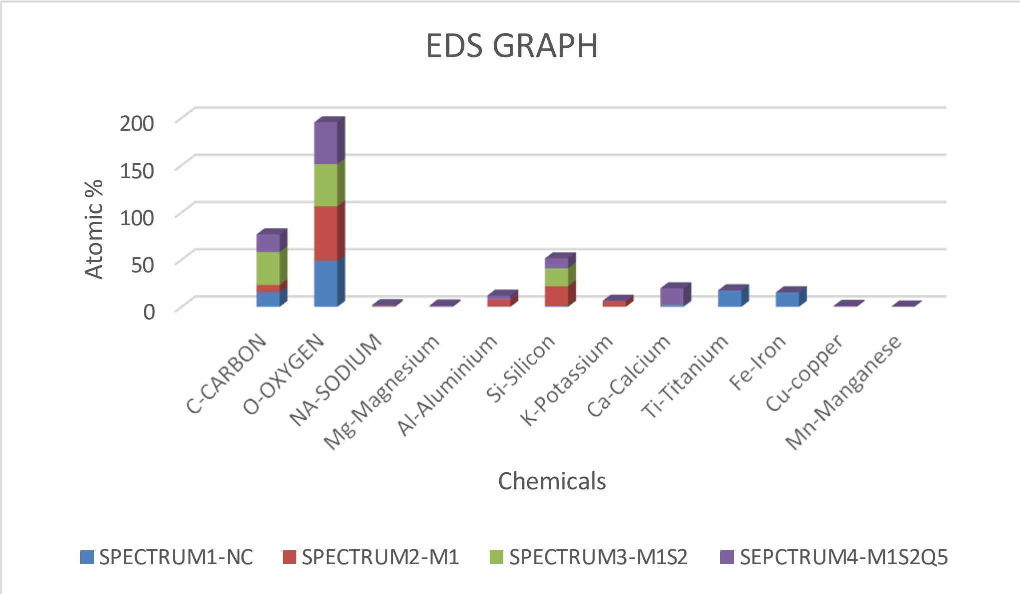

Figure 4.14 EDS Image

The EDS results reveal the presence of major elements such as calcium (Ca), silicon (Si), aluminum (Al), oxygen (O), and iron (Fe), which are the primary constituents of cementitious materials. The variations in chemical composition due to the incorporation of supplementary cementitious materials (SCMs) are discussed below:

1. Calcium (Ca) Content:
   - The calcium content in NC is found to be the highest due to the dominance of ordinary Portland cement (OPC).
   - With the addition of fly ash (M1), a slight reduction in calcium content is observed due to the dilution effect of the pozzolanic material.
   - The M1S2 mix (silica fume + fly ash) further reduces the calcium content, as silica fume has minimal calcium contribution.
   - The M1S2Q5 mix shows a significant increase in calcium content compared to M1S2, indicating the presence of fine calcium-rich particles from the quarry dust, enhancing the hydration process.
2. Silicon (Si) Content:
   - The silicon content increases progressively from NC → M1 → M1S2 → M1S2Q5, with the highest values recorded in M1S2Q5.

- This trend is attributed to the addition of silica fume and fly ash, both of which are rich in SiO_2 and contribute to secondary hydration reactions, leading to enhanced strength and durability.

3. Aluminum (Al) Content:
   - The aluminum content is notably higher in M1 and M1S2, as fly ash contains aluminosilicates that contribute to the pozzolanic activity.The presence of quarry dust in M1S2Q5 does not significantly alter the aluminum content, indicating that it mainly affects calcium and silicon availability rather than alumina-based compounds.
4. Oxygen (O) Content:
   - Oxygen levels remain relatively stable across all mixes, correlating with the oxides present in cementitious compounds.
   - However, a marginal increase in M1S2 and M1S2Q5 suggests an increase in hydrated phases due to the pozzolanic reaction of silica fume and fly ash.
5. Iron (Fe) and Other Minor Elements:
   - The iron content shows minor variations across all mixes but remains within typical ranges for concrete.
   - Trace elements such as magnesium (Mg), potassium (K), and sulfur (S) are also detected in varying proportions, indicating the influence of SCMs on the overall composition.

Interpretation of EDS Findings

The EDS results indicate that the incorporation of silica fume, fly ash, and quarry dust alters the chemical composition of concrete, particularly in terms of calcium, silicon, and aluminum content. The key observations are:

- Reduction in Ca content with the inclusion of SCMs, leading to a more refined and denser microstructure.
- Increase in Si content, particularly in M1S2Q5, signifying enhanced pozzolanic activity.
- Presence of aluminosilicates, confirming the supplementary role of fly ash and silica fume in cement hydration.
- Optimal mix M1S2Q5 exhibits the highest silicon and calcium silicate concentrations, suggesting superior strength and durability due to enhanced hydration and secondary reactions. The EDS analysis validates that the optimized mix M1S2Q5 exhibits a well-balanced chemical composition, which contributes to superior

mechanical performance. The higher calcium silicate content in M1S2Q5 enhances strength and elastic properties, making it a suitable choice for structural applications. These findings corroborate the experimental strength results, confirmingthe beneficial role of SCMs in sustainable concrete production

4.7 SEM ANALYSIS

A tool used to examine the microstructure of materials by capturing magnified pictures is the scanning electron microscope. The crushed mix identification powder samples are gold-coated and subjected to a 20000x magnification electron microscope scan.

In this study, SEM investigations were conducted to qualitatively analyze the microstructure of GPC utilizing FA-GGBS-silica fume-TSP and GPC with fine aggregate replaced by quarry dust. The SEM picture of the geopolymer matrix in the FA-GGBS-silica fume-TSP and GPC with fine aggregate replaced by the quarry dust system is displayed in the figures. In comparison to the homogeneity in the non-TSP & quarry dust-added samples under the same curing circumstances, it was noticed that the specimen's microstructure homogeneity is enhanced with the addition of TSP & quarry dust under EEC settings. Min Areas and Max Areas & mean were calculated in SEM images of geopolymer concrete which played a crucial role in both qualitative and quantitative characterization, comparative analysis, quality control, and optimization of mix designs. These techniques contributed to advancing the understanding and development of geopolymer concrete as a sustainable and durable construction material. The powdered samples were been tested 20000 times with zoom images and were shown in Figure 4.15 fly ash, figure 4.16 GGBS, Figure 4.17 silica fume, Figure 4.18 tandur stone powder and Figure 4.19 Quarry dust.

4.7.1 SEM ANALYSIS – FLY ASH

Fly ash particles typically exhibited a range of morphologies, which included spherical in shape and porous structures. The SEM image revealed the shape and surface characteristics of fly ash particles, which were based on the source and the fly ash composition.

SEM image of fly ash analyzed the fly ash particles size distribution and measured individual dimensions particles & using image analysis software, it determined the average particle size, area of the particle, maximum, minimum, and mean area particles, and the allocation of the fly ash sample, and particle area is 80.667mm^2, the mean area of the particle is 106.181mm^2, the minimum area of the particle is 11.839mm^2 and the maximum area of the particle is 194.869mm^2 and the mean length of fly ash is 79.687 mm figure 4.15 shows the SEM image fly ash and calculated areas of fly ash particles.

	Label	Area	Mean	Min	Max	Angle	Length
1		151.000	106.907	47.000	156.133	89.236	150.013
2		77.000	125.824	0.000	255.000	85.486	76.236
3		123.000	66.439	0.000	123.680	99.462	121.655
4		83.000	115.671	0.000	229.805	88.603	82.024
5		123.000	83.090	0.000	134.230	93.752	122.262
6		83.000	106.048	0.000	236.244	92.793	82.098
7		55.000	136.601	84.111	216.296	85.764	54.148
8		62.000	124.890	2.467	222.646	82.405	60.531
9		97.000	97.673	0.000	210.708	92.386	96.083
10		62.000	144.932	44.000	255.000	80.538	60.828
11		51.000	123.580	0.000	220.960	83.157	50.359
12		59.000	97.874	0.000	161.966	84.094	58.310
13		59.000	81.729	0.000	141.517	86.055	58.138
14		69.000	89.820	0.000	135.794	88.315	68.029
15		56.000	91.636	0.000	223.057	81.573	54.589
16	Mean	80.667	106.181	11.839	194.869	87.575	79.687
17	SD	30.168	22.180	25.528	46.893	5.265	30.159
18	Min	51.000	66.439	0.000	123.680	80.538	50.359
19	Max	151.000	144.932	84.111	255.000	99.462	150.013

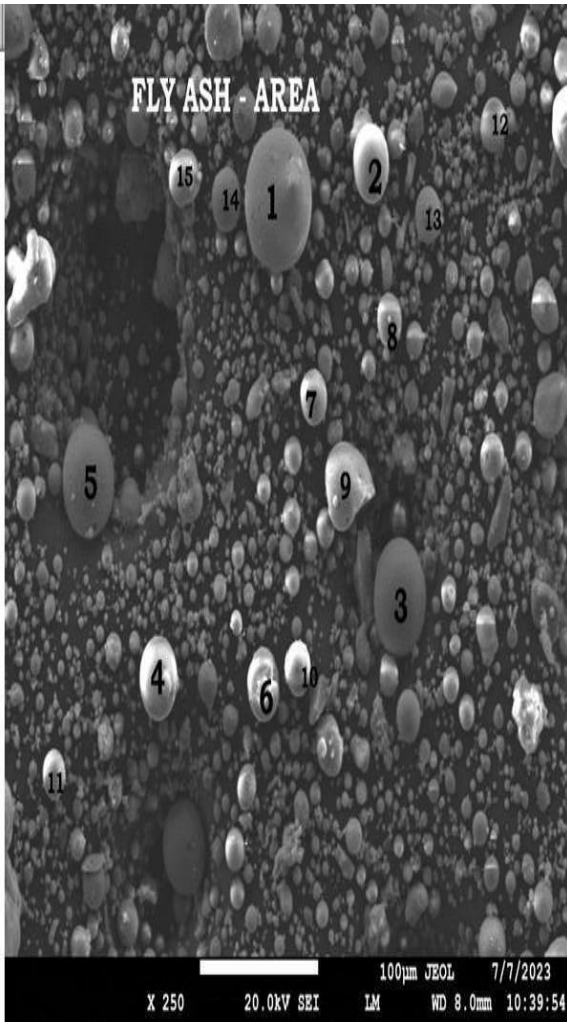

Figure 4.15 SEM Image for Fly Ash Sample

4.7.2 SEM ANALYSIS – GGBS

Random particles are selected from SEM images to find the minimum and maximum areas of the selected particles and the length of the particle from the SEM image of the GGBS sample. It is observed that the shape of the particle is an irregular shape. The area of the particle is 6571.44 mm^2, the mean of the particle is 154.70 mm^2, the minimum area of the particle is 44.66 mm^2, the maximum area of the particle is 254.55 mm^2, and the mean length of GGBS is 106.687 mm Figure 4.16 shows the SEM image GGBS and calculated areas of GGBS particles.

	Label	Area	Mean	Min	Max
1		11046	134.185	42	255
2		5969	186.831	44	255
3		2795	146.704	47	255
4		18375	162.3	41	255
5		4458	129.923	42	255
6		4733	117.277	43	251
7		4513	160.924	45	255
8		2298	133.809	46	255
9		4956	220.424	52	255
10	Mean	6571.444	154.709	44.667	254.556
11	SD	5085.835	32.373	3.391	1.333
12	Min	2298	117.277	41	251
13	Max	18375	220.424	52	255

Figure 4.16 SEM Image for GGBS Sample

4.7.3 SEM ANALYSIS – SILICA FUME

Random particles were selected from SEM images to find the minimum and maximum areas of the selected particles and the length of the particle from the SEM image of the Silica fume sample. It was observed that the shape of the particles was irregular in shape. The area of the particle is 4467.22 mm^2, the mean of the particle is 140.30 mm2, the minimum area of the particle is 40.44 mm^2, the maximum area of the particle is 229.11 mm^2, and the mean length of the silica fume is 110.56 mm Figure 4.17 shows the SEM image Silica fume and calculated areas of Silica fume particles.

