Development and characterization of ceramic waste powder-bentonite blended GGBS based cement less geo-polymer concrete designed using the Taguchi's Method

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ABSTRACT

The demand for sustainable and environmentally friendly construction materials has led to the exploration of alternative binders in concrete production. This research paper presents the development and characterization of ceramic waste powder-bentonite blended GGBS-based cement-less geo-polymer concrete designed using the Taguchi's method. Geo-polymer concrete offers a promising alternative to traditional cement-based concrete as it reduces carbon emissions and utilizes industrial by-products. The primary objective of this study is to optimize the mixture proportions and evaluate the mechanical and durability properties of the geo-polymer concrete incorporating ceramic waste powder and bentonite blended GGBS.A series of experiments are conducted based on the Taguchi's orthogonal array design to investigate the compressive strength, workability, and durability of the geo-polymer concrete. The results reveal that the inclusion of ceramic waste powder and bentonite enhances the compressive strength of the geo-polymer concrete. The optimized mixture proportions lead to higher compressive strength values, indicating the potential of this cement-less geo-polymer concrete as a structural material. Additionally, the addition of ceramic waste powder and bentonite improves the workability and flow characteristics of the concrete mixture, facilitating easier handling, placement, and compaction.

The durability properties of the geo-polymer concrete, including resistance to chloride ion penetration, sulphate attack, and alkali-silica reaction, are also evaluated. The findings demonstrate improved durability performance with reduced chloride ion penetration, reduced susceptibility to sulphate attack, and mitigated risk of alkali-silica reaction.

This research contributes to the advancement of sustainable construction materials by utilizing ceramic waste powder and bentonite as supplementary materials in GGBS-based cement-less geo-polymer concrete. The findings provide valuable insights into the mechanical and durability properties of the geo-polymer concrete, supporting its potential as a viable and eco-friendly alternative to conventional cement-based concrete.

KEYWORDS: Geo-polymer Concrete (GPC), Ceramic waste powder(CWP), Ground Granulated Blast Furnace Slag (GGBS), Molarity, Alkaline activators.

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CHAPTER 1

INTRODUCTION

1.1 Outline

In this chapter the pertinent research on the inclusion of ceramic waste in concrete mixtures is compiled. Additionally, it gives an explanation of geo-polymer concrete and how to optimize mixture proportions using the Taguchi method and other multi-response optimization approaches. Due to the similarities between ceramic waste and other types of industrial by-products and SCMs, the reuse of ceramic wastes in concrete as an alternative to aggregate and cement has been the subject of in-depth research. In fact, its incorporation into concrete can increase sustainability and lessen environmental impact.

1.2 Overview

Concrete is one of the most widely used construction materials due to its durability, strength, and versatility. However, traditional Portland cement-based concrete production is associated with significant environmental drawbacks, including high carbon emissions and resource depletion. As sustainable construction practices gain momentum, researchers and engineers are exploring alternative binder systems that can mitigate these environmental concerns while maintaining or even enhancing concrete performance. One such alternative is geo-polymer concrete.

Mortar and/or Concrete Using Ceramic Waste Ceramic ware can be divided into two classes based on the materials used in their creation. Bricks, structural wall and floor tiles, roof tiles, and products made of burned red clay are included in Group 1 while items made of white clay are included in Group 2. These items include technical ceramics (ceramic electrical insulators), ceramic sanitary ware (washbowls, lavatory pans, bidets, and bathtubs), as well as medical and laboratory vessels. The use of ceramic waste as a cement or aggregate replacement in traditional concrete has been extensively studied in previous literature, and is detailed in the sections below. The known prior studies focused on the utilization of recycled ceramic waste materials as fine aggregate, coarse aggregate, and binding elements in concrete compositions.

1.3 Problem Statement

The construction industry is facing significant environmental challenges due to the extensive use of Portland cement in concrete production, which is responsible for substantial carbon emissions. To mitigate these environmental impacts, the development of sustainable and eco-friendly alternatives to conventional cement-based concrete is imperative.

Geo-polymer concrete, a cement-less alternative, has emerged as a promising solution due to its reduced carbon footprint and superior mechanical properties. This concrete utilizes industrial by-products, such as Ground Granulated Blast Furnace Slag (GGBS) and waste materials like ceramic waste powder and bentonite, to create a binder system through geo-polymerization.

However, the successful formulation and optimization of ceramic waste powder-bentonite blended GGBS based geo-polymer concrete require meticulous experimentation and characterization. Various factors, including the proportion of ceramic waste powder, bentonite, GGBS, activators, and curing conditions, significantly influence the properties of geo-polymer concrete. Thus, there is a need to establish an efficient and systematic approach for designing the concrete mixture to achieve desired mechanical strength, durability, and workability.

1.4 Scope and Objectives

This study's primary objectives are to create and assess geo-polymer concrete built with CWP's performance. Using CWP alone in the mix did not produce sufficient workability or compressive strength, according to the sample mixes. Therefore, to encourage the geo-polymerization process and improve performance, slag (GGBS) was employed as a partial replacement for CWP. Natural crushed stone was substituted with dune sand as a more environmentally friendly alternative. Following a thorough analysis of the physical, mechanical, and short-term durability properties, the mixture proportions were optimized. The following are the project's specific goals: Design geo-polymer concrete mixture proportions based on a parametric orthogonal array developed using the Taguchi method.

- Assess the compressive strength of various geopolymer concrete mixtures.

- Examine the impact of various geo-polymer concrete mix proportions on the durability characteristics during the short term.
- Adjust the mixture proportions using the fundamental Taguchi optimization techniques.

1.4.1 Assess The Environmental Impact Of Geo-Polymer Concrete

The objective is to evaluate the environmental benefits of geo-polymer concrete compared to traditional cement-based concrete. This involves conducting a life cycle assessment (LCA) to quantify the carbon footprint, energy consumption, and resource depletion associated with geo-polymer concrete production. The objective is to demonstrate the potential environmental advantages of using geo-polymer concrete as a sustainable alternative.

1.4.2 Explore Applications And Promote The Adoption Of Geo-Polymer Concrete

The objective is to identify potential applications for geo-polymer concrete in various construction projects, such as infrastructure, buildings, and precast elements. This involves showcasing the advantages and performance characteristics of geo-polymer concrete to architects, engineers, and contractors to promote its adoption and encourage the use of sustainable construction materials.

In geo-polymer concrete, ceramic waste powder serves as an additional source of reactive alumina and silica, contributing to the formation of the geo-polymer gel. This, in turn, improves the mechanical strength and durability of the resulting concrete. By utilizing ceramic waste powder, researchers aim to reduce the environmental impact of the ceramics industry and enhance the sustainability of concrete production.

By taking into account the most important influencing factors that lead to high compressive strength and suitable workability at ambient curing conditions, the Taguchi technique is used in this study to propose the ideal mix proportion for geo-polymer concrete. The paper's goal is accomplished through in-depth experimental research. The creation of a mathematical model that incorporates all relevant factors is seen as being outside the purview of this work.

In summary, geo-polymer concrete offers a sustainable alternative to traditional cement-based concrete by utilizing industrial by-products and reducing carbon emissions. Its lower environmental impact, improved durability, and potential for waste utilization make it an attractive option for achieving sustainable construction practices. Further research and development efforts are needed to optimize its performance, standardize production methods, and promote its widespread adoption in the construction industry.

1.5 Introduction

Some detail about the geo-polymer concrete and its use in the industry is given in this chapter.

1.5.1 Geo-polymer Concrete

- A Sustainable Alternative to Concrete Based on Portland Cement.
- It is produced by activating aluminosilicate materials, such as fly ash, ground granulated blast furnace slag (GGBS), or meta kaolin, with alkaline activators.

Geo-polymer concrete is a type of cement-less concrete that utilizes industrial by-products and aluminosilicate materials as the binder. Unlike traditional cement-based concrete, geo-polymer concrete relies on a chemical reaction called geo-polymerization, which occurs when the alumino-silicate materials react with alkali activators. This reaction forms a three-dimensional polymeric network that provides the binding strength and durability required for construction applications.

The use of Ground Granulated Blast Furnace Slag (GGBS), Bentonite, and Ceramic Waste Powder in the development of cement-less geo-polymer concrete is a promising approach for sustainable construction practices. These materials offer unique properties that contribute to improved mechanical strength, reduced carbon footprint, and enhanced workability. The utilization of industrial by-products like GGBS and ceramic waste powder, along with the inclusion of naturally occurring bentonite, aligns well with the principles of sustainability, waste reduction, and resource conservation in the construction industry. Further research and practical application of these materials hold great potential in achieving environmentally friendly and durable construction materials for a greener future.

1.5.2 Benefits in Industry

The key advantage of geo-polymer concrete lies in its lower carbon footprint compared to traditional concrete. Geo--polymer binders can be produced by utilizing industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), and silica fume, which are considered waste materials in other industries. By diverting these materials from landfills and incorporating them into geo-polymer concrete, the environmental impact of concrete production can be significantly reduced. Additionally, geo-polymer concrete has shown improved resistance to corrosion, fire, and chemical attack compared to conventional concrete.

- High compressive strength
- Reduced carbon emissions
- Enhanced durability
- Improved thermal properties
- Reduced shrinkage

Geo-polymer concrete finds applications in various construction projects, including infrastructure development, precast elements, and repair and rehabilitation works.

The development and application of geo-polymer concrete have gained attention in recent years, with research efforts focused on optimizing its mechanical properties, workability, and durability. Various factors, such as the type and composition of aluminosilicate materials, alkali activators, curing conditions, and supplementary additives, can influence the performance of geo-polymer concrete. Researchers are actively exploring different combinations and proportions of these materials to achieve the desired strength, durability, and workability characteristics.

Geo-polymer concrete has shown promise in various construction applications, including infrastructure projects, precast elements, and sustainable building designs. However, there are still challenges to overcome, such as standardization, market acceptance, and cost-effectiveness. Ongoing research aims to address these challenges and further enhance the understanding and application of geo-polymer concrete in the construction industry.

1.6 Research Methodology:

Technique and Approach The performance of the geo-polymer concrete mix design was maximized in this study using the Taguchi method. The Taguchi experimental design was performed through five variables, each at four levels, including binder content (400,435,470,505 and 540g),CWP replacement percentage by GGBS (5,7.5,10,12.5 and 15%), alkali-activator solution (AAS)-to-binder ratio (0.45,0.5, 0.55, 0.6 and 0.65), sodium silicate-to-sodium hydroxide ratio (1.0, 1.5, 2.0,2.5 and 3), and sodium hydroxide solution molarity or molar concentration (8, 10, 12,14 and 16). On the basis of the L25 array acquired using the Taguchi method, a total of 25 mixes were created. Yet, 1600 tests would be required if the Taguchi method were not applied. The compressive strength and setting time of hardened concrete were measured. Later, the ideal mixture proportions of the CWP-GGBS blended geo-polymer concrete that would maximize the various performance criteria were found using the Taguchi optimization methods based on the Best Worst Method (BWM) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

Organization of the Thesis

The following six chapters comprise this thesis:

Chapter 1: The problem statement is briefly introduced, followed by sections on the goals, methods, significance, and structure of the thesis.

Chapter 2 provides a thorough and in-depth analysis of the literature on the use of various types and volumes of ceramic waste as cement and aggregate replacements in the creation of concrete. Additionally, a background on geo-polymers is provided. Chapter 3: The qualities of the material as received, the proportions of the concrete mixtures, sample preparation, and experimental tests are all thoroughly described.

Chapter 4: Mechanical properties (compressive strength) and test results of geo-polymer concrete mixtures are presented and discussed.

Chapter 5: Main results and recommendations for future investigations on the usage of CWP in geo-polymer concrete mixtures are explained. Taguchi Optimization technique is also provided in detail here.

Chapter 6: Sustainable Development Goals are discussed in this chapter.

1.7 Research Significance (or Impact Statement)

The growing global economy and population expansion are to blame for the rising need for concrete. In order to produce cement, the primary ingredient in concrete, many natural resources have been depleted. Making cement has an effect on the environment and contributes significantly to the atmospheric emission of carbon dioxide. In actuality, over the last 200 years, the amount of CO2 in the atmosphere has increased by 42%. Environmentally friendly building materials have been developed in an effort to reduce these CO2 emissions. In the past, additional cementitious materials (SCMs) have been used to partially replace cement. However, environmental contamination and the depletion of raw materials won't stop unless the cement can be entirely replaced. On one occasion, the manufacture of an inorganic alkali-activated geo-polymer successfully replaced all of the cement. This innovative substance makes a promise to cut carbon emissions and lessen the use of natural resources. Because industrial by-products make up the majority of the precursor binders, it also offers to recycle these wastes rather of dumping them in landfills or stockpiles. Geo-polymers have been thoroughly studied in the past, with an emphasis on materials like meta-kaolin, GGBS, fly ash, and others. However, the by-product of making ceramics, ceramic waste powder, has not been investigated as a binder for geo-polymer concrete. Additionally, no research has been done into the partial replacement of CWP with GGBS in such concrete. Additionally, the ideal combination proportions for CWP-GGBS blended geo-polymer concrete have not been determined based on performance.

The purpose of this study is to offer experimental support for the prospective use of CWP and GGBS in blended geo-polymer concrete. This innovative geo-polymer concrete's physical, mechanical, and durability characteristics will be assessed. The proposed geo-polymer concrete will offer an innovative, long-lasting solution to two well-known environmental problems, the exhaustion of natural resources and carbon dioxide emissions. Additionally, instead of throwing away industrial waste in landfills and stockpiles, it will recycle it for use in building materials and other applications.

CHAPTER 2

Literature Review

2.1 Outline

This chapter summarizes the utilization of ceramic waste in concrete mixtures was the subject of pertinent study. Additionally, it gives an explanation of geo-polymer concrete and how to optimize mixture proportions using the Taguchi method and other multi-response optimization approaches. Due to the similarities between ceramic waste and other types of industrial by-products and SCMs, the reuse of ceramic wastes in concrete as an alternative to aggregate and cement has been the subject of in-depth research. In fact, its incorporation into concrete can increase sustainability and lessen environmental impact.

Role of construction Industry in Global Development

The construction industry plays a significant role in global development, but its conventional practices have considerable environmental impacts, such as high carbon emissions and the depletion of natural resources. To address these challenges, sustainable construction materials have gained immense interest. Geo-polymer concrete, an eco-friendly alternative to Ordinary Portland Cement (OPC)-based concrete, has emerged as a promising solution due to its low carbon footprint and utilization of industrial by-products. This literature review explores the development and characterization of ceramic waste powder-bentonite blended Ground Granulated Blast Furnace Slag (GGBS) based cement-less geo-polymer concrete, with a focus on the use of Taguchi's method for mix design optimization. Atmospheric temperatures, precipitation rates and patterns, water supplies, habitats on land and in the water, threatened and endangered species, and agricultural production are just a few of the numerous natural and man-made resources that could be impacted by climate change. Estimates show that 5–6% of all carbon dioxide greenhouse gases created by human activities come from the production of cement (van Deventer et al. 2010). Emissions of petrol and dust into the atmosphere originate from the consumption of raw materials and energy. The exhaust gases from cement kilns contain nitrous oxides (NOx), carbon dioxide, water, oxygen, small amounts of dust, chlorides, fluorides, Sulphur dioxide, carbon monoxide, and much smaller amounts of organic compounds and heavy metals. (Devi et al. 2017).

2.2 Conventional Experimental Design

According to the conventional experimental design method, which takes more time and costs more money, several tests are needed to examine the impact of a wide variety of parameters at their various levels on the properties of GPC. To examine the impact of these parameters with fewer experiments, a suitable approach of experiment design might be chosen. (Yuan *et al.* 2015). In this study we have planned to use Taguchi method of optimization to investigate the properties of GPC optimized max under the influence of different parameters.

One of the experimental design methodologies, the Taguchi Method, is successfully used for optimization in systematic designs. information on performance Signal to Noise (S/N) is an optimization criterion used in Taguchi design. The three types of performance statistics are the largest-best, nominal-best, and smallest-best. S/N values are calculated based on the experimental data and the biggest best performance statistics S/N. Taguchi approach has been used in a number of investigations. The application of this technique has received more attention lately, especially in concrete.

2.3 Taguchi Method Is A Fractional Factorial Design Method

In order to study a large number of variables with a small number of experiments, the Taguchi method, a fractional factorial design method, uses a special set of arrays called orthogonal arrays (OA). When compared to conventional experiment design techniques, the design of experiments utilizing OA is relatively efficient. The OA minimize uncontrolled parameters and cut down on the number of experiments. For instance, the classic factorial design needs 34 or 81 test runs when employing four parameters at three proportions, whereas the Taguchi technique only needs nine. The signal-to-noise (S/N) ratio is used by the Taguchi method to optimize. The S/N ratio aids in data analysis and optimal outcome prediction. In essence, OA offers a collection of tests that are fairly balanced, and S/N ratio acts as an objective function for optimization. The effectiveness, cost-effectiveness, resilience, and simplicity of output interpretation are the key benefits of Taguchi methods.

Although the Taguchi approach has been extensively utilized in other technical applications, it has only recently been used to geo-polymer concrete. Riahi et al. looked at the geo-polymer concrete made with fly ash and constructed utilizing the Taguchi method's 2- and 7-day compressive strengths. Using the Taguchi approach, they looked into how SH concentration and curing conditions affected compressive strength. By taking into account the impacts of aggregate content, sodium silicate to sodium hydroxide ratio, alkaline activator to fly ash ratio, and curing process, Olivia et al. designed nine geo-polymer concrete mixes. It was claimed that the components of the geo-polymer concrete mix may be optimized using the Taguchi method. Khalaj et al. discovered that the Taguchi approach may be used to effectively design the split tensile strength of geo-polymers based on Portland cement.