SL.NO	Label	Area	Mean	Min	Max
1		7433	183.216	41	255
2		4915	158.898	44	251
3		6561	130.573	42	255
4		3454	117.981	46	189
5		2796	127.598	44	238
6		3337	117.764	44	194
7		1472	176.877	46	255
8		5993	98.62	1	170
9		4244	151.226	56	255
10	Mean	4467.222	140.306	40.444	229.111
11	SD	1930.882	28.819	15.412	34.596
12	Min	1472	98.62	1	170
13	Max	7433	183.216	56	255

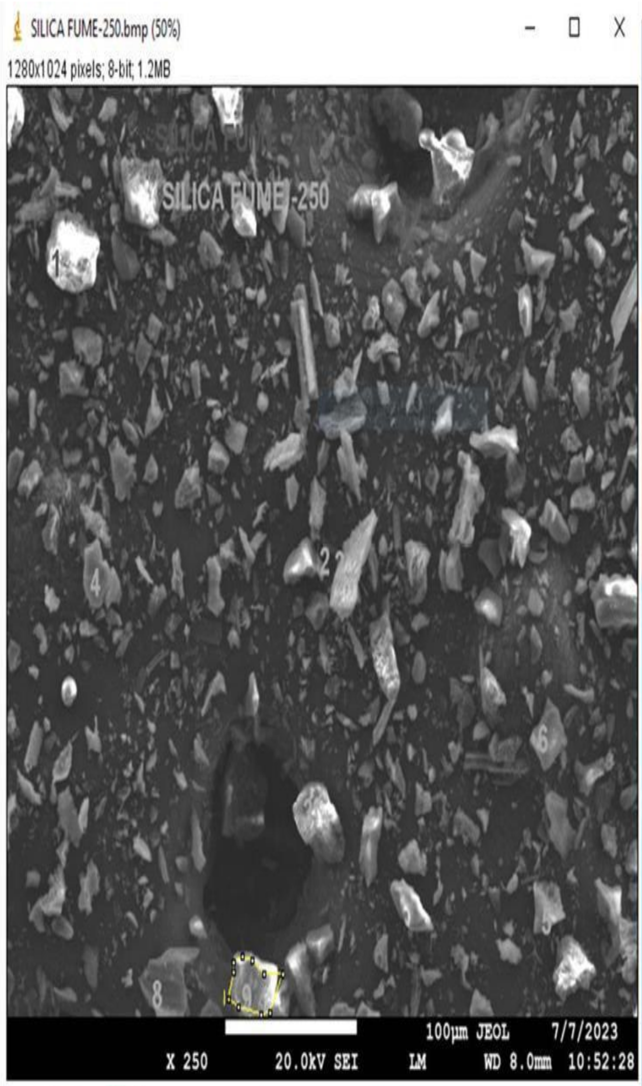

Figure 4.17 SEM Image for Silica Fume Sample

4.7.4 SEM ANALYSIS - TANDUR STONE POWDER

Random particles are selected from SEM images to find the chosen particles' minimum and maximum areas and the particle's length from the TSP sample's SEM image. It was observed that the shape of the particles was irregular in shape. The area of the particle is 1981.44 mm^2, the mean of the particle is 142.20 mm^2, the minimum area of the particle is 45.77 mm^2, the maximum area of the particle is 254.66 mm^2, and the mean length of TSP is 95.56 mm. Figure 4.18 shows the SEM image TSP and calculated areas of TSP particles.

SL.NO	Label	Area	Mean	Min	Max
1		2849	132.595	45	255
2		3156	154.907	44	255
3		2604	173.501	44	255
4		2361	134.086	47	252
5		1783	137.848	42	255
6		768	156.858	46	255
7		1820	127.316	49	255
8		1031	134.36	45	255
9		1461	128.341	50	255
10	Mean	1981.444	142.201	45.778	254.667
11	SD	819.754	15.844	2.539	1
12	Min	768	127.316	42	252
13	Max	3156	173.501	50	255

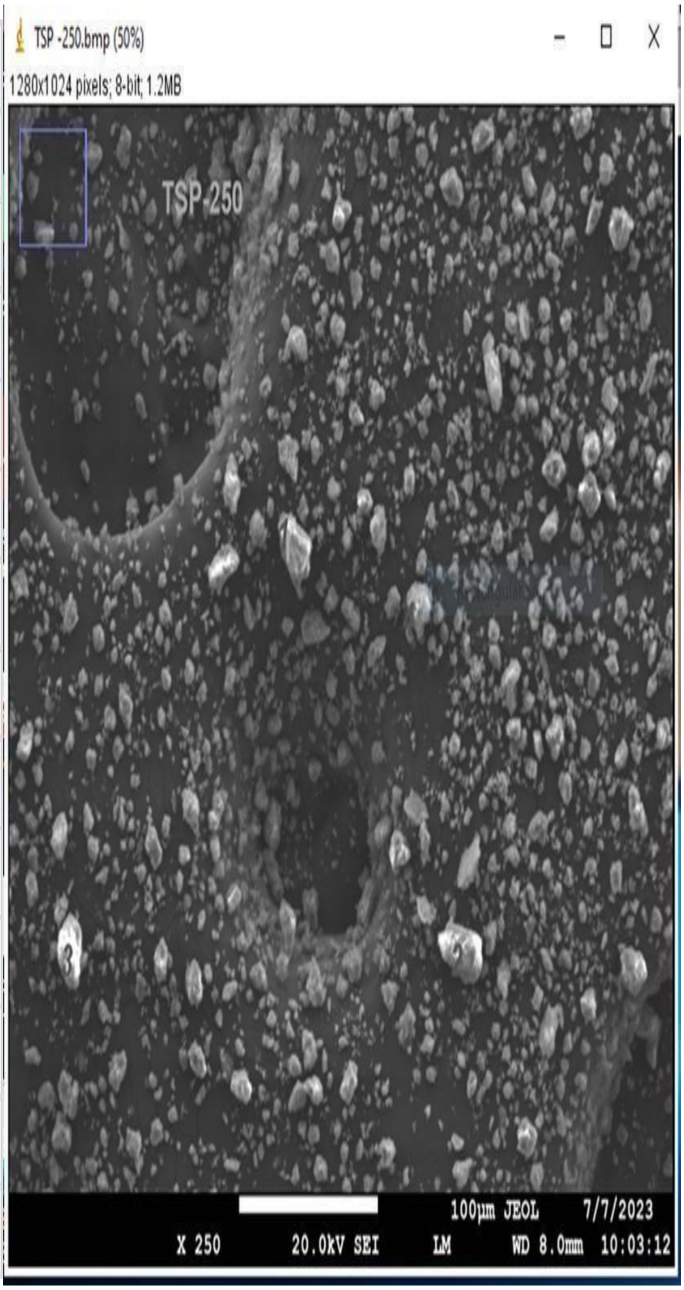

Figure 4.18 SEM Image for Tandur Stone Powder Sample

4.7.5 SEM ANALYSIS - QUARRY DUST

Random particles were selected from SEM images to find the minimum and maximum areas of the selected particles and the length of the particle from the SEM image of the QD sample. It was observed that the shape of the particles was irregular in shape. The area of the particle is 27683.67 mm^2, the mean of the particle is 126.02 mm^2, the minimum area of the particle is 43.33 mm^2 and the maximum area of the particle is 228.22 mm^2, and the mean length of QD is 111.31 mm Figure 4.19 shows the SEM image quarry dust and calculated areas of quarry dust particles.

Sl.No	Label	Area	Mean	Min	Max
1		29997	105.566	45	241
2		106144	115.76	44	198
3		51176	92.321	41	255
4		16561	191.758	42	255
5		12218	141.787	43	255
6		4174	157.176	45	255
7		9456	90.641	42	170
8		9742	152.758	43	255
9		9685	86.414	45	170
10	Mean	27683.67	126.02	43.333	228.222
11	SD	32800.48	36.632	1.5	37.818
12	Min	4174	86.414	41	170
13	Max	106144	191.758	45	255

Figure 4.19 SEM Image for Quarry Dust Sample

Therefore microstructural analysis of the prepared geopolymer samples was conducted using a Scanning Electron Microscope (SEM) equipped with an Energy Dispersive Spectroscopy (EDS) detector. SEM imaging provided insights into the morphology, including particle distribution, cracks, and surface texture. Simultaneously, EDS analysis was performed to determine the elemental composition of key phases identified in the SEM images. This combined approach ensured a comprehensive understanding of both the physical structure and chemical properties of the samples.

Chapter 5 LIFE CYCLE ASSESSMENT

5.1 LIFE CYCLE ASSESSMENT OF GPC

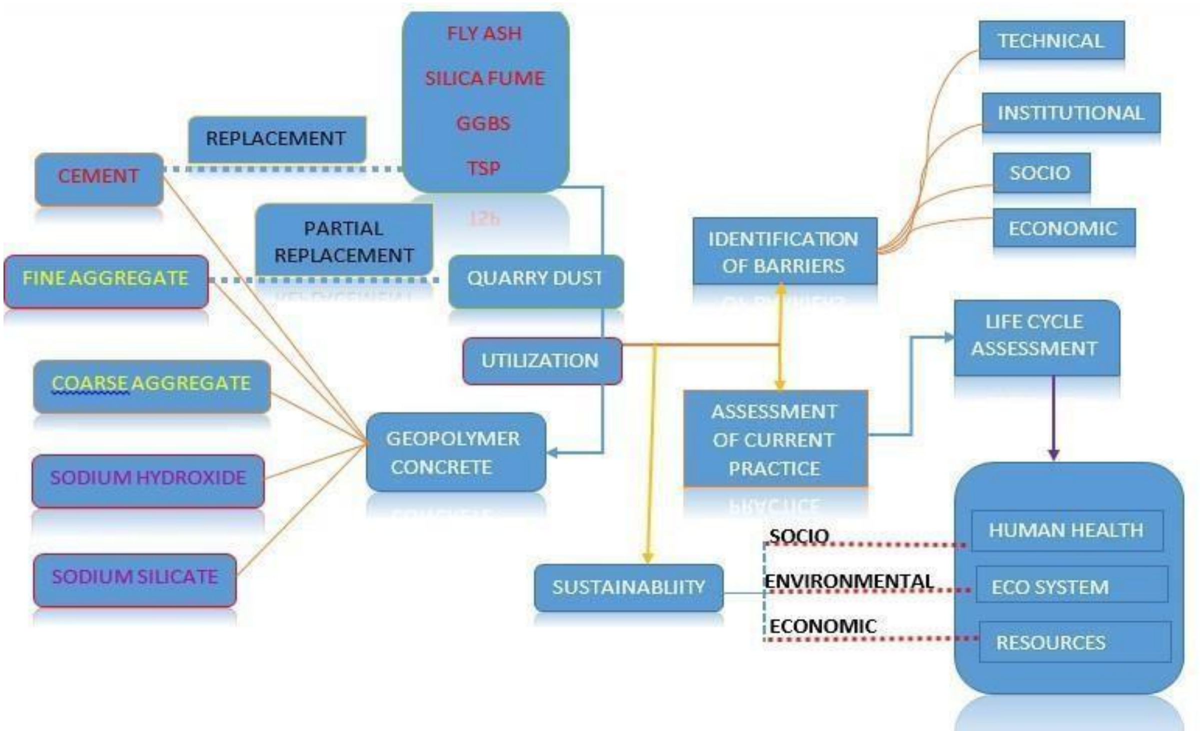

Figure 5.1 Flow Chart 1 of LCA

This study provides a life cycle impact assessment of recycled aggregate concrete, geopolymer concrete, OPC concrete, and recycled aggregate-based geopolymer concrete using the mid-point approach of the CML 2001 impact-assessment technique. Using five distinct effect categories— Potential for eutrophication, acidification, global warming, ozone [112], potential for depletion, and potential for human toxicity — The life cycle impact analysis was carried out by utilizing Open LCA software. Contribution analysis was then carried out for each of the five impact categories. According to the data, there was a 53.7% reduction in the potential for global warming at the time geopolymer concrete was used rather than OPC concrete. In addition, the usage of geopolymer concrete was noted to be a decrease in the impact categories potential for acidification and photochemical oxidant generation in addition to climate change.

The life cycle assessment is a thorough tool for evaluating the overall environmental effect of geopolymer concrete. LCA entails methodical assessment of a system or product from the extraction of raw materials to the final disposal of it after its useful life, during every stage of its life cycle [114]. This method considers several environmental metrics, such as resource depletion, energy usage, & greenhouse gas emissions.

This document outlines the process of conducting a Geopolymer concrete life cycle assessment utilizing Open LCA software, a versatile tool that aids in quantifying and evaluating environmental impacts. Open LCA facilitates the integration of various data sources and enables a detailed analysis of the environmental performance of production supplies.

Regarding cutting-edge building materials like geopolymer concrete, life cycle assessment techniques are more approachable and applicable when using Open LCA software.

5.2 LIFE CYCLE ASSESSMENT OF GPC USING TSP & BLENDED QUARRY DUST

Many methods and approaches were employed in evaluating the ecologically sustainable performance of GPC compared to OPC concrete. The life cycle assessment (LCA) is one such evaluation method.

Assessing Environmental Effects with Imperfections using the Life Cycle Assessment (LCA) Method.

The life cycle assessment (LCA) approach is comparable to a "cradle-to-grave" or "cradle-to-gate" approach for evaluating the environmental impacts at every stage of the demolition process, from raw material extraction to application. [113]. It's quite important for the way in which a certain product system manages its surroundings; it even helps compare the environmental impacts of several prototypes. So, it's a program that uses GPC technology to support the claim that GPC is less bad for the environment than OPC concrete [114].

5.3 MATERIALS AND METHODS

As per ISO 14040 and 14044, the Life Cycle Assessment method was utilized in four phases. The first phase establishes the research goals and boundaries, i.e., goal & scope of work. Then, in the second & third phases, life cycle impact assessments (LCIA) and inventory analyses were conducted. The last step is an interpretation based on impact-assessment analysis and inventory. Lastly, a flowchart was utilized to demonstrate the life cycle inventory procedure.

5.4 GOAL AND SCOPE

The main objective of LCA is to examine the impacts of three mixtures on the environment such as OPC concrete, GPC (M1S2) & RAGC (M1S2Q5), to determine the effects of conventional concrete and GPC by adding TSP and RA on the environment. It all starts when natural resources are extracted, like aggregates, cement, raw materials, and alkali activators & it ends through the creation of GPC, but we used sodium hydroxide & sodium silicate as activators for the RAGC & GPC combination. The life cycle inventory study considered the manufacture from the raw material to the finished product of silicates and hydroxide, and it's established as 1 m^3 of GPC, RAGC of particular strength. And compared it with OPC concrete. For all three types of combinations, the strength conditions considered in this research investigation ranged from

25 to 30 MPa. As shown in Figure 5.2, the sources of their components and the manufacturing processes are where the system boundaries in this research study started and finished.