2.4 Taguchi Method in Concrete Taguchi

Taguchi Concrete Method Taguchi is a fractional factorial design technique that employs orthogonal arrays to study a lot of variables with the least amount of experiments possible. This approach can be used to examine how various aspects interact in a single research. For data analysis and result prediction, the signal-to-noise (S/N) ratio is frequently used. Hadi et al. optimized the mixture proportions of ambient-cured geo-polymer concrete using fly ash, meta-kaolin, and silica fume as mineral additions and GGBS as the primary binder using the Taguchi method. Taguchi is a fractional factorial design technique that employs orthogonal arrays to study a lot of variables with the least amount of experiments possible. This approach can be used to examine how various aspects interact in a single research. For data analysis and result prediction, the signal-to-noise (S/N) ratio is frequently used. Hadi et al. optimized the mixture proportions of ambient-cured geo-polymer concrete using fly ash, metakaolin, and silica fume as mineral additions and GGBFS as the primary binder using the Taguchi technique. The sodium silicate to sodium hydroxide ratio (SS/SH), sodium hydroxide (SH) molar concentration, binder content, alkaline activator to the binder content, and sodium hydroxide (SH) were all examined by the authors for their effects on the properties of geo-polymer concrete. The samples were evaluated for compressive strength using a total of nine distinct mixtures. According to the study, the highest compressive strength over the course of seven days was 60.4 MPa, and it was at room temperature when curing. When GGBFS was largely replaced with fly ash, meta-kaolin, and silica fume, the compressive strength of geo-polymer concrete decreased. Onoue and Bier. investigated the viability of the Taguchi Method's dynamic approach to optimize alkali activated mortar using GGBFS and natural pozzolans. The design parameters were the binder content, sodium hydroxide solution concentration, GGBFS replacement ratio, mixing regime, mixing time, curing temperature, and cumulative temperature in heat curing. The response variables were flow and flexural and compressive strength. An L18 orthogonal array was used for the experiments, and the S/N ratios were used to optimize the response variables. The study found that mortar can be utilized as a building material, although expansion fractures were noticed because gypsum formed after the mortar was submerged in a 10% sulphuric acid solution for a long time. According to this study, the ideal set of design parameters was 6 M SH concentration, SS-to-SH of 0.75, 30% GGBFS replacement, 4 minutes of mixing time, 90°C for curing, and 540°C/hour for total heat treatment temperature. Imşek and Uygunolu determined the ideal mixture proportions of concrete containing various polymers using the Taguchi-based TOPSIS optimization approach. This study used an L27 orthogonal array to conduct a total of twenty-seven tests, taking into account thirteen parameters with three control levels each. Thermal conductivity, compressive strength at 3, 7, and 28 days, slump flow, water absorption, split tensile strength, production cost, and water permeability were all examined on the concrete samples. The ideal mix design contained 450 kg of cement, 120 kg of fly ash, 0.46 water to binder ratio, 1.05% superplasticizer, 0.5 fine aggregate to total aggregate ratio, and 0.15 coarse aggregate to total aggregate. It also contained 10% polypropylene fiber, 5% low-density polyethylene fiber, 5% polyethylene terephthalate, and 10% dimethyl terephthalate. These values were thermal conductivity of 0.70 W/m.K, 36.4 MPa, 14 cm, 2.46%, 2.64 MPa, \$608/mm^2 and 2.28 cm, respectively. They also included 28-day compressive strength, slump flow, water absorption, splitting tensile strength, production cost, and water permeability. A similar strategy was used to find the ideal mixture proportions of high strength self-compacting concrete in a ready mix concrete plant, which was based on the TOPSIS-based Taguchi optimization method. The average convective heat transfer coefficient, the percentage of air content, the slump flow, the T50 duration, the water absorption, the compressive strength, the splitting tensile strength, and the production cost are the performance criteria 35 that the author established for this study. Cement dosage (400 and 425), water-to-cementitious material ratio (0.35, 0.37, and 0.39), aggregate mixture ratio (0.6, 0.65, and 0.7), superplasticizer content (1, 1.25, and 1.5), fly ash content (80, 100, and 120 kg), and mixture content (100, 110, and 120 kg) were the five variables that had an impact on these performance criteria. After conducting the Taguchi experiment, it was discovered that the ideal mixture levels had the following characteristics: an average convective heat transfer coefficient of 14.556 W/m^2.K percentage of air content of 0.1%, slump flow of 760 cm, a T50 time of 3 seconds, water absorption of 1.7%, compressive strength of 81.2 MPa, splitting tensile strength of 5.1 MPa, and production cost of 50.9$/$mm^2$. In a current investigation, Sharifi et alusing the Taguchi optimization method, the ideal mix design for the high-strength self-compacting concrete was modeled. The authors selected 10 distinct quality parameters, including cost, heat transfer coefficient, air %, slump flow, T50 duration, absorbed water percentage, compressive strength at 2, 7, and 28 days, and splitting tensile strength at 28 days. The study's elements were also taken into consideration. In this study, analysis of variance (ANOVA) was used to evaluate the contributing elements and the best mixture designs while also utilizing the Best-Worst approach to determine the overall weight of the experiment with respect to each quality attribute. The ideal mixture design was found to contain 425 kg of cement, 0.35 kg/m^3 of water to cementitious binder, 0.6 kg/m^3 of coarse aggregate to fine aggregate, 1 kilogram/m3 of superplasticizer, 120 kg of fly ash, and a 120 second mixing period.

2.5 Past Research Objectives

Following are the objectives of the previous research histories:

2.5.1 Develop An Optimized Mixture Design For Geo-Polymer Concrete

The objective is to determine the optimal combination of aluminosilicate materials, alkali activators, and supplementary additives to achieve the desired mechanical properties, workability, and durability of geo-polymer concrete. This involves conducting experimental studies to investigate the effects of various parameters on the performance of geo-polymer concrete.

2.5.2 Characterize The Mechanical Properties Of Geo-Polymer Concrete

The objective is to assess the compressive strength, flexural strength, and tensile strength of geo-polymer concrete. This involves conducting mechanical tests on geo-polymer concrete specimens and comparing the results with those of traditional cement-based concrete. The objective is to demonstrate the potential of geo-polymer concrete as a viable alternative with comparable or improved mechanical performance.

2.5.3 Evaluate The Durability Performance Of Geo-Polymer Concrete

The objective is to assess the resistance of geo-polymer concrete to various deteriorating factors, such as chemical attack, freeze-thaw cycles, and alkali-silica reaction. This involves conducting durability tests on geo-polymer concrete specimens and analyzing the results to determine its long-term durability and suitability for different exposure condition.

2.5.4 Investigate The Microstructural Properties Of Geo-Polymer Concrete

The objective is to analyze the microstructure of geo-polymer concrete using techniques such as scanning electron microscopy (SEM) and X-ray diffraction (XRD). This analysis helps in understanding the formation and structure of the geo-polymer gel and its relationship to the mechanical and durability properties of the concrete.

2.5.5 Environmental Considerations

Atmospheric temperatures, precipitation rates and patterns, water supplies, habitats on land and in the water, threatened and endangered species, and agricultural production are just a few of the numerous natural and man-made resources that could be impacted by climate change. Cement production consumes a lot of energy and has a big impact on global warming. The primary environmental, health, and safety issues associated with cement manufacturing are air emissions and energy use.

The production of cement requires a sizable amount of non-renewable resources, such as raw materials and fossil fuels. Estimates show that 5–6% of all carbon dioxide greenhouse gases created by human activities come from the production of cement (van Deventer *et al.* 2010). Emissions of petrol and dust into the atmosphere originate from the consumption of raw materials and energy. The exhaust gases from cement kilns contain nitrous oxides (NOx), carbon dioxide, water, oxygen, small amounts of dust, chlorides, fluorides, sulphur dioxide, carbon monoxide, and much smaller amounts of organic compounds and heavy metals. (Devi *et al.* 2017). Metals and organic compounds are released when commercial trash is burned in a cement kiln. Dust emissions are also produced by the clinker cooler, grinders, crushers, and material handling equipment (Devi *et al.* 2017). Both the air quality and human health are being negatively impacted by these pollutants. Emissions affect local and global ecosystem, contributing to problems including acid rain, ozone depletion, global warming, biodiversity loss, and lower crop output. (Pariyar *et al.* 2013).

This study examines how different mix parameters affect the mechanical and durability characteristics of ambient-cured geo-polymer concrete including CWP and slag. Five variables—binder content, slag replacement percentage, AAS/Binder, SS/SH, and SH solution molarity—each with four levels, were evaluated. Sixteen geo-polymer concrete combinations were created using the Taguchi method. The mixtures were examined in order to determine the ideal blend for the best performance in terms of compressive strength, elastic modulus, water absorption, scorptivity, and abrasion resistance. SEM and electron dispersive X-ray (EDX) were used to describe the morphology and microstructure of this ideal mixture. The engineering community is especially interested in this data since it offers cutting-edge performance and microstructure characterization of geo-polymer concrete including CWP.

2.6 Ceramic Waste as Cement Replacement in Mortar/Concrete

Sun et al. looked into the thermal behavior of pastes made of geo-polymers and ceramic waste. After being subjected to various temperatures, the compressive strength was examined. Nine mixes with various replacement ratios of activating solutions were the subject of the study. It was determined that the initial reacting system affects the compressive strength of the geo-polymer made from ceramic waste. Additionally, the alkaline activating solution is crucial to the geo-polymerization procedure. After two hours of calcination at 1000°C, the ideal geo-polymer concrete mix design produced the highest compressive strength of 71.1 MPa. El-Dieb and Kanaan also looked at the impact of cement replacement with ceramic waste powder on the qualities of freshly-poured and cured concrete, including slump, compressive strength, drying shrinkage strain at 120 days, quick chloride ion penetration test, and more.

Strength could be improved with 10% CWP replacement level, workability retention might be improved with replacement levels between 10% and 20%, and durability could be improved with replacement levels of 40%. A multi-criteria performance index was used to handle multiple performance requirements. It was reasonable to replace cement with 10–20% CWP in order to increase the mixture's workability, retention, and strength. All of the performance criterion were optimized by the addition of 30–40% CWP. Puertas et al. investigated the potential of employing discarded ceramic tile as a raw material in the mixtures used to create Portland cement clinker. In this study, burnt red or white ceramic wall tile wastes, as well as mixtures of the two, were examined for their reactivity and burn-ability as cement raw mixes. Chemical examination to identify the constituent components, differential thermal analysis (DTA) and thermos-gravimetric analysis (TG), X-ray diffraction analysis (XRD) mineralogical analysis, and morphological analysis were the tests carried out. The raw mixtures with ceramic waste that had particles smaller than 90 m were said to have good reactivity. However, using ceramic waste with particles smaller than 45 m could result in an increase in reactivity. However, the resultant clinker's mineral composition and phase distribution were on par with those of clinker generated in the traditional manner.