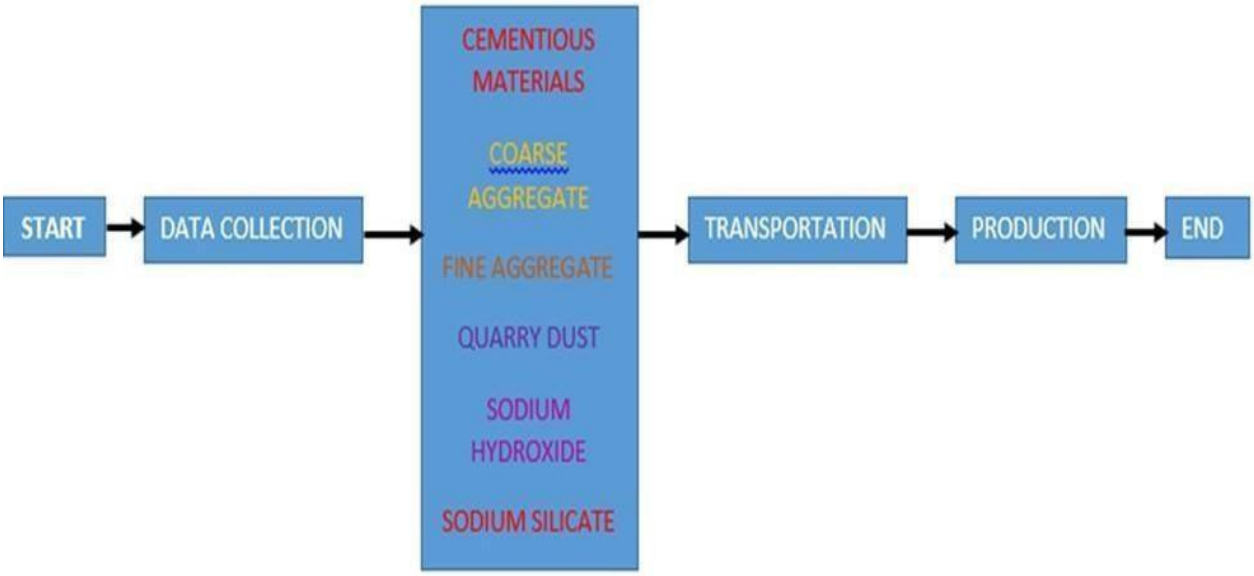

Figure 5.2 Flow Chart 2 of LCA

5.5 STUDY AREA

The Life Cycle Assessment (LCA) technique was implemented for three distinct concrete mixes, drawing on the inventory study conducted in Hyderabad, Telangana. For all three mixes, the manufacturing site was believed to be at the Hyderabad Campus of Osmania University. Additionally, the Hyderabad site of the Hyderabad Cement facility was taken into consideration for cement collection, cementitious materials, coarse aggregate, & fine aggregate, respectively.

5.6 MIX DESIGN ADAPTATION

The Telangana study provided a mix design for both the regular concrete and the RAGC combination. In this investigation, RA completely (i.e., 100% replacement) replaced the natural aggregate. The concrete variants 28-day compressive strengths are 28 MPa. But the GPC and RAGC combinations, whose compressive strengths were 30 MPa and 27 MPa, respectively were taken from the mix design process. RA made up 50 percent of the usual fine aggregate in the RAGC combination. Table 5.1 displays the mix design for each of the three combinations.

Table 5.1 Mix design of three concrete mixtures

INGREDIENTS	OPC Kg/m^3	GPC (M1S2) Kg/m^3	RAGC (M1S2Q5) Kg/m^3
Cement	394	0	0
Fly Ash	0	131.33	131.33
GGBS	0	131.33	131.33
Silica Fume	0	13.133	13.133
TSP	0	118.197	118.197
Fine Aggregate	791	791.0	395.5
Quarry Dust	0	0	395.5
Coarse Aggregate	1068	1068	1068
Water	185	20	20
Sodium Hydroxide	0	40	40
Sodium Silicate	0	101	101

5.7 INVENTORY ANALYSIS

The life cycle inventory is the following step after establishing the goal and parameters. The cutoff approach was based on the notion that the primary producer of a specific material is attributed to a primary consumer and does not own any control or recognition over the recycled material.

The current study uses the emission/energy ratio approach to produce emission data for several manufacturing activities across the Telangana region. For every constituent in GPC and OPC concrete, the energy inventory data and emissions were available in the literature. The following stage requires figuring out the kilogram/joule (Kg/MJ) of emissions and energy for each constituent in technical publication correspondingly. Each element's energy generated (in MJ) was multiplied by its average emission/energy ratio, after which the result was expressed in terms of Telangana location. Moreover, a flow chart was used to illustrate how the inventory data was collected, as shown in Figure 5.1.

5.8 LIFE CYCLE IMPACT ASSESSMENT (LCIA)

Using Open LCA, a midpoint methodology known as the CML 2001 baseline (Centrum voor Milieukunde Leiden), the impact was examined. The CML technique examined many effect categories for the eco-invent dataset [112, 113, 114]. However, five effect categories - global warming potential (GWP), atmospheric depletion (ADP), generation of photochemical oxidants (POF), ozone depletion, and human toxicity - were examined in this study. The effect categories listed above were reviewed and contrasted with three different mix types such as conventional concrete mix, GPC mix, and RAGC mix. Equations can be used to represent the category indicators, as shown below [97,99]:

“GWP = ∑ Load (i) × GWP” (i) “ODP = ∑ Load (i) × ODP” (i) “ADP = ∑ Load (i) × ADP” (i) “POF = ∑ Load (i) × POF” (i) “HTP = ∑ Load (i) × HTP” (i)

Where,

Each inventory item (i) has an environmental load denoted by load (i); the GWP, ODP, ADP, POF, and HTP inventory items (i) have corresponding GWP (i), ODP (i), ADP (i), and HTP (i) as their characterization factors.

Mathematical Approach

ODP Contribution

ODP for GPC

ODP=(0.00007×0.077)+(0.000036×1.0)

ODP=0.00000539+0.000036

ODPtotal=0.0000413kg CFC-11 eq.

ODP for RAGC

ODP=(0.000066×0.066)+(0.0000367×1.0)

ODP=0.00000396+0.0000367

ODPtotal=0.00004102kg CFC-11 eq.

HTP Contribution

HTP for OPC

$HTP=(0.0007*6)+(0.3*2)+(0.002*3.8)+(0.001*5)+(0.001*3)$

$HTP=0.0042+0.60+0.0076+0.005+0.003$

$HTPtotal=0.695kg$ 1,4-DB eq./m^3

HTP for GPC

$HTP=(0.9*9)+(1.2*6)+(0.7*9)+(0.9*8)+(0.8*6)$

$HTP=8.1+7.2+6.3+7.2+4.8$

$HTPtotal=33.656kg$ 1,4-DB eq./m^3

HTP for RAGC

$HTP=(0.6*9)+(1.1*6)+(0.725*9)+(0.9*8)+(0.8*6)$

$HTP=5.4+6.6+6.525+7.2+4.8$

$HTPtotal=30.510kg$ 1,4-DB eq./m^3

EP Contribution

EP for OPC

$EP=(0.002*0.13)+(0.035*1)+(0.054*0.1)+(0.009*0.1)+(0.34*0.05)$

$EP=0.00026+0.035+0.0054+0.0009+0.017$

$EPtotal=0.058232kg$ PO_4^{3-} eq./m^3

EP for GPC, RAGC

$EP=(0.04*0.13)+(0.0655*1)+(0.095*0.1)+(0.09*0.1)+(0.79*0.05)$

$EP=0.0052+0.0655+0.0095+0.009+0.0395$

$EPtotal=0.12163kg$ PO_4^{3-} eq./m^3

GWP Contribution

GWP for OPC

$GWP=(4.5*10)+(3.5*9.6)+(4.5*9)+(4.2*9.6)+(6.1*8.4)+(5*10)$

$GWP=45+33.6+40.5+40.32+51.24+50.0$

GWP total=260.08kg CO_2 eq./m^3

GWP for GPC

GWP=(4.5*8.5)+(3.5*6.6)+(4.5*2.1)+(4.2*5.2)+(6.1*2.2)+(5*1.1)

GWP=38.25+23.1+9.45+21.84+13.42+5.5

GWP total=111.56kg CO_2 eq./m^3

GWP for RAGC

GWP=(4.5*10)+(3.5*9.6)+(4.5*9)+(4.2*5.9)+(6.1*1.5)+(5*0.9)

GWP=38.25+23.1+9.45+24.78+9.15+4.5

GWPtotal=109.23kg CO_2 eq./m^3

AP Contribution

AP for OPC

AP=(0.002×1.2)+(0.004×0.95)+(0.003×1.5)+(0.002×1.6)+(0.001×0.005)+(0.0005×0.001)

AP=0.0024+0.0038+0.0045+0.0032+0.000005+0.0000005

APtotal=0.01905kg SO_2 eq./m^3

AP for GPC

AP =(0.002*0.13)+(0.035*1)+(0.054*0.1)+(0.009*0.1)+(0.34*0.05)

AP =0.00026+0.035+0.0054+0.0009+0.017

APtotal=0.50108kg PO_4^{3-} eq./m^3

AP for RAGC

AP =(0.002*0.13)+(0.032*1)+(0.054*0.1)+(0.009*0.1)+(0.34*0.05)

AP =0.00026+0.035+0.0044+0.0009+0.017

APtotal=0.47769kg PO_4^{3-} eq./m^3

5.9 RESULTS AND DISCUSSION

In this section use CML 2001 midpoint technique was used to examine and compare the impacts on the environment and the procedural contributions of three distinct mixes. The findings of the life cycle inventory for the components that make up concrete were provided in the first part. The quantity of influence categories for the three different types of mixes - concrete mix, GPC, and RAGC - are examined in the next section. Finally, all three concrete compositions' contribution analyses were shown.

5.9.1 LIFE CYCLE INVENTORY RESULTS

One kilogram of cement requires the entire amount of energy (coal, electric, and transportation combined) to be determined using the emission/energy approach to be 2.918 MJ/kg. On the other hand, the total energy needed for RAGC (the total energy of crushing & transportation) & aggregate (the total energy of mining, crushing, & transportation) is 0.00565 MJ/Kg & 0.00873 MJ/Kg, respectively. Transportation production needs 0.0723 MJ/Kg of energy in total. Table 5.2 provides the energy information for each ingredient and the energy used for transportation.

Step 1: Calculation of Production Energy (MJ/kg)

1. Cement Production Energy Calculation

Cement production is an energy-intensive process involving:

- Limestone Quarrying
- Raw Material Grinding
- Clinker Formation in Kiln (high energy-consuming stage)
- Final Cement Grinding

<u>Formula for Production Energy:</u>

$$\text{Production Energy (MJ/kg)} = \frac{\text{Total Energy Used in Process (MJ)}}{\text{Total Output (kg)}}$$

Calculation for Cement:

Energy consumption for cement kiln = 2.4MJ/kg of clinker

Grinding and material preparation = 0.4MJ/kg

Packing and dispatch = 0.118 MJ/kg

Total Energy for Cement Production

Total Energy=2.4+0.4+0.118=2.918 MJ/kg

2. Fine and Coarse Aggregate Production Energy

Aggregate production mainly involves:

- Excavation/Mining
- Crushing/Screening

Energy consumption values are relatively low because crushing is less energy-intensive than cement production.

Estimated Energy Usage for Aggregates:

- Excavation and handling = 0.004 MJ/kg
- Crushing/Screening = 0.00165 MJ/kg

Total Energy for Fine Aggregate:

Production Energy=0.004+0.00165=0.00565 MJ/kg

Total Energy for Coarse Aggregate:

Production Energy=0.004+0.00473=0.00873 MJ/kg

3. Recycled Aggregate Production Energy

Recycled aggregates involve:

- Demolition Waste Collection
- Crushing and Screening

Since recycled aggregates avoid primary extraction and quarrying, the energy demand is typically lower.

Estimated Energy for Recycled Aggregate:

Production Energy=0.003+0.00224=0.00524 MJ/kg

Step 2: Calculation of Transportation Energy (MJ/kg)

Formula for Transportation Energy:

$$\boxed{\text{Transportation Energy (MJ/kg)} = \frac{\text{Fuel Consumption (L)}}{\text{Material Weight (kg)}} \times \text{Energy Content of Fuel (MJ/L)}}$$

Calculation for Cement Transportation:

- A Truck carries 12 tonnes (12,000 kg) of cement per trip.
- Fuel consumption for the truck = 0.35 L/km
- the transport distance = 50 km
- Diesel energy content = 38.6 MJ/L

Energy per trip:

Energy for one trip=50 km×0.35 L/km×38.6 MJ/L=675.5 MJ

Energy per kg of cement:

Transportation Energy=675.5 MJ/12,000 kg =0.055 MJ/kg

Calculation for Aggregates Transportation:

Aggregates are typically denser, requiring more energy per unit mass for transport.

- Typical transport energy for aggregates ranges from **0.005 – 0.008 MJ/kg** based on distance and truck efficiency.

Table 5.2 Energy production

Ingredients	Production Energy (Mj/Kg)	Transportation Energy (Mj/Kg)
Cement	2.918	0.055
Fine Aggregate	0.00565	0.00795
Coarse Aggregate	0.00873	0.00630
Recycled Aggregate	0.00524	0.00309

5.10 ENVIRONMENTAL IMPACT ANALYSIS OF ALL THE THREE MIXES

The environmental effects of regular concrete and GPC, as well as their RAGC, were compared in this study. The implications were assessed using the Open LCA program, and the results showed that using a different binder might assist in lessening some of the environmental problems. The effect category about which the construction sector is most concerned is greenhouse gas pollution (GWP), which is caused by the production of CO_2 and greenhouse gas emissions. Because aggregates are recycled, Figure 5.3 indicates that ADP is lower in RAGC and GPC compared to conventional concrete, respectively. Because mining energy is eliminated and transportation energy is decreased, recycling aggregates uses less energy than regular aggregate. Figure 5.4 compares and displays the GWP-100-year global warming potential of OPC concrete, GPC, and RAGC. It was demonstrated that, in comparison to the other three mixes, OPC concrete has the greatest GWP. The related image illustrates how the GWP drops with regular concrete, GPC, and RAGC. This trend implies that, relative to the other mixtures, the ones with larger cement percentages shown higher GWPs. Figure 5.5 displays the impact category, or the ETP of the three combinations, and indicates that compared to the OPC mixture, GPC, and RAGC have equal ETPs of 0.12163 kg PO4- Eq/m^3. This was because the other two mixes contained sources of silicate and hydroxide. Compared to typical aggregate production, applying GPC and RAGC results in lower NO_2, SO2, and ammonia emissions. Figure 5.6 presents the three types of mixes ability to deplete ozone and makes it abundantly evident that, for a functional unit of samples of 1 m^3 as specified, the manufacture of concrete mixtures has no direct effect on ozone depletion. In contrast, ozone depletion is significantly impacted by geopolymer mixes of both types —GPC & RAGC. A mixture's alkali activator is the cause of this effect.

Table 5.3 Impact Categories by CML Baseline Method

Indicator	OPC Concrete	GPC	RAGC	Units
Acidification Potential - Generic	1.01904	0.50108	0.47769	Kg-SO_2-Eq
Climate Change - GWP	260.08	111.545	109.237	Kg-CO_2-Eq
Eutrophication Potential	0.058232	0.12163	0.12163	Kg-PO_4-Eq
Human Toxicity	0.695	33.7	30.5102	Kg 1,4-DCB-Eq
Stratospheric Ozone Depletion	0	4.13 X 10^{-5}	4.102 X 10^{-5}	Kg CFC - 11 - Eq

5.11 IFFERENT INDICATORS – LCA

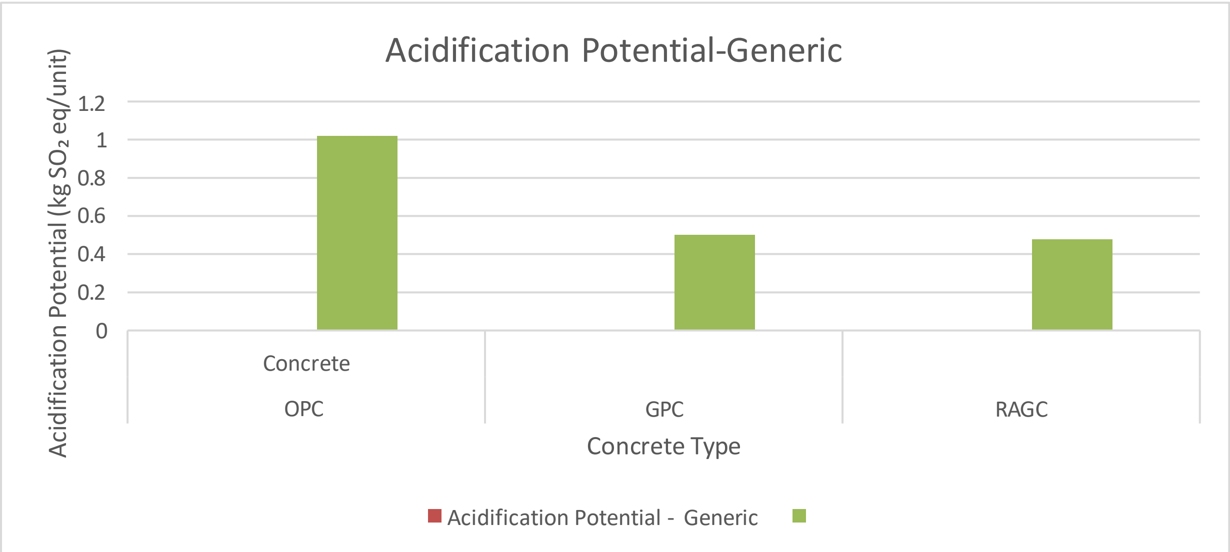

Figure 5.3 Acidification Potential – Generic

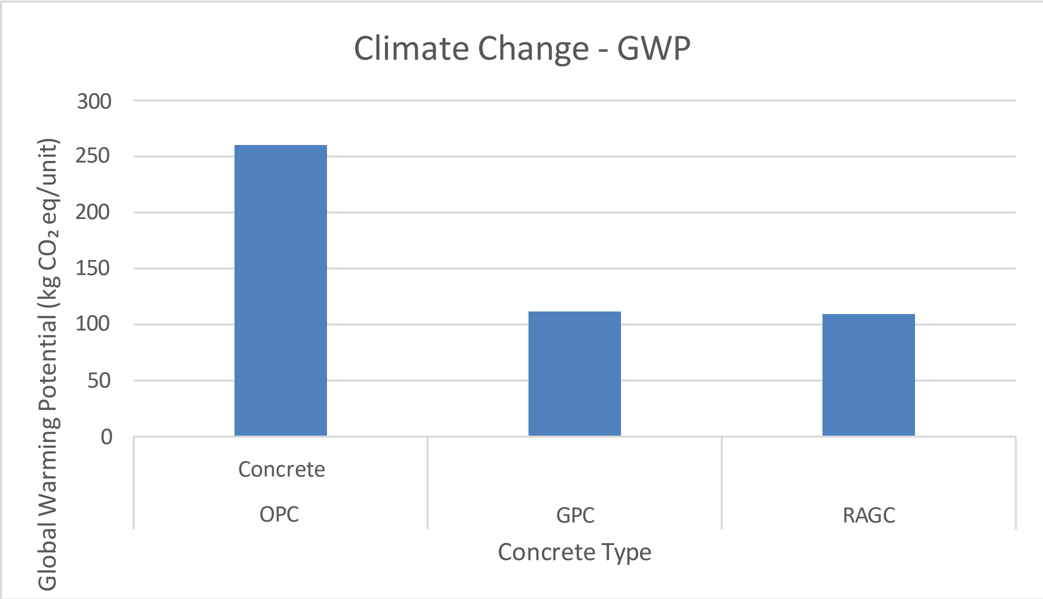

Figure 5.4 Climate Change – GWP

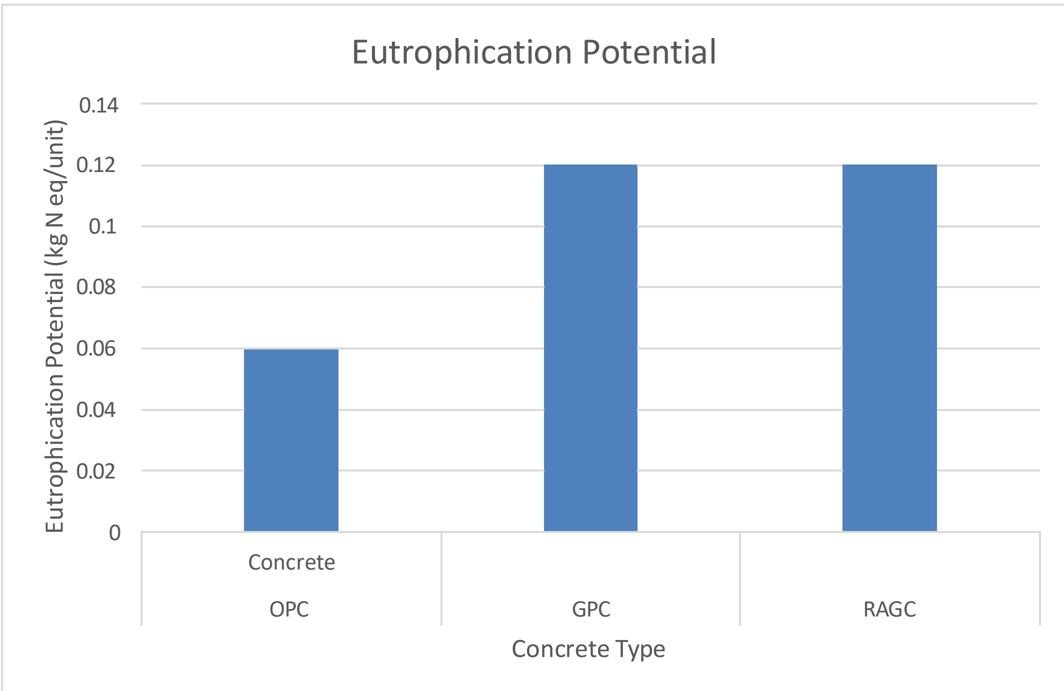

Figure 5.5 Eutrophication Potential

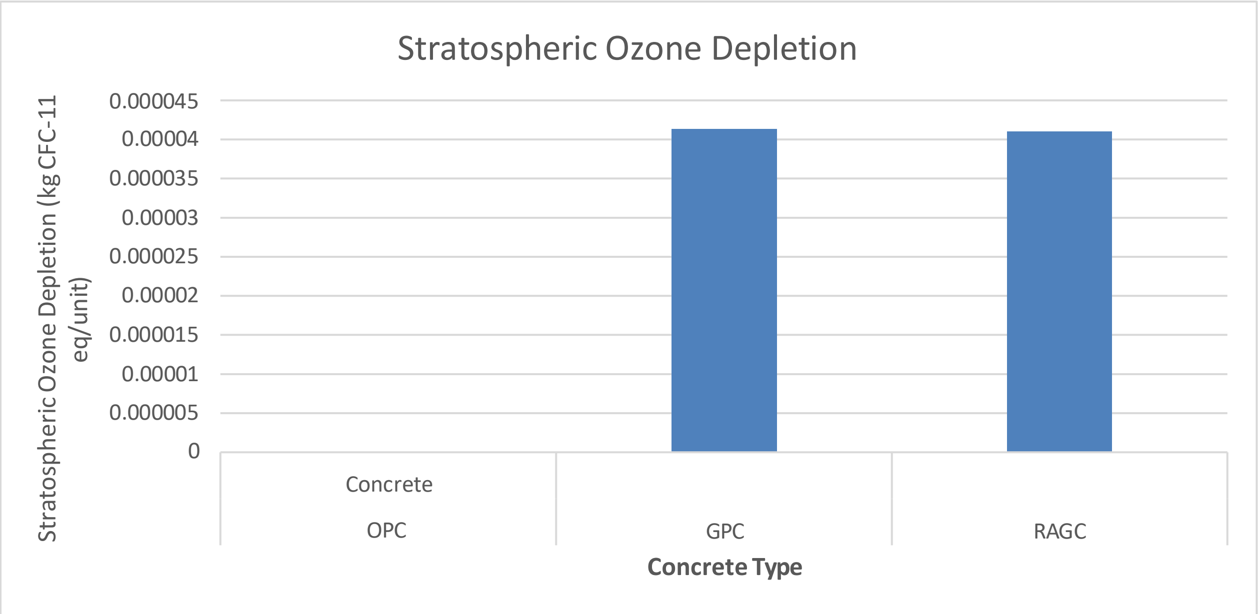

Figure 5.6 Stratospheric Ozone Depletion

5.12 CONCLUDING REMARKS AND SUGGESTIONS

These inferences may be made in light of the LCA study of the OPC, GPC, and RAGC Mixtures.

An LCA study was carried out using the CML 2001 baseline approach and Open LCA software. Five distinct effect categories were examined and contrasted for each combination to determine which blend was best for the environment. The LCA study leads to the conclusion that OPC in concrete mixes is the primary cause of adverse environmental effects that were produced; additionally, the usage of aggregates has an influence on GWP, EP, and ADP among other environmental consequences.

GPC and RAGC blends are preferred to reduce the GWP generated by regular concrete cement. In comparison to OPC concrete, the application of GPC is shown to reduce the GWP impact by up to 57.34%.

In both cases of GPC and RAGC, using an alkaline activator was important for the surrounding effects. As a result, choosing the right source of the GPC's alkaline activators combination is crucial.

Using geopolymer concrete contributes to mitigating the effects of climate change and reducing the possibility of acidification and photochemical oxidant production in the impact categories. The environmental implications were all reduced when recycled aggregates were used in both GPC and RAGC.

Chapter 6 -CONCLUSIONS

6.1 GENERAL

This part introduces conclusions drawn from mechanical and durability properties and from structural behavior investigations on FA, GGBS, and TSP with Silica fume & Fine aggregate with quarry dust-based GPC incorporated with TSP.