2.7 Ceramic Waste as Coarse Aggregate Replacement in Mortar/Concrete

The use of ceramic waste as a substitute for coarse aggregate in concrete was investigated by Senthamarai and Devadas Manoharan. Testing was done to determine the compressive, flexure, tensile, and elastic modulus of the concrete as well as the characteristics of the ceramic aggregates. The outcomes suggested that ceramic waste aggregates might potentially be used in the creation of concrete because their qualities were comparable to those of natural aggregates. Additionally, compared to control mixes, concrete mixtures made using ceramic waste aggregates were more workable and cohesive. Ceramic waste aggregate concrete had compressive, splitting tensile, and flexural strengths that were, respectively, 3.8, 18.2, and 6.0% lower than those of regular concrete. Senthamarai et al. examined the permeation parameters, including void content, water absorption, sorption, and chloride penetration, to determine the durability features of concrete built with ceramic electrical insulator trash as coarse aggregate. We tried six different water-to-cement ratios. It was discovered that the permeation characteristic values of the concrete prepared with the ceramic waste aggregate were higher than those of normal concrete. A lower water-to-cement ratio, however, resulted in a decrease in these values, indicating that the ceramic insulator waste can be employed as coarse aggregate in concrete. Guerra et al. reported on the impact of employing recycled ceramic material from sanitary installations on the mechanical qualities of concrete. A constant water-cement ratio of 0.51 was used to create five concrete mixtures with varying mass replacement rates of coarse aggregate by ceramic waste. Based on the findings of the compressive strength tests, the authors came to the conclusion that it had no negative effects to replace up to 7% of the mass of coarse aggregate with ceramic waste. Beyond this point, the concrete's qualities fell short of those of the control mixture prepared with no ceramic waste. Medina et al. looked into the usage of recycled coarse aggregate made from used sanitary ware as a partial (15, 20, and 25%) replacement for natural coarse aggregate in structural concrete. The experimental program assessed the microscopic studies, such as XRD and scanning electron microscope (SEM), compressive strength, and consistency. The authors came to the conclusion that the control equivalent lacked the recycled aggregate concrete's better compressive and tensile strength. The research revealed that the recycled ceramic aggregate had no impact on cement hydration processes. In order to create concrete that will come into close contact with water that is intended for human consumption, Medina et al. investigated the effects of employing recycled ceramic sanitary ware trash as a partial substitute (25%) for natural coarse aggregate. Water from the migration was analyzed chemically and subjected to a leaching test. The findings showed that the pH or electrical conductivity of water suited for human consumption were unaffected by the addition of ceramic waste aggregate to concrete. However, it was observed that using this recycled aggregate caused the concentration of alkalis to increase while all other elements, including B, Si, Cl, and Mg, decreased in the water. Porcelain and common red ceramics were employed as alternatives for coarse aggregate in concrete in previous work by Keshavarz and Mostofinejad. By casting 65 specimens from 8 different mixes, the compressive, tensile, and flexural strength and water absorption were evaluated. The compressive strength of red ceramic and porcelain tile waste increased by up to 19 percent, according to experimental results. When porcelain waste was added, the tensile and flexural strengths rose by up to 41% and 67%, respectively. Tests on the water absorption of concrete revealed that red ceramic waste enhanced it by 91% while porcelain increased it by up to 54%. The investigation came to the conclusion that red ceramic waste's high porosity was to blame for its inferior performance to porcelain. In replacement rates ranging from 20 to 100%, Anderson et al. substituted three distinct waste ceramic tile materials for coarse aggregate in concrete. The normal-strength concrete was represented in this investigation by a conventional concrete mix with a characteristic cube strength of 40 MPa. In order to preserve the same design strength as typical concrete, the water-to-cement ratio was kept constant at 0.55 for all the tested mixtures. Testing was done to determine the compressive, flexure, tensile, and elastic modulus of the concrete as well as the characteristics of the ceramic aggregates. Results showed that the porous nature of the ceramic tiles caused a general drop in compressive strength and an increase in water absorption. The viability of employing ceramic waste in place of cement and fine and coarse aggregates in concrete was investigated by Pacheco-Torgal and Jalali. There were two stages to the study's execution. White stoneware twice fired (WSTF), sanitary ware (SW), and white stoneware once fired (WSOF) are the four concrete mixes that were made in the first stage with a 20% substitution of ceramic powder for cement. Using ceramic sand and crushed ceramic coarse aggregate, concrete mixes were created for the second step. All concrete mixtures underwent testing for compressive strength, water absorption, permeability, and chloride diffusion. The highest 20 mechanical performance for all ceramic waste was found in the concrete mixture with 20% ceramic brick CB waste. The study also showed that ceramic sand is a good alternative to conventional sand since it offers improved durability and does not result in a loss of strength. Results of concrete mixtures including ceramic aggregate underperformed marginally in terms of water permeability and absorption. The potential use of sanitary waste as fine and coarse aggregate in concrete was investigated by Halicka et al. There were two phases to the experiment. The concrete specimens with ceramic aggregate and alumina cement were tested in the first stage. The second stage involved the examination of concrete sample constructed exclusively using alumina cement. We looked at the materials' tensile, compressive, and abrasion resistance. According to the study, concrete built with ceramic sanitary ware aggregate had an abrasion resistance that was almost 20% higher than concrete made with gravel. For the preparation of certain types of concrete subjected to strong abrasive forces, the sanitary ceramic aggregate was therefore advised. In a study by Zegardo et al., sanitary waste was crushed to sizes between 0 and 4 mm and 4 and 8 mm, respectively, to be utilized as a coarse aggregate in concrete. The physical and mechanical characteristics of the resulting concrete, including its bulk density, compressive and tensile strength, water absorption, water permeability, and frost resistance, were assessed and compared to those of reference mixes generated with gravel and basalt aggregates. The results showed that the compressive and tensile strengths of concrete with recycled ceramic aggregate were 24 and 34% greater than those of concrete with gravel-basalt aggregate. According to the study's findings, recycled ceramic waste aggregate can be used to make concrete without needing to undergo any additional processing. In a different study, Awoyera et al. substituted ceramic waste for the coarse and fine aggregate in concrete. The ceramic tiles were crushed using a hammer mill and graded using British Standard (BS) sieves to reflect natural aggregates. The coarse particles were 12.7 mm in size and the fine aggregates ranged in size from 0 to 4 mm. Additionally, cement, river sand, and gravel were used in this investigation. A mix ratio of 1:1.5:3 (cement: sand: gravel) and a water to binder ratio of 0.6 were used to create concrete samples. Slump, compression strength, and tensile strength testing were performed. Concrete with a 75% substitution of coarse ceramic aggregate produced strength greater than the desired 25 MPa strength. With increasing curing age, both compressive and split tensile strengths grew.

2.8 Ceramic Waste as Fine Aggregate Replacement in Mortar/Concrete

López et al. looked explored the use of white ceramic powder made from used ceramic tiles as a partial replacement for fine aggregates. Rubble from demolition sites and ceramic industry trash were used to make the ceramic powder. The goal of the study was to examine the physical and mechanical characteristics of laboratory-produced concrete with different amounts of fine aggregate (10–50% by mass) made of white cement powder while maintaining a water-to-cement ratio of 0.51. According to test results, replacing 50% of the sand with ceramic powder increased compressive strength by up to 29% when compared to the control mix. It was determined that by utilizing the energy contained in the ceramic waste product used to make concrete, concrete was transformed into a more environmentally friendly material. Abadou et al. looked at the impact of using recycled fine aggregate made from crushed sanitary and earthenware ceramics. Six mortar mixtures made with ceramic waste and beach sand were created for this study. Numerous tests were conducted, including those for workability, porosity, flexural and compressive strength, and elastic modulus. By replacing up to 50% of the natural dune sand with waste ceramic aggregate, the results indicated a considerable improvement in compressive (up to 22.3 MPa) and flexural strength (up to 0.85 MPa) compared to the reference mortar. Additionally, Huang et al. investigated the Portland cement concrete (PCC) and asphaltic concrete using cement ceramic waste materials as fine aggregates to determine its compressive strength, indirect tensile strength, dynamic modulus, toughness index, and water absorption. According to the test results, adding crushed scrap increased the PCC's compressive strength. However, due to significant water absorption, it was advised to utilize less than 10% of crushed scrap. The test findings also showed that adding up to 15% by weight of ground waste for hot mix boosted the binder's overall resistance to deformation. In order to determine if it would be feasible to make mortar and concrete using ceramic waste and fly ash, Torkittikul and Chaipanich carried out an experimental test program. The ceramic debris that was used in this investigation came from Thai ceramic companies. Researchers looked at the density, compressive strength, and workability of concrete and mortar combinations. Research results showed that the compressive strength of concrete without fly ash (FA) enhanced by up to 50% of the weight of ceramic waste aggregate. When ceramic waste was used to replace fine aggregate at 100%, the compressive strength of fly ash concrete was at its highest. Awoyera et al. carried out additional research to determine the impact of laterite and ceramic waste on the mechanical properties of concrete. The ceramic fine and coarse aggregates replaced 25, 50, 75, and 100% of sand and gravel, respectively, in the mixing of concrete number 23. In different ratios of 10, 20, and 30%, laterite was used to partially replace river sand to create laterite concrete. We looked at direct and indirect tensile strength. The study came to the conclusion that concrete produced with up to 75% ceramic coarse aggregate replacement produced higher strength based on the test findings. Additionally, by partially replacing sand and cement with crushed ceramic waste and microsilica, respectively, Nayana and Rakesh evaluated the characteristics of cement mortar. To assess the impact of the recycled materials, compression strength and durability tests were carried out, including water absorption, sorptivity, and sulfate resistance. In order to create mortar, microsilica was used to replace cement in proportions of 5 and 10 and ceramic waste in amounts of 15, 30, and 50%. In comparison to the control mix, the compressive strength of recycled mortar rose by 20% when 15% ceramic and 10% micro-silica were added. However, it fell as more ceramic debris was added. In comparison to the reference mix, the mixture with 15% ceramic waste and 0% micro-silica had reduced water absorption and sorptivity by 1.2 and 12%, respectively. Jackiewicz-Rek et al. also created four mortar combinations to test the workability, mechanical attributes, and freeze-thaw resistance of cement mortar amended with ceramic waste fillers. Three mortars that were substituted for natural aggregates in the reference mortar M0 had 10, 15, and 20% of ceramic fillers, by weight of cement, in line with EN 196-1. According to the characteristics of fresh mortars, adding more ceramic filler reduced the consistency and flexibility of the mortar.

The inclusion of ceramic waste aggregates led to a systematic increase of the mechanical characteristics, with the advantages growing with the addition rate, according to the findings of the flexural and compressive strength tests.