6.2 CONCLUSIONS

Predicted on the outcomes obtained through experimental investigation, the findings that follow were determined:

6.2.1 Fresh & mechanical properties prior to Geo-Polymer Concrete produced by using TSP, blended quarry dust.

- With increasing dosages of TSP with silica fume and fine aggregate with quarry dust in GPC, the slump value of GPC was observed to increase, which may be due to the water absorption characteristics. It is observed that the workability of concrete was increased with an increase in slump value.
- With the addition of TSP and quarry dust, the increased compressive strength of GPC was correlated with increasing dosage of TSP with silica fume at 5%, 10% & 15% and fine aggregate with quarry dust at 10%, 20%, 30%, 40% & 50% from 0.084% to 0.465%.
- By incorporating 50% recycled fine aggregates with quarry dust and supplementing with 10% Silica fume, the compressive strength demonstrates a 0.465% increase compared to normal concrete. Consequently, replacing 50% of fine aggregates with quarry dust and 10% of Silica fume with TSP in compression appears viable.
- With the addition of TSP and quarry dust, the tensile strength was increased with an increase in the quantity of TSP with silica fume at 5%, 10% & 15% and fine aggregate with quarry dust at 10%, 20%, 30%, 40% & 50% from 0.069% to 1.884%.
- By adding TSP and quarry dust, the flexural strength was observed to be increased with an increase in the quantity of TSP with silica fume at 5%, 10% & 15% and fine aggregate with quarry dust at 10%, 20%, 30%, 40% & 50% from 0.528% to 2.661%.
- The experimental behavior of mix compositions under flexure loading and shear testing showed that the flexural and shear strength was observed to vary by 1.884% and 2.661%, respectively, which is high when compared to normal concrete.

6.2.2 Optimum mix for durability and performing microstructural study of Geo polymer concrete Produced using TSP & blended quarry dust

- RCPT was conducted on specimens all 4 specimens, NC, M1, M1S2, and M1S2Q5; when compared with all four specimens, the mix containing M1S2Q5 showed a maximum reduction of the chloride ion penetration.
- EDS analysis clearly shows higher peaks of SiO2 in the specimen containing M1S2Q5, due to which the higher SiO2 may represent more elastic behavior.
- EDS analysis has clearly shown that the percentage of calcium silicates was observed to be less in specimens M1S2Q5. The lower percentage of calcium silicates may be the reason for the high strength when compared to another concrete mix.

- **Life Cycle Assessment of geopolymer concrete (GPC) using tandur stone slurry powder (TSP) & blended quarry dust.** The energy required for manufacturing and transportation of all mixture products per kilogram of 2.918 MJ of energy was needed for one kilogram of cement, including the energy needed for coal, electricity, and transportation. However, the total energy needed for RAGC (the total energy of crushing & transportation) and aggregate (the total energy of mining, crushing, & transportation) is 0.00565 MJ & 0.00873 MJ, respectively.0.0723 MJ of energy was needed in total for manufacturing and transportation.
- Using the CML 2001 baseline approach and Open LCA software, an LCA study were carried out. Five distinct effect categories were examined and contrasted for each combination. The LCA concluded that the OPC in concrete mixes was the primary cause of the adverse environmental effects that were produced. Additionally, the usage of aggregates had an influence on GWP, EP, and ADP, among other environmental consequences.
- Using GPC & RAGC mixes is a better choice for lowering GWP generated by regular concrete cement. OPC concrete comparing, application of GPC is shown to reduce the GWP impact by up to 57.34%.

6.2.3 Cost Analysis of geopolymer concrete (GPC) using tandur stone slurry powder (TSP) and conventional concrete

The cost analysis of mixes exhibited better strength, and fractures were analyzed for cost optimization. The cost required for optimum mix M1S2Q5 was 23.75% lower when compared to normal concrete (NC). Hence it is beneficial to use mix design M1SQ5 compared to normal concrete.

6.3 SCOPE FOR FUTURE WORK

- The thesis focused on examining the strength, durability, and structural behavior of geopolymer concrete (GPC) prepared using fly ash (FA), ground granulated blast furnace slag (GGBS), and ternary supplementary pozzolan (TSP) combined with silica fume and fine aggregate mixed with quarry dust. Due to time constraints, the study’s scope had to be limited, leaving several areas open for further investigation. To advance research in this blended GPC, the following suggestions are proposed:
- **X-ray Diffraction (XRD) Analysis:** Conducting XRD studies on GPC mixtures containing FA, GGBS, TSP, silica fume, and quarry dust is essential to better understand the chemical changes occurring due to the inclusion of TSP. Additionally, advanced testing techniques like Mercury Intrusion Porosimetry (MIP) are recommended to analyze pore size variations caused by TSP and silica fume in GPC.
- **Future Research Potential:** Expanding this research could significantly contribute to the construction industry. It may serve as a valuable resource for researchers seeking to understand the performance and toughness of geopolymer concrete across diverse environmental conditions.
- **Further Durability Studies:** Research on GPC incorporating FA, GGBS, TSP, silica fume, and quarry dust should be extended to explore additional durability aspects. Future investigations should include drying shrinkage, creep behavior, freeze-thaw resistance, Alkali- Aggregate Reaction (AAR), and carbonation rates to gain a comprehensive understanding of its long-term performance.

These extended studies will enhance the understanding of blended GPC's behavior and improve its potential applications in construction.

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ELSEVIER

Case Report

Experimental study of geopolymer concrete with recycled fine aggregates and alkali activators

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ABSTRACT

In the atmosphere, greenhouse gas concentration has rapidly increased due to anthropogenic activities which cause global warming. However, the existing technique has a lot of fuel and energy consumption and is involved in CO_2 emission. To overcome this issue Geopolymer Concrete (GPC) produced by using Alternate Aggregate and Chemical Activators has been used. Thus, Tandur Tone Slurry Powder is used in place of cement and quarry dust as the fine aggregate in this Geopolymer Concrete, which increases the material's strength and efficiency while lowering energy demand and fuel usage. Experimental investigation highlighting mechanical properties and durability performance of geopolymer concrete mixes. In this work, scanning electron microscope (SEM) and X-ray diffraction analysis (XRD) methods were used to examine the microstructure of geopolymer concrete. By an orthogonal design, nine GPC pastes with varying mole ratios of SiO2/Al2O3, Na2O/Al2O3, and H2O/Na2O were chosen to study the effects on mechanical strength and microstructure. In comparison to conventional concrete, the findings show that when the concentration of Tandur stone slurry powder increases up to 20% Tandur stone slurry powder & 6% quarry dust concrete (Mix 2), the concrete's tensile strength and compressive strength improve at the age of 28 days. GPC with different aggregate and chemical activators has a 25% lower production cost than Ordinary Portland Cement (OPC). Microscopic examination revealed structural traits like gels with a network made of SiO4 and AlO4 tetrahedra. Hence the experimental study of Geopolymer Concrete produced by using Alternate Aggregate and Chemical Activators using natural aggregates is widely tested and reported by analyzing fresh and mechanical properties along with microstructure estimation.

1. Introduction

Geopolymer concrete is a type of concrete and also a family of mineral polymers. It is an example of an inorganic polymer. This concrete is made by reacting aluminate and silicate-bearing materials with a caustic activator such as fly ash or slag from iron and metal production. After an antacid fluid reacts with a silica and alumina-rich base substance, a geopolymer is formed and is a suitable substitute for Ordinary Portland Cement (OPC). In that case, CO2 emissions are continuing to climb as the world's businesses continue to expand. CO2 emissions in Cement production account for roughly 5–7%. But the case of production in construction materials necessitates a lot of fuel, which uses a lot of energy [1]. As a result, the effectiveness of geopolymer concrete production is largely reliant on the activators used as well as the types of aluminosilicates available. In comparison to other natural zeolitic minerals, it is amorphous rather than crystalline. It is also found that the polymerization process necessitates a rapid reaction of silica (Si) and alumina (Al) in an alkaline environment, resulting in a three-dimensional polymeric chain of Si–O–Al–O linkages. Unlike OPC or pozzolanic cement, Geopolymer achieves compressive strength by the polycondensation of silica and alumina, as well as a high alkali content [2]. To achieve compressive strength, a geopolymer comprising OPC forms calcium silicate hydrates (C–S–H), as well as polycondensation of silica and alumina and high alkali content. During polymerization, the reactions listed below occur.

$$(Si_2O_5Al_2O_2)_n + H_2O + OH^- \rightarrow Si(OH)_4 + Al(OH)^{4-} \quad (1)$$

However, there has been relatively little investigation into the influence of mixed alkali cations on the high-temperature performance of fly ash-based geopolymers [3]. Because of the growing building of infrastructure across the world, it is anticipated that OPC output will expand by roughly 200% from 2015 to 2025 [4]. Increased production

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CERTIFICATE

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FORM 2
THE PATENTS ACT 1970 (39 of 1970)
AND
The Patents Rules, 2003
COMPLETE SPECIFICATION
(See section 10 and rule13)

TITLE OF THE INVENTION

DEVELOPMENT OF CARBONLESS PRODUCTION OF COMPOSITES IN THE LABORATORY

APPLICANT

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Government of India

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GEOGRAPHICAL INDICATIONS

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TITLE OF INVENTION	DEVELOPMENT OF CARBONLESS PRODUCTION OF COMPOSITES IN THE LABORATORY
FIELD OF INVENTION	BIO-MEDICAL ENGINEERING
E-MAIL (As Per Record)	linfo@lexgin.com
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PRIORITY DATE	
REQUEST FOR EXAMINATION DATE	--
PUBLICATION DATE (U/S 11A)	21/07/2023

PICTURE GALLERY

Picture 1- Site at Tandur Stones factory

Picture2- quarry dust at site

Picture 3 – Greasing Mould

Picture4- Mixing in lab

Picture 5- Fresh Geopolymer Concrete

Picture 6 – Removing casted specimens from mould

Picture 7 – Compressive Testing in Laboratory

Small portions of wet samples for microstructural study

Picture 8 - Sample M1

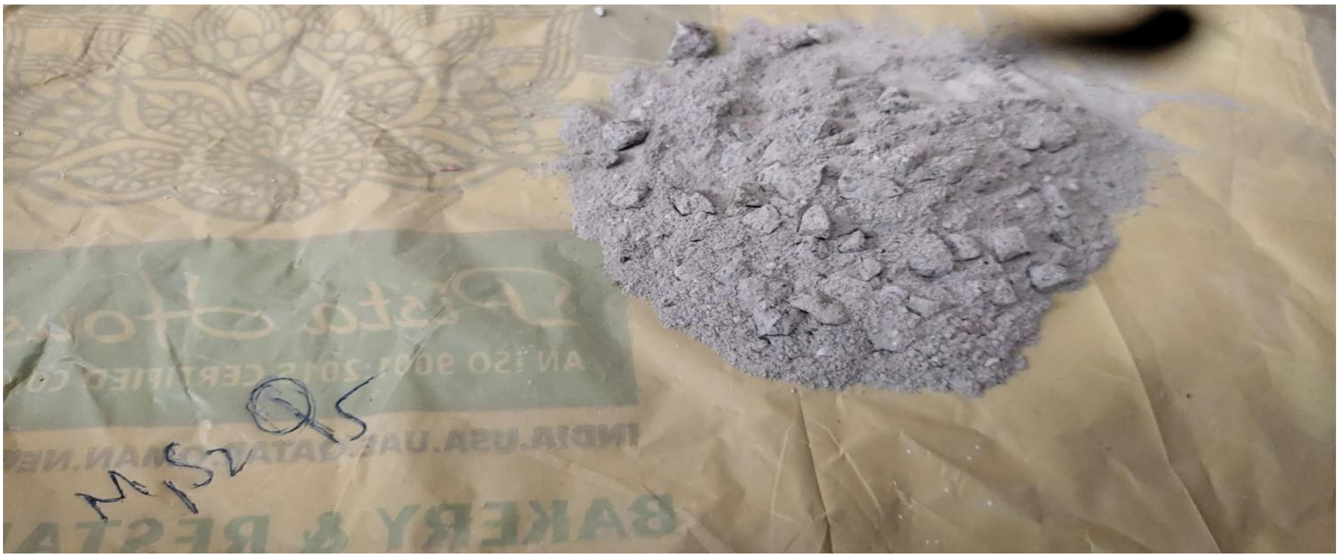
Picture 9 - Sample M1S2

Picture 10 - Sample M1S2Q5

Dry Sample for EDS TEST

Picture 11- Dry Sample M1

Picture 12- Dry Sample M1S2



Picture 13 – Dry Sample M1S2Q5

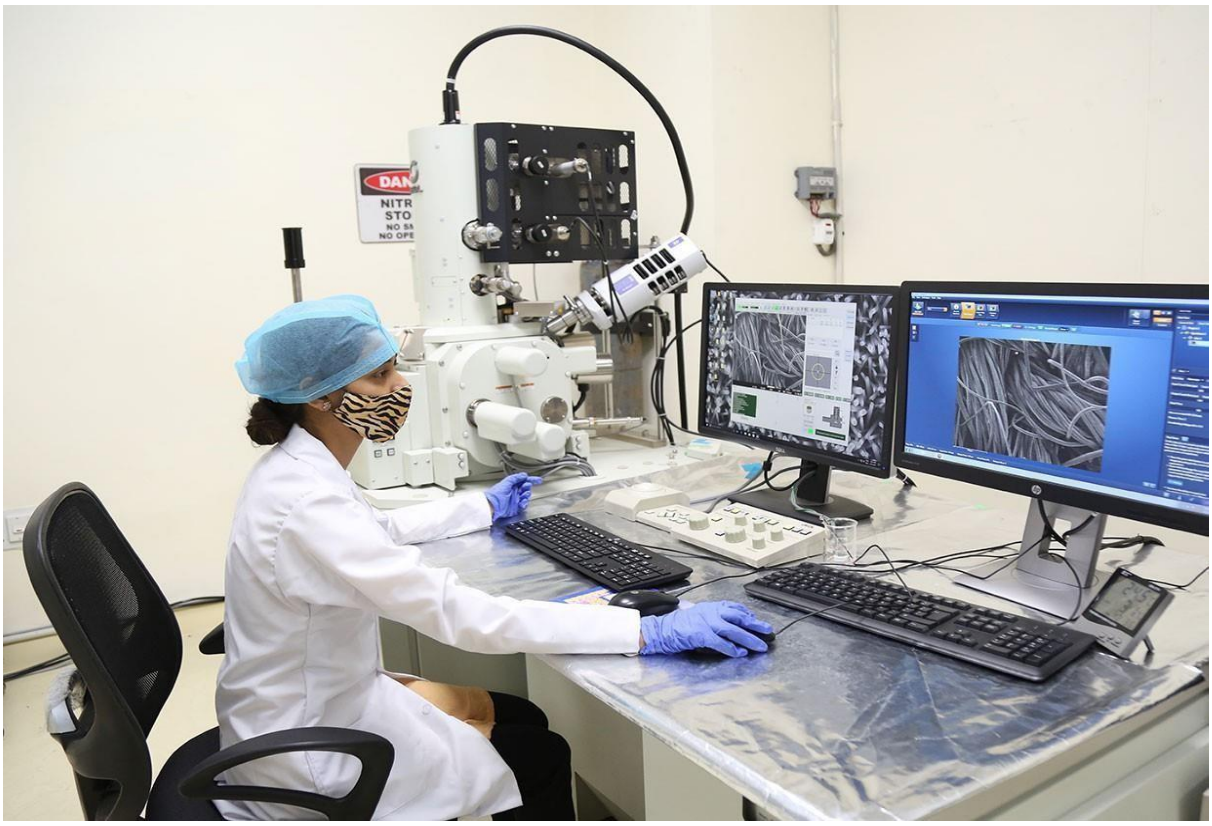
Picture 14 – Packed Samples

Picture 15 – RCPT Test in OU Lab

Picture 16 – RCPT Test in OU Lab

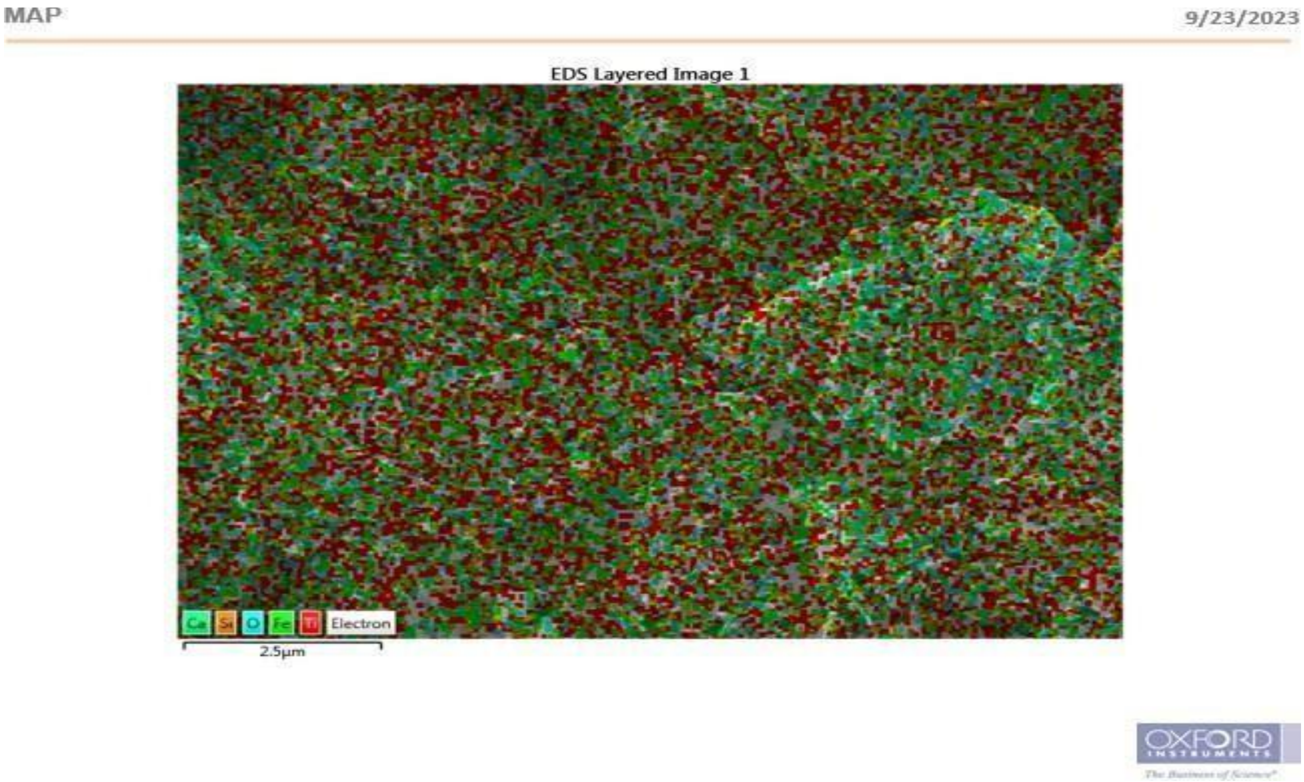
Picture 17 – SEM & EDS Equipment in LPU