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Utilizing ceramic aggregates increased compressive strength by 42% and flexural strength by 50% at 2 days. The inclusion of ground ceramic waste had no effect on compressive strength up to 25 cycles, according to the freeze-thaw resistance. On the other hand, it was discovered that freeze-thaw adversely affected the flexural strength of mortars, with the reduction increasing with the percentage of ceramic waste. The study also demonstrated that ground sanitary waste can be used as an efficient filler in cement mortars at addition rates of less than 20% (by weight of cement). Binici investigated the applicability of basaltic pumice and ceramic industrial waste as potential replacements for traditional crushed fine aggregates. According to the absolute volume approach, the concrete mixture was created by maintaining a constant binder content (400 kg/m3) and a water to cement ratio between 0.48 and 0.51. The concrete samples were put through testing for compressive strength, abrasion resistance, and chloride penetration. The study found that crushed ceramic and crushed basaltic pumice concretes have lower abrasion resistance than standard concretes. In fact, when the rate of finely crushed ceramic reduced, the abrasion resistance increased. Significantly more concrete specimens with 60% crushed ceramic were resistant to chloride penetration than other examples.

2.9 Geo-polymer Mortar/Concrete

The previously published research on geo-polymer concrete focused on the optimization of combination proportions using Taguchi, BWM, and TOPSIS approaches. Numerous research have looked into the usage of geo-polymer concrete as a sustainable substitute for OPC concrete over the past few years. Geo-polymer concrete is a cement-free kind of construction in which industrial waste products serve as the primary binders. The ingredients that make up these binders are calcium or aluminum silicates. Geo-polymer concrete, as opposed to OPC concrete, goes through an activation reaction with an alkaline solution. The most common alkaline activator solution is a mixture of sodium silicate and sodium hydroxide, however potassium silicate and potassium hydroxide have also been used. The CWP/GGBFS that is reacted with by these activator solutions solidifies when it is cured at low temperatures. Following the dissolution of the chemical elements in CWP and GGBFS, a three-dimensional macro-molecular structure is created through geo-polymerization.

Numerous experimental studies have demonstrated that geo-polymer concrete has good mechanical and durability features as well as the ability to lessen the environmental impact and resource consumption connected with the construction sector. Below, a sample of earlier articles is discussed. Ramujee and Potha Raju looked into the geo-polymer concrete made from fly ash's mechanical characteristics. Fly ash was utilized in this study as a precursor binder material to create concrete. G20, G40, and G60 were the three geo-polymer concrete grades that were made, coupled with a control mix for comparison. Samples underwent tests for splitting tensile strength and compressive strength. Under heat curing conditions, the cube compressive strength for geo-polymer concrete specimens ranged from 30 to 71 MPa as opposed to 27 to 68 MPa for the control. The study's findings led to the conclusion that geo-polymer concrete's mechanical performance was comparable to that of regular Portland concrete. The geo-polymer concrete acquired its maximum strength far more quickly under heat curing circumstances than under ambient curing settings, according to research findings 26. Muttashar et al. assessed the effectiveness of used garnets as a sand substitute for producing self-compacting geo-polymer concrete. For this study, five self-compacting geo-polymer concrete mixtures with garnet content ranging from 0% to 100% were created. Slump flow, V-funnel and L box tests, field emission scanning microscopy (FESEM), water absorption, and acid resistance were all performed on the samples. Results showed that in terms of cost-effectiveness, environmental impact, and resource conservation, wasted garnet may substitute sand by up to 25%. Up to 60 days of exposure to a high carbon dioxide environment, this concrete exhibited exceptional resistance to quick carbon dioxide penetration. Fly ash with a high unburned content (21%) was used by Valencia-Saavedra et al. to create single and binary geo-polymer concrete. The microstructural analysis of the geo-polymer paste using XRD, Fourier transform infrared (FTIR) spectroscopy, and SEM enhanced the findings of this work. The results of the study showed that concretes with a strength of up to 48 MPa may be produced utilizing the right alkaline activation conditions. The study also showed that the inclusion of GGBFS enhanced the density, decreased the setting time, and raised the compressive strength of concrete made using a fly ash-based geo-polymer. After 28 days of curing, a strength of about 43 MPa was attained using an additional 20% GGBFS and a Na2O/SiO2 ratio of 0.25. This is a 115% improvement over fly ash-only concrete.

Additionally, as the alkali agent was increased while the L/S was decreased, the compressive strength and ultrasonic velocity rose. The engineering qualities of the geo-polymer can be significantly improved by curing in saturated limewater as opposed to air, according to the results. For example, LFS saw increases in compressive strength and ultrasonic pulse velocity of up to 59 and 23%, respectively. The effects of high volume waste ceramic powder on the strength and microstructure of alkali-activated mortars exposed to 31 high temperatures were studied by Huseien et al. Wastes from Malaysian agro and construction sectors, including CWP, GGBFS, and FA, were used to create concrete mixtures. To assess the temperature dependence of the residual compressive strength, weight loss, and microstructure of mortar specimens as prepared, temperatures as high as 900°C were applied. At high temperatures, the deterioration of alkali-activated mortar specimens was assessed using XRD, TGA, FTIR spectroscopy, and field emission scanning electron microscopy (FESEM). The study found that raising the CWP concentration from 50 to 70% boosted the suggested mortars' resistance to high temperatures. Additionally, replacing GGBFS with FA reduced the deterioration of the mortar, with mixtures comprised of 70% CWP, 20% GGBFS, and 10% FA demonstrating the best resistance to high temperatures. Another study looked at how CWP affected the effectiveness of alkali activated mortars manufactured with GGBFS and FA. In this investigation, a modest concentration of an alkaline solution (4 M) was used to activate the ternary blend. 50, 60, and 70% of the total mass of the binder were maintained as CWP. The samples were examined at eight various ages after being cured at a constant temperature of 27°C. To assess the impact of the high CWP concentration on the formulation of sodium aluminum silicate hydrate (N-A-S-H), calcium aluminum silicate hydrate (C-A-S-H), and calcium silicate hydrate (C-S-H) gels, microstructure tests such as XRD, SEM, and FTIR were carried out. Results revealed that large volume CWP produced alkali-activated mortars that were safe for the environment and had compressive strengths greater than 70 MPa after 28 days. The increase in CWP content improved the workability and setting time. El-Hassan et al. examined the effectiveness of alkali-activated GGBFS concrete with various fly ash substitution percentages. To facilitate the binding process, sodium silicate was mixed with three different molarities 32 of sodium hydroxide. Up to 3% by volume of steel fibers were included into the alkali-activated mixture at various volume ratios. The proportions of the binder, alkali activator, dune sand, and coarse aggregate were adjusted, and samples were allowed to cure under natural lighting. The study found that higher fiber content and less slag produced concrete mixtures that were less workable but had better mechanical qualities. The mechanical characteristics could be enhanced by replacing up to 25% of the fly ash. The compressive strength grew quickly, reaching an average of 72 and 78% of the 28-day compressive strength at ages 1 and 7, respectively. The study also demonstrated that the inclusion of steel fiber enhanced the compressive strength of samples taken after 1 and 7 days by up to 39 and 52%, respectively. El-Hassan et al. also investigated the behavior and microstructure of concrete containing alkali-activated slag and slag-fly ash under three distinct 28-day curing regimes: air, intermittent water curing, and continuous water curing. Slag, desert dune sand, and aggregate were fixed components of three concrete mixtures, and an alkaline solution made of sodium silicate and sodium hydroxide was used to activate the mixtures. The AAS-to-slag ratio ranged from 0.45 to 0.55. Samples were examined to determine their mechanical and transport characteristics. With an alkaline activator solution to slag ratio of 0.50, the test produced the best results. The research indicated that intermittent water curing was the most efficient. Slag, desert dune sand, and aggregate were fixed components of three concrete mixtures, and an alkaline solution made of sodium silicate and sodium hydroxide was used to activate the mixtures. The AAS-to-slag ratio ranged from 0.45 to 0.55. Samples were examined to determine their mechanical and transport characteristics. With an alkaline activator solution to slag ratio of 0.50, the test produced the best results. a form of curing that lowers porosity and sensitivity while boosting electrical resistivity, elastic modulus, and compressive strength in the bulk. Calcium aluminosilicate hydrate (CaAsH), which is the primary reaction product that contributes to strength, was identified through microstructure characterization.

2.10 Greenhouse Gas Emissions

Geo-polymer concrete is referred to as green concrete because OPC is not present. Geo-polymer concrete has been shown to have strong mechanical properties and lower greenhouse gas emissions. (Reed et al. 2014).

The research has made considerable use of FA and SG to make GPC mixes. However, strict rules around coal-fired power facilities have resulted in FA shortages in a number of global countries. It is critical to find substitutes for FA that might be used as precursors in the production of GPC in order to promote commercialization of GPC, reduce costs, and meet the expanding demand for infrastructure.

In order to find sustainable alternatives to traditional concrete building, all available alternative raw material sources should be investigated. Bentonite clay and CWP powders are two examples of such basic materials. The former (CWP) is the leftover or waste product created following the excavation or crushing of massive parent mass rock to create aggregates (Kürklü & Görhan 2019). More than 15% of the entire aggregate production's waste dust comes from quarrying activities (Hill et al. 2001)[1]. These wastes don't biodegrade and cause environmental contamination, which puts people's health in danger. Without treatment or recycling, the storage and disposal of these materials can pose serious environmental problems.

In the vicinity of rock quarries, enormous amounts of fine dust particles that are damaging to plants, animals, and people can be seen suspended in the air or gathered near to the stone crusher (Kürklü & Görhan 2019.The latter (Bentonite) is an aluminum-phyllosilicate clay made primarily of montmorillonite minerals and is often created when volcanic ash is chemically weathered in the presence of water. Therefore, a new method of recycling this garbage must be developed. This waste material can effectively replace some of the binding elements used in GPC while building infrastructure. With the use of the Taguchi optimization technique, an optimized GGBS, Bentonite, and CWP-based GPC mix will be created. This study will examine the effects of using CWP and bentonite as a partial replacement for GGBS in ambient-cured GGBS-based GPC. In comparison to OPC, it uses a lot more industrial waste materials, such as slag, fly ash, rock dust, and silica fume, in addition to having CWP smaller carbon impact. (Reed *et al.* 2014).