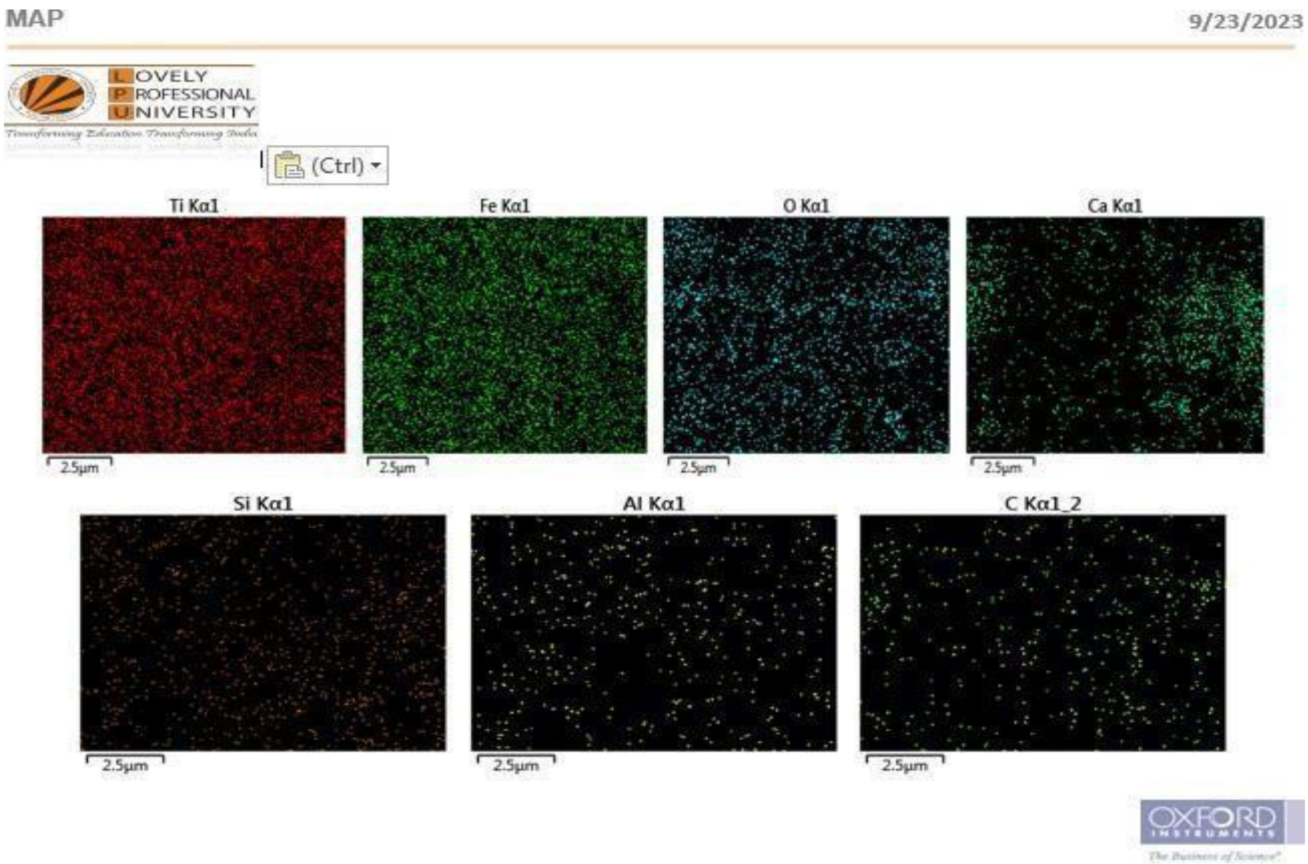
Picture 18 – SEM Equipment in LPU



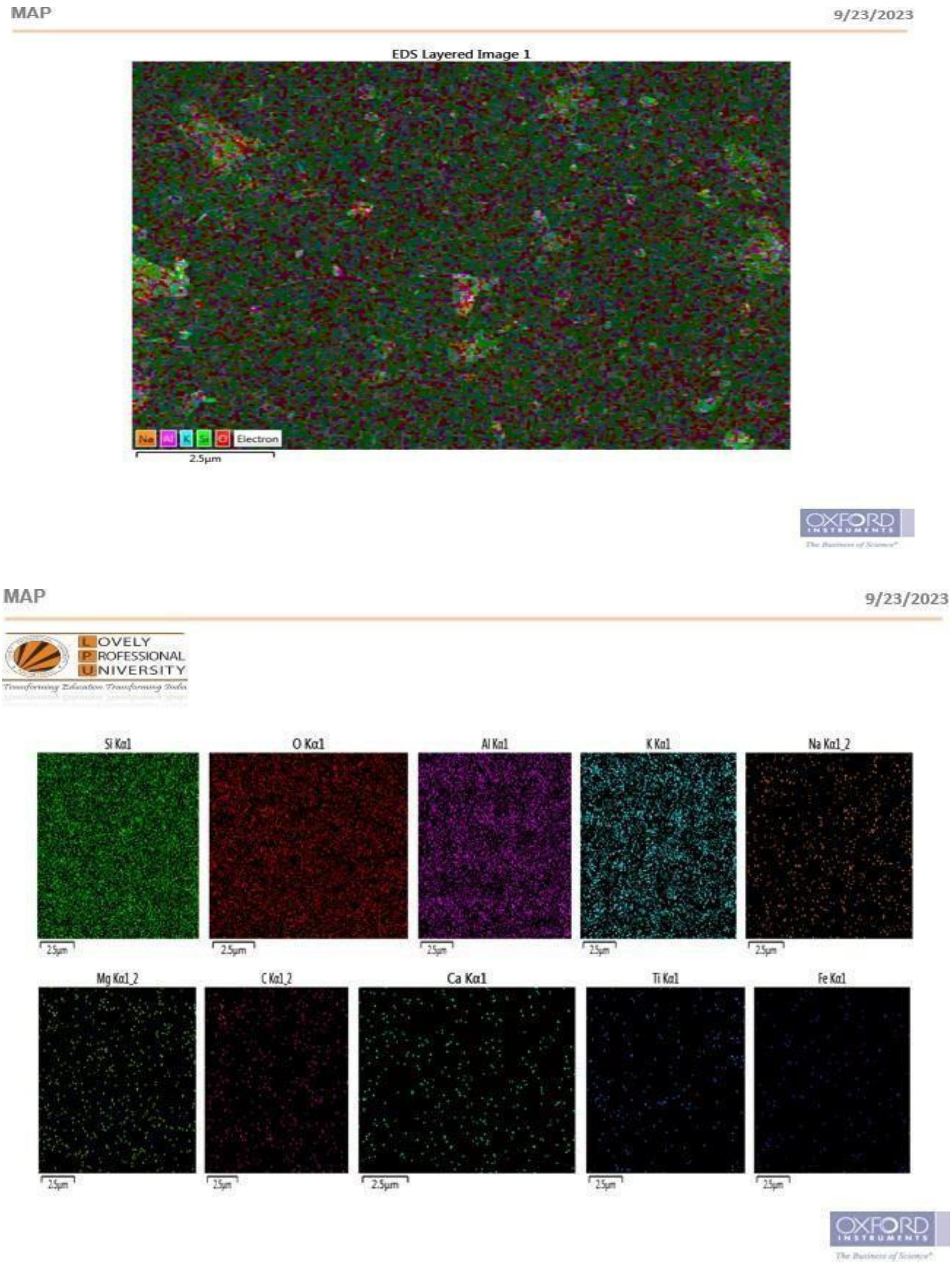
Picture 19 – EDS Sample testing in LPU

Picture 20 – EDS Equipment in LPU



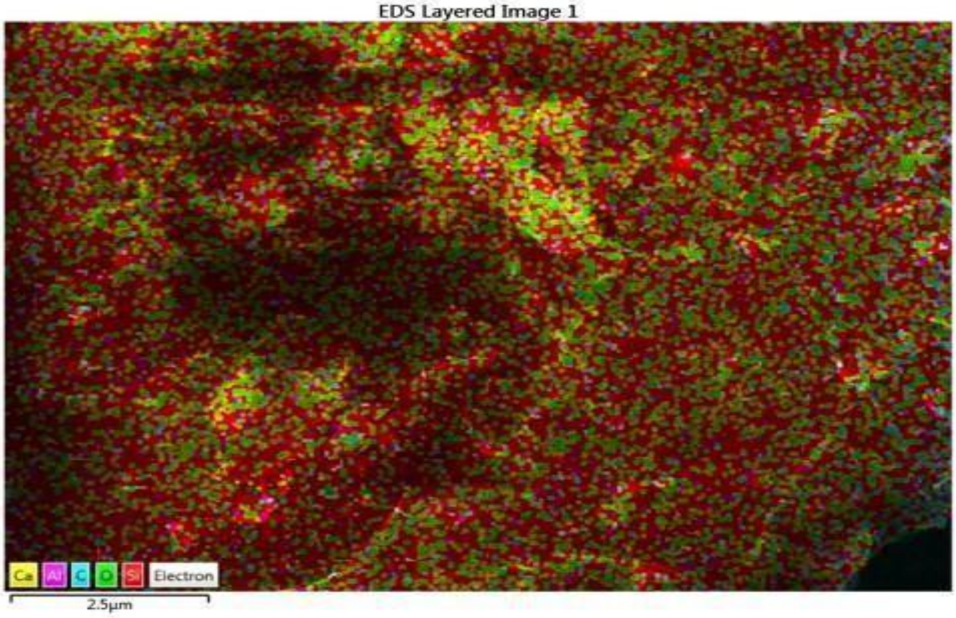


Picture 21 -EDS Test image for NC Sample – Chemical Composition



Picture 22 - EDS Test image for M1 Sample – Chemical Composition

EDS Layered Image 1



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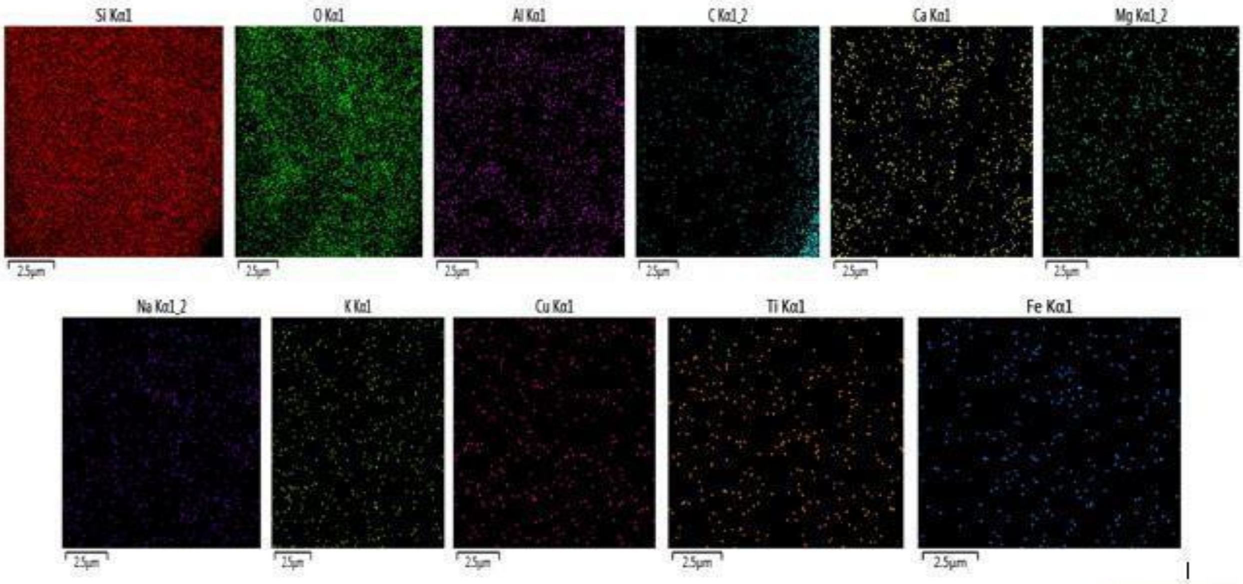

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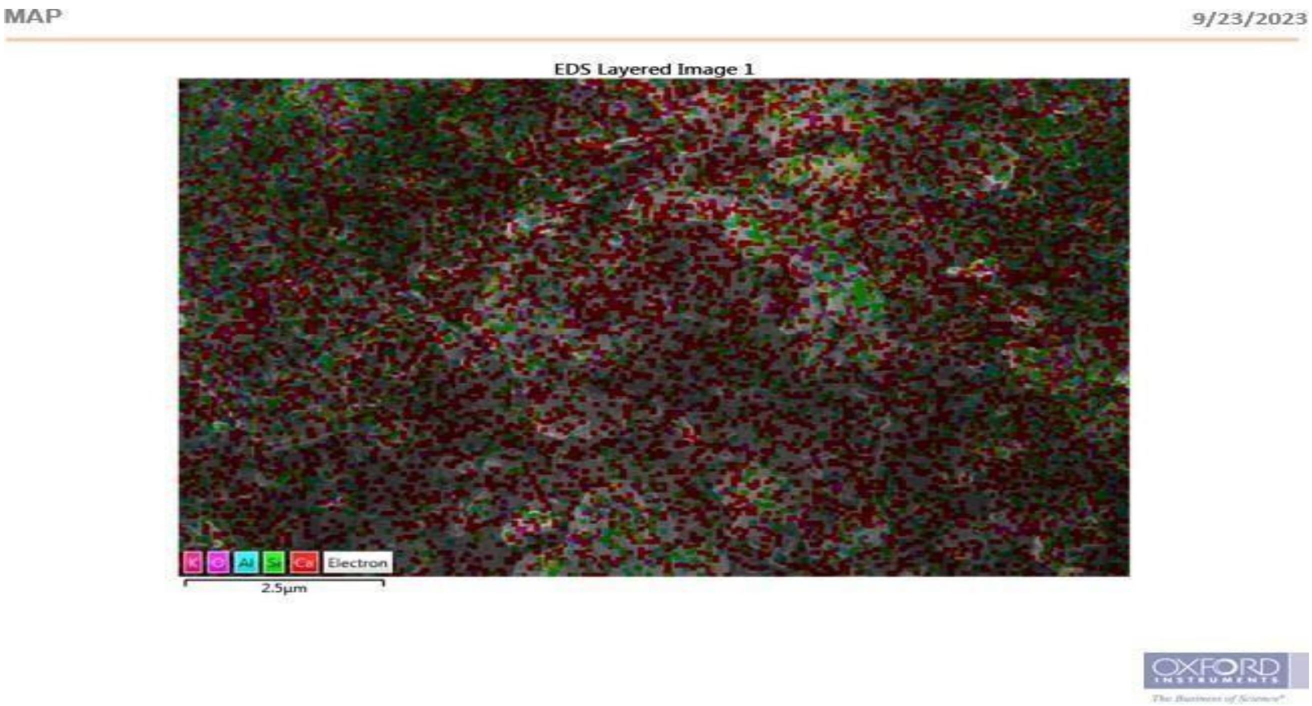
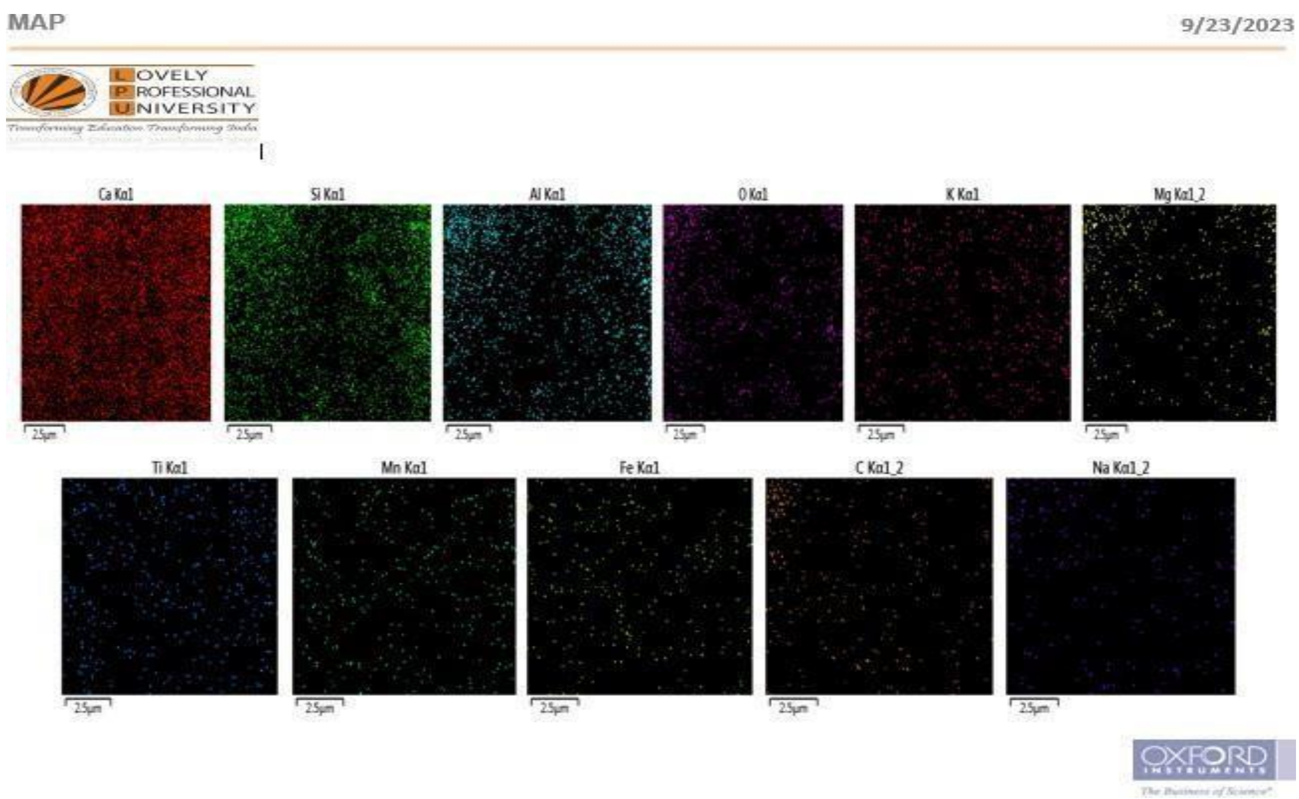
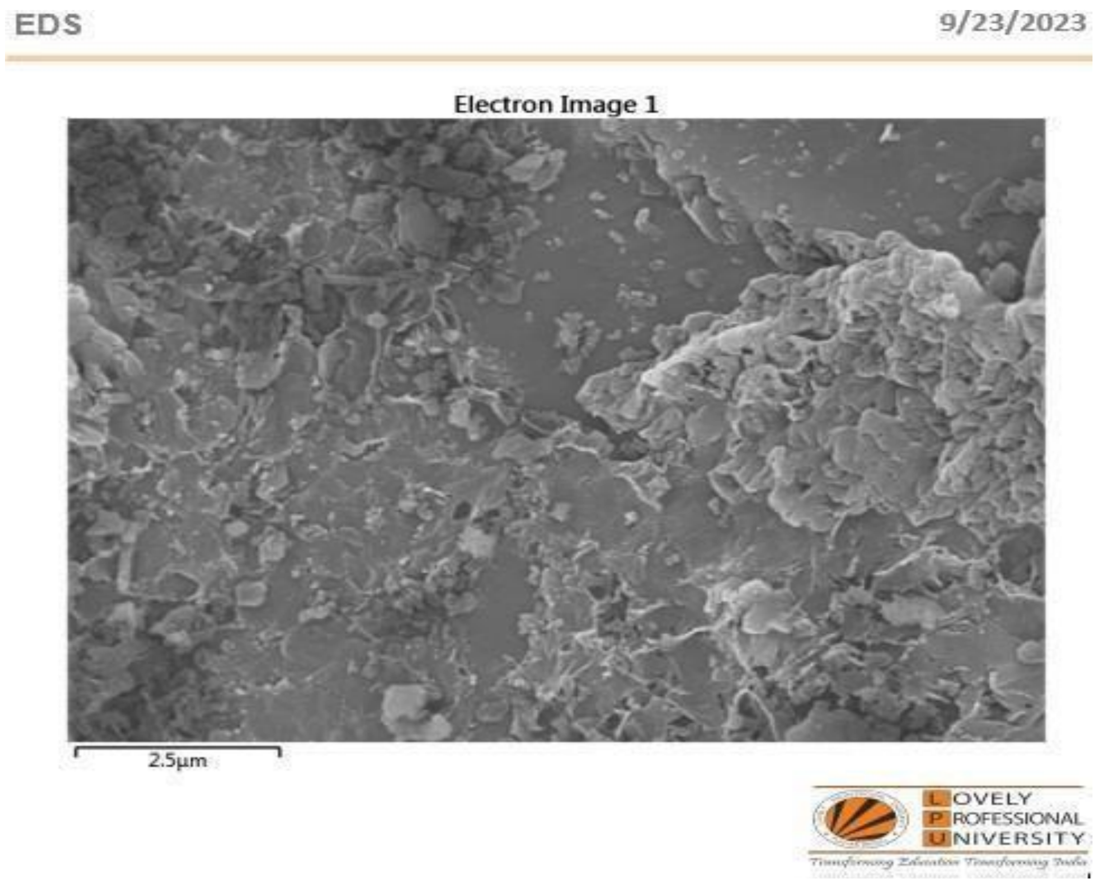
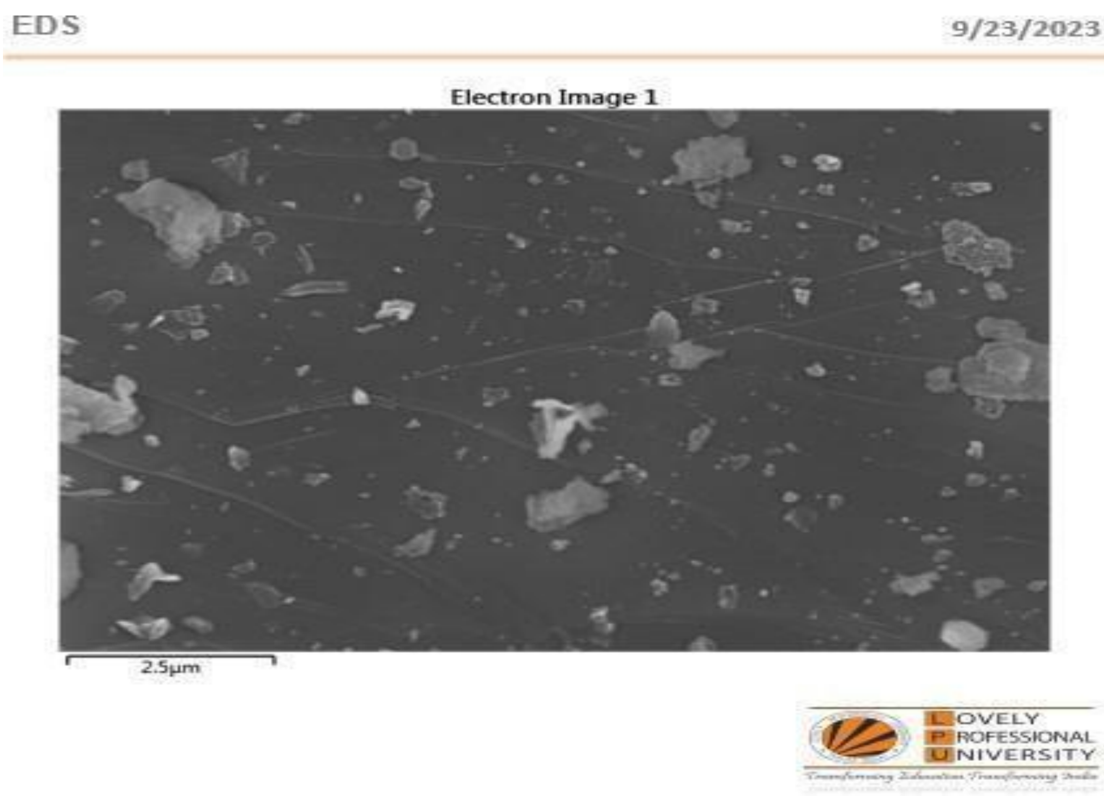
Picture 23 - EDS Test image for M1S2 Sample – Chemical Composition





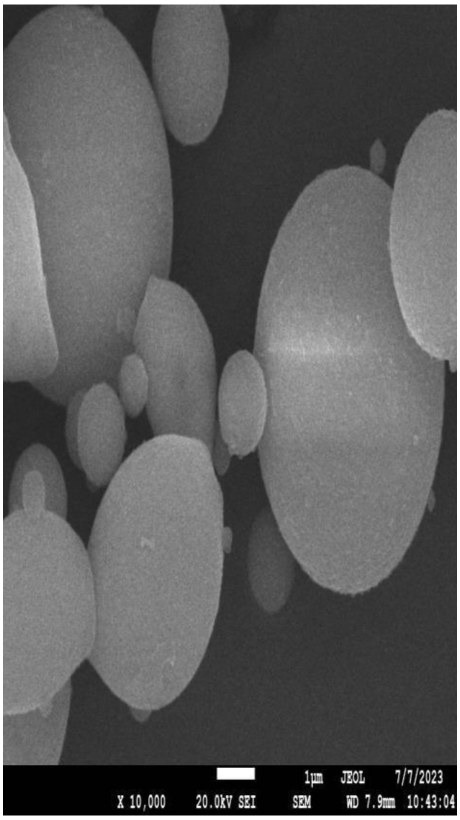
Picture 24 - EDS Test image for M1S2Q5 Sample – chemical composition

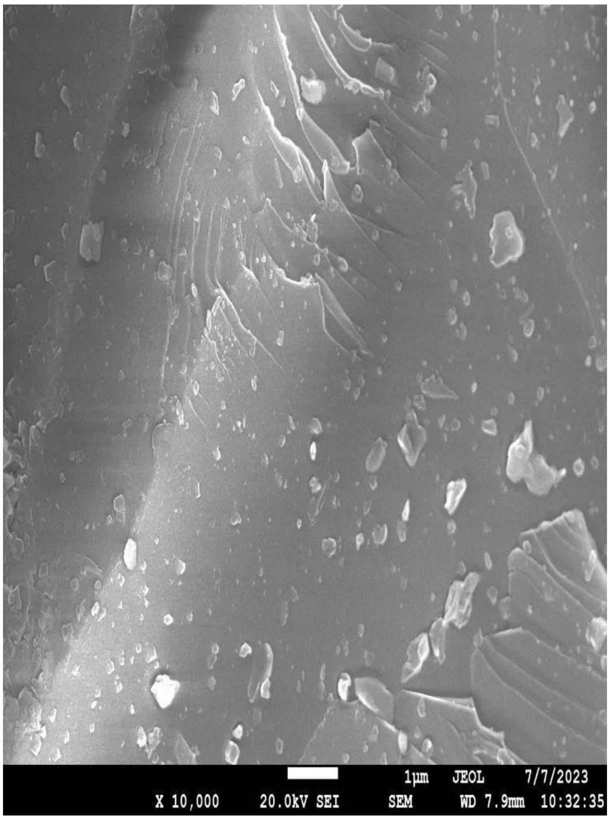




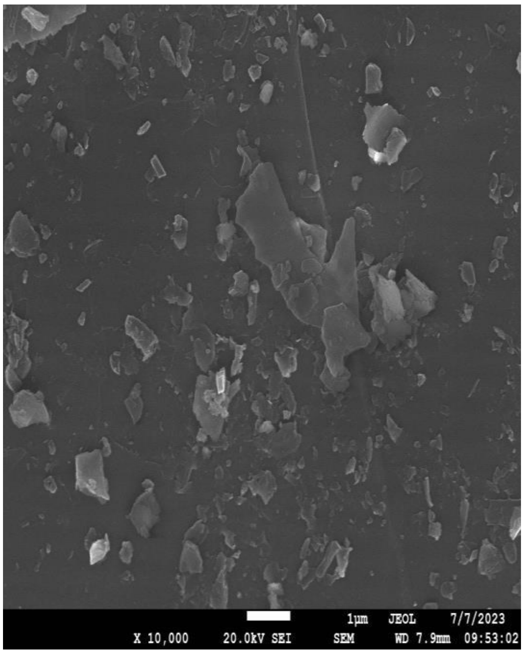
Picture 25 -EDS for NC and M1 Samples

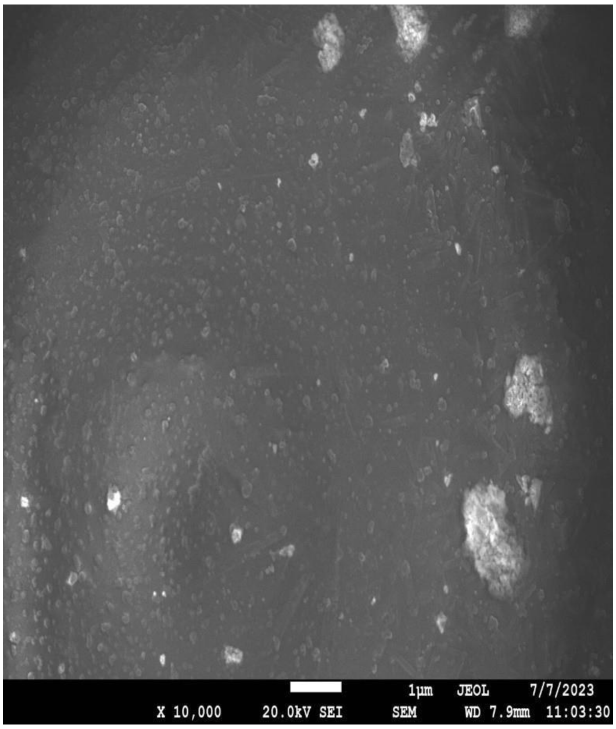
Picture 26 -EDS for M1S2 and M1S2Q5 Samples



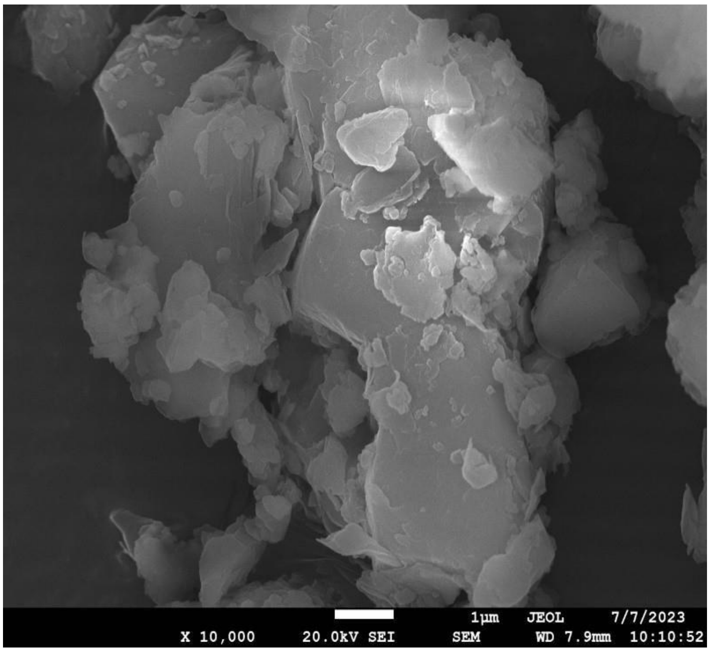


Picture 27 –SEM image of Fly Ash Picture 28 - SEM image of GGBS





Picture 29 -SEM image of QD Picture 30 -SEM image of Silica fume



Picture 30 - SEM image of TSP

Anusha Developers & Infrastructures Pvt. Ltd.

26/05/2024

To
M.Anitha
H.No: 10-4-13/118/28,
Sg Nagar, Nehru Nagar
Hyderabad, 500028.

The below table presents chemical composition of Tandur Stone Slurry Powder provided by the company.

CHEMICAL'S NAME	% OF THE CHEMICAL
Total Carbonate, or CO3,	85.220
Magnesium carbonate, or Mg C3.	3.360
Loss on ignition, or LOI	36.980
Silicon Dioxide, or SiO2.	10.840
Aluminum trioxide, or A12O3,	1.140
Ferrous trioxide, or Fe2O3.	1.600
Calcium oxide, or Cao	48.230
Total	98.790

(Mr.N.Samir Kiran)
Manager – Personnel
(Anusha Developer & Infrastructures Pvt. Ltd)

305, Surabhi Sapphire, Beside Lepakshi, RTC 'X' Road, Hyderabad - 500020.
< www.anushahomes.com > Ph.: 040 - 27620426

Picture 31 – TSP Chemical Composition by company

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Dated: 05 Dec 2019

Anitha M
Registration Number: 41800083
Programme Name: Doctor of Philosophy (Civil Engineering)

Subject: Letter of Candidacy for Ph.D.

Dear Candidate,

We are very pleased to inform you that the Department Doctoral Board has approved your candidacy for the Ph.D. Programme on 05 Dec 2019 by accepting your research proposal entitled: "EXPERIMENTAL STUDY OF GEOPOLYMER CONCRETE PRODUCE BY USING ALTERNATE AGGREGATE AND CHEMICAL ACTIVATORS"

As a Ph.D. candidate you are required to abide by the conditions, rules and regulations laid down for Ph.D. Programme of the University, and amendments, if any, made from time to time.

We wish you the very best!!

In case you have any query related to your programme, please contact Centre of Research Degree Programmes.

Head

Centre for Research Degree Programmes

Note:-This is a computer generated certificate and no signature is required. Please use the reference number generated on this certificate for future conversations.

Jalandhar-Delhi G.T.Road, Phagwara, Punjab (India) - 144411
Ph : +91-1824-444594 E-mail : drp@lpu.co.in website : www.lpu.in

Picture 32 – Letter of Candidacy