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2.11 Taguchi's Method for Mix Design Optimization

The Taguchi's method, a robust design and optimization technique, has gained popularity in various engineering fields, including concrete mix design. Researchers have applied this method to optimize the mix proportions of geo-polymer concrete by considering multiple factors such as the type and proportion of raw materials, molar ratios, alkaline activators, curing conditions, and other parameters. By employing the Taguchi's method, studies have successfully developed geo-polymer concrete mixtures with enhanced mechanical properties, durability, and cost-effectiveness.

2.12 Characterization Techniques for Geo-polymer Concrete

To assess the performance and properties of geo-polymer concrete, various characterization techniques have been employed. X-ray diffraction (XRD) is commonly used to identify the mineralogical composition of geo-polymer binders, while scanning electron microscopy (SEM) allows researchers to study the microstructure and interfacial transition zones. Fourier-transform infrared spectroscopy (FTIR) is utilized to analyze chemical bonds and hydration products, providing insights into the geo-polymerization process. Thermal analysis techniques, such as differential scanning calorimetry (DSC) and thermos-gravimetric analysis (TGA), have also been used to understand the geo-polymerization kinetics and thermal stability of geo-polymer concrete.

2.13 Performance and Properties of Ceramic Waste Powder-Bentonite Blended GGBS-Based Geo-polymer Concrete

Characterization techniques for geo-polymer concrete are essential for understanding its microstructure, properties, and performance. These techniques provide valuable insights into the geo-polymerization process, the formation of the geo-polymer gel, and the interactions between the geo-polymer binder and other components in the concrete mixture.

Numerous research studies have investigated the performance and properties of ceramic waste powder-bentonite blended GGBS-based geo-polymer concrete designed using the Taguchi's method. These studies have demonstrated that the incorporation of ceramic waste powder and bentonite can positively influence the mechanical strength, workability, and durability of geo-polymer concrete. The Taguchi's method has been effective in optimizing mix proportions, resulting in improved mechanical properties and reduced environmental impacts.

The performance and properties of ceramic waste powder-bentonite blended GGBS-based geo-polymer concrete are critical factors that determine its feasibility and applicability as a sustainable construction material. This section of the literature review delves deeper into various aspects of geo-polymer concrete, specifically focusing on the influence of ceramic waste powder and bentonite on its mechanical properties, workability, durability, and environmental impact.

2.14 Geo-polymer Concrete and Sustainable Construction

Geo-polymer concrete is a cement-less binder system that employs aluminosilicate-rich materials activated by alkaline solutions. It offers significant environmental benefits, including reduced greenhouse gas emissions, lower energy consumption, and decreased waste generation compared to OPC-based concrete. Researchers have investigated the mechanical properties, durability, and performance of geo-polymer concrete, highlighting its potential for sustainable construction applications.

2.15 Economic Considerations

The use of ceramic waste powder and bentonite in geo-polymer concrete contributes to waste reduction, resource conservation, and reduced environmental impact.

Additionally, the incorporation of GGBS as a supplementary material further enhances the sustainability profile of geo-polymer concrete by utilizing an industrial by-product. The economic feasibility of this technology is also a crucial aspect to consider, as it can affect its adoption in the construction industry.

2.16 Challenges and Future Directions

While significant progress has been made in the development and characterization of ceramic waste powder-bentonite blended GGBS-based geo-polymer concrete using the Taguchi's method, several challenges remain. These challenges include optimizing the mix design for specific applications, understanding the long-term durability performance, and addressing potential issues related to early-age cracking and workability. Future research should focus on addressing these challenges to foster the widespread adoption of geo-polymer concrete as a sustainable construction material.

CHAPTER 3

Materials and Methodology

3.1 Outline

This chapter highlights the details of the materials used in this project and methodology to attain optimum geo-polymer concrete mixture proportions. Following established test protocols, the properties of the items as they were received were first determined. The Taguchi method-designed blends' mechanical and durability properties were then evaluated as part of the optimization process. Compressive strength and the cement's initial and ultimate setting times were among these characteristics. After that examination, the best geo-polymer mix consisting of CWP, Bentonite, and GGBS was determined using the basic Taguchi approach.

3.2 Materials

There are different materials which were used to prepare Geo-polymer concrete. We used different percentages of the materials for different mix designs. The composition of the material was firstly tested from the lab and then after fulfilling the requirements we used these materials for our research on the Geo-polymer concrete. The following supplies are frequently used to make Geo-polymer concrete:

- Binder Contents(Ceramic waste powder, Bentonite, GGBS, Aggregates).
- Alkaline activators

3.2.1 Binder Contents

One of the most crucial characteristics of HMA that can impact the effectiveness of the mixture is the binder content. Its choice is crucial, especially when it comes to recycling options.

GGBS used in this study has pozzolanic and cementitious properties confirming ASTM C989/C989M-18a.

The chemical compositions of the materials are presented in the Table 1.

Table 3.1. Chemical Composition of Binder Contents

Composition	**Materials**		
	GGBS	**Bentonite**	**Ceramic Waste Powder**
SiO_2	31.79	56.88	21.7
TiO_2	-	1.45	-
Al_2O_3	17.07	15.45	8.54
Fe_2O_3	0.49	12.27	-
MgO	6.23	3.71	20.58
CaO	38.78	0.55	35.58
LOI	-	6.89	12.07

3.2.1.1 Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a by-product generated during the iron-making process in blast furnaces. When molten iron ore is reduced in the blast furnace, it results in the production of molten slag. GGBS is obtained by rapidly quenching the slag with water or steam, followed by finely grinding it into a fine powder. This process converts the amorphous slag into a pozzolanic material with reactive properties.

GGBS is known for its pozzolanic reactivity, meaning it can chemically react with calcium hydroxide, commonly formed during cement hydration, to produce additional cementitious compounds.

Fig.3.1. Ground Granulated Blast Furnace Slag (GGBS)

When used as a supplementary cementitious material, GGBS enhances the strength and durability of concrete, reduces the heat of hydration, mitigates thermal cracking, and decreases permeability. Additionally, incorporating GGBS in concrete contributes to sustainability by reducing the carbon footprint and promoting the utilization of industrial by-products.

3.2.1.2 Bentonite

Bentonite is a naturally occurring clay mineral with high plasticity and swelling properties when exposed to water. Due to its unique characteristics, bentonite has been widely used in various industries, including construction, geotechnical engineering, and environmental applications. In the context of concrete, bentonite is often utilized as an additive to improve the workability and fresh properties of the mixture.

Fig.3.2. Bentonite.

In cement-less geo-polymer concrete, the inclusion of bentonite can enhance the workability and cohesion of the geo-polymer binder. By acting as a lubricating agent, bentonite reduces the water demand and facilitates the mixing and casting process. Furthermore, bentonite can improve the early-age strength development and mitigate issues related to segregation and bleeding in fresh geo-polymer concrete.

3.2.1.3 Ceramic Waste Powder

Ceramic waste powder is a by-product generated in the ceramics industry during the production of ceramic products. This waste material is rich in silica and alumina, making it suitable for geo-polymerization. By incorporating ceramic waste powder into geo-polymer concrete, researchers can reduce waste generation and promote circular economy principles.

Ceramic waste powder refers to the byproduct generated during the production or processing of ceramics, such as tiles, sanitary ware, or porcelain.

Fig.3.3. Ceramic Waste Powder.

Ceramic waste powder typically contains a high percentage of silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3), which contribute to its pozzolanic properties. Instead of discarding this waste material, it can be utilized as a supplementary cementitious material in concrete production.

3.2.1.4 Aggregates

Aggregates are a fundamental component of concrete and play a significant role in construction materials. They are granular materials, usually inert, that are combined with cement and water to form concrete. Aggregates occupy a substantial volume in concrete and influence its strength, durability, and overall performance. There are two main types of aggregates used in concrete:

Coarse Aggregates: Coarse aggregates consist of particles larger than 4.75 mm (0.187 inches) in diameter. They typically include crushed stone, gravel, or recycled concrete. Coarse aggregates provide bulk to the concrete mixture, reducing the amount of cement paste required and improving economy. They also contribute to the concrete's mechanical properties, such as compressive and flexural strength, and play a critical role in providing dimensional stability and load-bearing capacity.

Fig.3.4.Coarse Aggregates.

Fine Aggregates: Fine aggregates consist of particles smaller than 4.75 mm (0.187 inches) in diameter. Commonly used fine aggregates include natural sand, crushed stone sand, or crushed gravel sand. Fine aggregates help in filling the voids between coarse aggregate particles, improving the workability and cohesiveness of the concrete mix. They also contribute to the concrete’s strength and help in achieving a smoother surface finish.

Fig.3.5. Fine Aggregates.

The physical characteristics of aggregates significantly impact the properties of concrete, including its strength, workability, durability, and overall performance in various construction applications. Engineers and concrete producers carefully assess and select aggregates based on these characteristics to ensure the quality and longevity of the concrete structures they build.

Table 3.2. Physical characteristics of coarse aggregate and fine aggregate

Properties	Fine Aggregates	Coarse Aggregates
Bulk density (kg/m^3)	1620	1549
Saturated surface dry water absorption (%)	1.3	0.9
10% Fine value (KN)	-	160
Specific gravity	2.71	2.7
Maximum aggregate size (mm)	4.75	20
Minimum aggregate size (mm)	-	10

3.2.2 Alkaline Activators

To create the alkaline activator solution, sodium hydroxide (SH) and sodium silicate (SS) were mixed together. By combining 98% pure SH flakes with particular amounts of water to make solutions with varied molarities, namely 8, 10, 12, 14 and 16 M, sodium hydroxide solution was created. The ratio of the components in the grade "N" sodium silicate solution was 26.3% $SiO2$, 10.3% $Na2O$, and 63.4% $H2O$.

3.2.2.1 Sodium Silicate

Sodium silicate, also known as water glass or liquid glass, is a chemical compound with the formula $Na2SiO3$ or $Na2SiO4$, depending on its composition.

It is a colorless, viscous liquid or a white solid, depending on its concentration.

Fig.3.6. Sodium Silicate.

As an alkali activator, sodium silicate can activate certain chemical reactions, particularly those involving alkaline conditions.

3.2.2.2 Sodium Hydroxide

Sodium hydroxide, chemical formula NaOH, is an inorganic compound commonly known as caustic soda or lye. It is a strong base and highly caustic, meaning it has the ability to react strongly with acids and has corrosive properties. Sodium hydroxide is an essential industrial chemical with a wide range of applications across various industries.

Fig.3.7. Sodium Hydroxide.

Sodium hydroxide (NaOH) plays a vital role in geo-polymer concrete as an essential alkaline activator. Geo-polymer concrete is a cement-less concrete that relies on the reaction between aluminosilicate materials (such as GGBS and ceramic waste) and an alkaline solution to form a three-dimensional network of geo-polymer bonds. This reaction, known as geo-polymerization, results in the hardening and binding of the concrete mixture.

3.3 Experimental Equipment

During our research we used following equipment for casting of cubes.

- Electronic Balance
- Compression testing machine (CTM)
- Thermometer
- Sieves
- Steel Moulds
- Wooden Slabs Moulds
- Hand riddle

- Measuring scale
- Shovel
- Steel Moulds
- Mixing Trays
- Oiling box
- Vicat apparatus
- Trowel
- Tamping rod
- Vicat apparatus

3.3.1 Compressive Strength Testing Equipment

3.3.1.1 Compression Testing Machine

This machine is used to measure the compressive strength of cement and other construction materials. It applies a gradually increasing compressive load to a cement sample until it fails. The maximum load at failure is recorded to calculate the compressive strength.

3.3.1.2 Test Cubes or Cylinders

Cement samples are cast into standardized cube or cylinder shapes and cured under specific conditions before testing. The most common sizes of cubes are 4in x 4in.

3.3.1.3 Weighing Scale

A precise weighing scale is used to measure the weight of the cement samples accurately.

3.3.1.4 Water Bath or Curing Tank

The samples are kept in a water bath or curing tank under controlled temperature and humidity conditions to promote proper cement hydration.

3.3.2 Setting Time Testing Equipment

3.3.2.1 Vicat Apparatus

The Vicat apparatus is used to determine the setting time of cement. It consists of a movable rod (needle) that is applied to the surface of a cement paste sample. The needle is gradually lowered into the paste, and the setting time is recorded when the needle no longer makes an impression on the surface.

3.3.2.2 Stopwatch or Timer

A stopwatch or timer is used to measure the time taken for the cement to reach initial and final setting stages.

3.3.2.3 Temperature and Humidity Control

The setting time of cement can be affected by temperature and humidity variations, so maintaining controlled conditions is essential during testing.

It's important to note that the specific testing methods and equipment may vary based on regional standards and laboratory protocols. The standards set by organizations like ASTM International or the International Organization for Standardization (ISO) provide guidelines for conducting these tests using appropriate equipment and procedures. Always refer to the relevant standard for accurate testing protocols.

3.4 Methodology

3.4.1 Compressive Strength

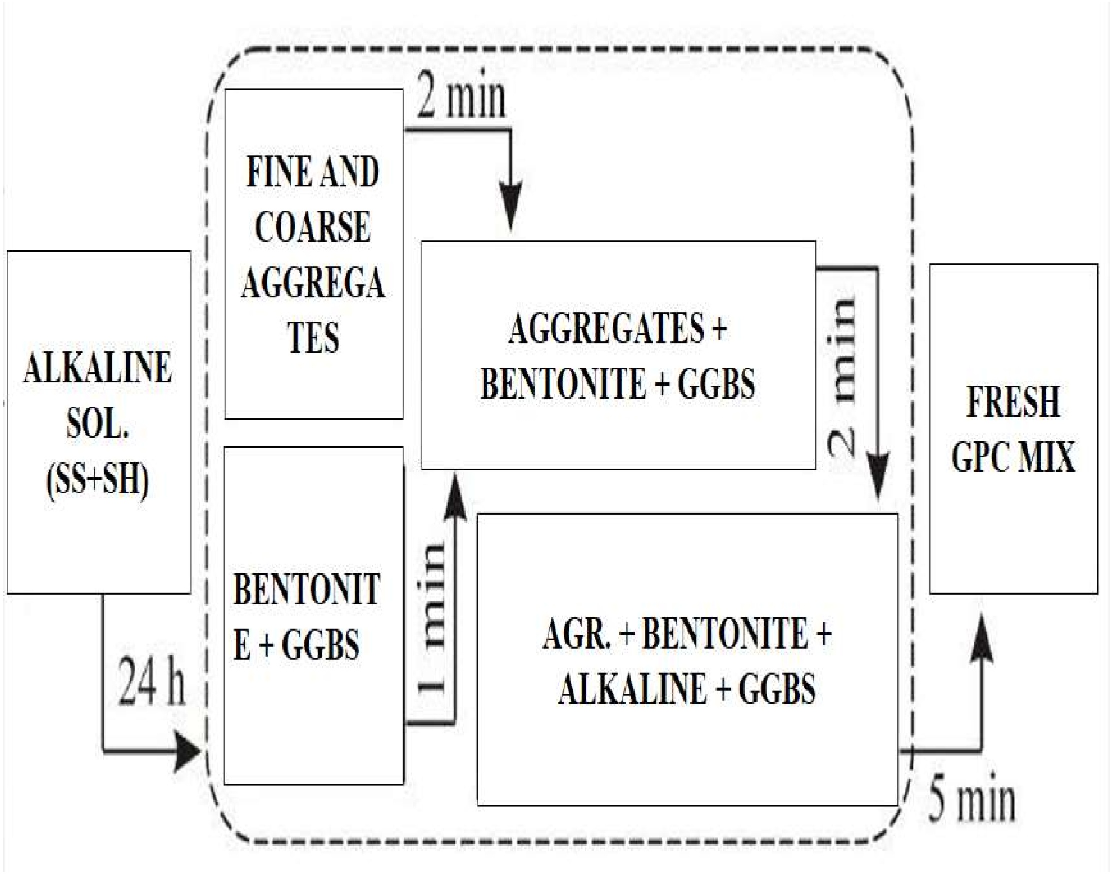
3.4.1.1 Design of Experiment

The experimental program’s steps are listed below:

1. Choosing the proper parameters and levels for them.
2. Select an appropriate orthogonal array and arrange the parameters and levels using the Taguchi method.
3. Conducting tests using geopolymer mixes selected in accordance with the Taguchi experimental design methodology.
4. Calculating the experimental results' signal-to-noise ratio (S/N).
5. Using Taguchi analysis to simultaneously optimize a number of parameters.
6. Running verification tests using the improved GPC mix.

3.4.1.2 Mix Proportions

By following a proper mixing sequence, the GGBS-based Geo-polymer Concrete can achieve a well-dispersed, homogeneous mixture with optimal geo-polymerization and binding properties. This approach helps in producing a high-quality and sustainable concrete material with improved mechanical and durability characteristics.



It is important to note that specific mix proportions would require detailed experimental investigation and optimization using the Taguchi method to achieve the desired properties. The mix proportions are influenced by factors such as the properties of the raw materials, desired concrete strength, workability, and environmental conditions.

The different mix portions used during experiments are given in the table:

Table.3.3. Calculated Mix proportions.

CALCULATED VALUES USED FOR CASTING									
MIX ID	**GGBS (g)**	**Bentonite (g)**	**CWP(g)**	**20mm Agg(g)**	**10mm Agg(g)**	**Fine Agg(g)**	**AL(g)**	**SH/ Lit**	**SS/ Lit**
M1	1600	300	100	3549	2366	3185	900	320	320
M2	1359	653	163	3408	2272	3058	1088	400	600
M3	1058	1058	235	3259	2173	2925	1293	480	960
M4	694	1515	316	3104	2070	2786	1515	560	1400
M5	270	2025	405	2943	1962	2641	1755	640	1920
M6	2020	379	126	3203	2135	2874	1263	480	1440
M7	1688	810	203	3048	2032	2735	1485	560	560
M8	900	900	200	3432	2288	3080	1200	640	960
M9	598	1305	272	3280	2187	2944	1414	320	640
M10	235	1763	353	3351	2234	3007	1058	400	1000
M11	2160	405	135	3048	2032	2735	1485	560	560
M12	1250	600	150	3432	2288	3080	1200	640	960
M13	979	979	218	3280	2187	2944	1414	320	640
M14	646	1410	294	3351	2234	3007	1058	400	1000
M15	253	1894	379	3203	2135	2874	1263	480	1440
M16	1600	300	100	3432	2288	3080	1200	640	960
M17	1359	653	163	3280	2187	2944	1414	320	640
M18	1058	1058	235	3351	2234	3007	1058	400	1000
M19	694	1515	316	3203	2135	2874	1263	480	1440
M20	270	2025	405	3048	2032	2735	1485	560	560
M21	1740	326	109	3280	2187	2944	1414	320	640
M22	1469	705	176	3351	2234	3007	1058	400	1000
M23	1136	1136	253	3203	2135	2874	1263	480	1440
M24	743	1620	338	3048	2032	2735	1485	560	560
M25	200	1500	300	3432	2288	3080	1200	640	960

3.4.1.3 Preparation of Specimen

Cubes of sizes 4in x 4in were prepared shown in figure 10. A total of 4 cubes of the same mix design were prepared in the prescribed 25 mixes. These cubes were left for a testing period of 14 days and 28 days. After the prescribed time the cubes were to be tested to determine the compressive strength using the CTM (compression testing machine).

Fig.3.8. Steel molds for cubes casting.

Following are the steps for making the cubes for each of the mix design:

3.4.1.3.1 Calculate the mix proportions

To get the necessary compressive strength, calculate the cement, water, and other materials mix ratio. Depending on the needs of the project, the mix proportions might change, however a typical mix may contain cement-to-water ratios. The quantities of all Mix design for Cubes calculated before in table 3.1.

Fig.3.9. Mixing of ingredients.

3.4.1.3.2 Preparation of Alkaline solution

The Alkaline solution was prepared by mixing the required quantities of Sodium Hydroxide and Sodium Silicate for each of the mix design.The prepared solution was kept for 24 hours till the final casting process of the cubes.

Fig.3.10. Alkaline solution making.

3.4.1.3.3 Making Mixture of All Ingredients

The weighed quantity of each of the ingredient of the mix design was taken in the mixing tray and mixed thoroughly for a while. After mixing the Alkaline solution prepared 24 hours before this process was added for making paste.

Fig.3.11. Concrete paste for Casting.

3.4.1.3.4 Pouring Paste In The Cubes

The molds were oiled before pouring concrete to stay safe from sticking of concrete in the molds after hardening. Then concrete was poured in the cubes. Safety precautions were taken in mind during the pouring. Temping was continuously done by the temping rod to remove air bubbles from it.

Fig.3.12. Pouring concrete paste into cubes.

3.4.1.3.5 Demolding

The next step was to remove the cubes from the molds. This process was done very gently so that the cubes finish surface could not be disturbed. After demolding the cubes was taken in the comfortable environment for 14 and 28 days as per testing requirements.

Fig.3.13. Demolding of Cubes.

3.4.1.3.6 Testing of Cubes

After the specified time duration, we took the specimens out of the store. Allowed the specimens to reach room temperature before testing to eliminate any temperature-related effects. Labeled each specimen for easy identification. Positioned the specimen on the compression testing machine's lower platen.

Fig.3.14. Demolded cubes for testing.

Aligned the specimen carefully so that the load was applied uniformly on the vertical axis. We ensured that load-bearing surfaces of the specimen were clean and free from any debris. Began the compression test by applying a steadily increasing load at a constant rate (usually 0.5 Mpa/s) until the specimen fails. Monitored the load and corresponding deformation until the specimen fractures. Recorded the maximum load or stress at failure.

Fig.3.15. Cubes testing.

3.4.2 Initial and Final Setting Time

Monitoring and controlling the initial and final setting time are important for ensuring proper workability, placement, and strength development of geo-polymer concrete. By understanding the effects of the binder materials, additives, and mixture proportions, researchers can manipulate the setting time to meet specific project requirements and optimize construction operations the initial and final setting time of ceramic waste powder-bentonite blended GGBS-based cement-less geo-polymer concrete are influenced by the presence of supplementary materials, such as ceramic waste powder and bentonite, as well as the mixture proportions determined using the Taguchi's method. The understanding and control of these setting characteristics contribute to achieving the desired workability, placement, and early strength development of geo-polymer concrete, making it a viable and sustainable alternative to traditional cement-based concrete.

3.3.2.1 Preparation of Specimen

The specimen was prepared by mixing the ingredients 100g of each (each ingredient used in the research). The paste was mixed thoroughly for a while so that the mixture should have homogeneous in nature.

Fig.3.16. Paste for Setting time.

3.3.2.2 Testing for Setting Time

The specimen was placed in the vicat apparatus by filling in the ring and then for Initial setting and final setting time following steps were followed:

3.3.2.2.1 Initial Setting Time

- Fill the Vicat apparatus with the freshly mixed geo-polymer mixture.
- Ensure the mold is clean and free from any residue or debris.
- Lower the needle gently onto the surface of the geo-polymer concrete without causing any disturbance to the mixture.
- Release the needle and allow it to penetrate the concrete mixture under its weight.
- Start a timer as soon as the needle makes contact with the concrete mixture.
- Check the penetration of the needle at regular intervals (e.g., every 15 minutes)

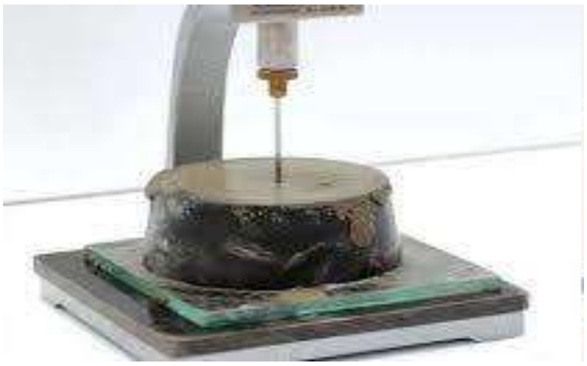


Fig.3.17. Initial setting time check.

3.3.2.2.2 Final Setting Time

- Prepare a second Vicat mold filled with the geo-polymer concrete.
- Repeat the same procedure as in the initial setting time test, using the same needle and apparatus.

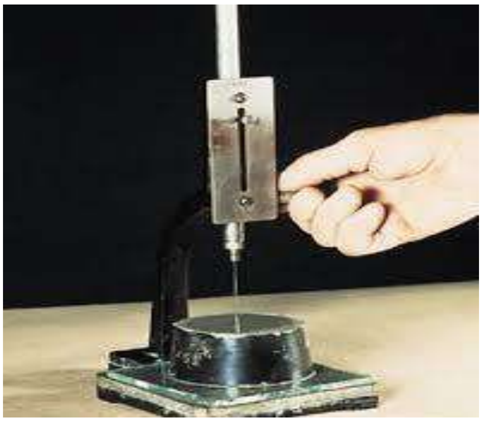


Fig.3.18. Final setting time check.

- This time, check the penetration of the needle at more extended intervals (e.g., every 30 minutes) until the needle no longer leaves any visible impression on the concrete surface, indicating the final setting time.

Fig.3.19. Stopwatch.

After all this process the initial and final time of the concrete was noted for all of the different mix designs.

Chapter 4

Experimental Work and Results

4.1 Outline

This study's primary goal is to apply Taguchi optimization techniques to CWP and GGBFS-based geo-polymer concrete in order to produce a mix that is optimal for mechanical and durability attributes. This much variation in the proportions of the geo-polymer concrete mixture was achieved using a Taguchi L25 orthogonal array with 5 components and 5 levels. The compressive strength and setting time test results are included. This chapter also investigates the potential use of CWP as a binder in the creation of geo-polymer concrete.

4.2 Experimental Work

The mix designs made using Taguchi's Method were casted and tested for required parameters. Our required parameters were as follows:

- Compressive Strength
- Initial and Final Setting Time

Every mix design was unique in its composition i.e.no one the mix design had composition matched with any other.

4.2.1 Taguchi's Mix Designs

4.2.1.1 Compressive Strength

The following experimental data was calculated before making the cubes by using Taguchi's Method:

4.2.1.1.1 Replacement level

The following levels of replacement were designed using Taguchi's Method:

Table.4.1. Levels of Used materials.

Levels	GGBS Replacement with Bentonite	GGBS Replacement with CWP	Total Slab Replacement %	Al/Binder	Mol	Binder Content	SS/SH
1	15	5	20	0.45	8	400	1.0
2	30	7.5	37.5	0.5	10	435	1.5
3	45	10	55	0.55	12	470	2.0
4	60	12.5	72.5	0.6	14	505	2.5
5	75	15	90	0.65	16	540	3.0

4.2.1.1.2 Levels of Parameters

Following Levels of parameters were designed:

Table.4.2. Levels of parameters.

Experiment	Level of Parameters					
	GGBS	Slag Replacement	Al/Binder	Mol. NaOH	Binder Content	SS/SH
1	1	1	1	1	1	1
2	1	2	2	2	2	2
3	1	3	3	3	3	3
4	1	4	4	4	4	4
5	1	5	5	5	5	5
6	2	1	2	3	4	5
7	2	2	3	4	5	1
8	2	3	4	5	1	2
9	2	4	5	1	2	3
10	2	5	1	2	3	4
11	3	1	3	4	5	1
12	3	2	4	5	1	2
13	3	3	5	1	2	3
14	3	4	1	2	3	4
15	3	5	2	3	4	5
16	4	1	4	5	1	2
17	4	2	5	1	2	3
18	4	3	1	2	3	4
19	4	4	2	3	4	5
20	4	5	3	4	5	1
21	5	1	5	1	2	3
22	5	2	1	2	3	4
23	5	3	2	3	4	5
24	5	4	3	4	5	1
25	5	5	4	5	1	2

After all the samples were prepared, these were tested for compression test in the CTM. The compression testing machine gives the maximum force value that the sample can bear. This data is then used to calculate the strength of the concrete samples.

Fig.4.1. Compression testing Machine.

4.2.1.2 Initial and Final Setting Time

The initial setting time and the ultimate setting time are two key components used to evaluate concrete's setting characteristics. The first setting period of concrete is the time it takes for it to transition from a liquid to a semi-rigid condition, while the ultimate setting period is the amount of time it needs to fully harden and reach its maximum strength. Concrete now becomes stiffer and loses its flexibility. It is possible to conduct common test methods like the Vicat apparatus test. These tests involve testing the concrete's resistance to penetration periodically until the initial and final setting points are attained.

To make a cement paste or mortar sample with a certain constituent quantity, all mix designs should be used. The ingredients should be carefully combined to create a homogeneous mixture. A base plate, a Vicat mold, a Vicat plunger, and a Vicat needle form the Vicat device.

Make sure the equipment is spotless and residue- and dirt-free. Perform the consistency test right now. To carry out the consistency test, fill the Vicat mold with the prepared cement paste or mortar sample. Level the surface of the sample with a trowel or straight edge. Place the mold on the base plate of the device. Make sure the Vicat plunger makes contact with the paste or mortar by gently pressing it against the sample's surface.

Holding the plunger by its handle will cause it to fall into the sample due to its own weight. Keep track of how deeply the plunger inserted itself into the sample. This measurement corresponds to the initial setup time. Repeat the test until the plunger doesn't leave any impressions. This depth of penetration indicates the final setting time.

Calculate the interval between the addition of water to the cement and the corresponding depths of penetration to find the beginning and final setting times. After each test, thoroughly clean the Vicat mold, plunger, and needle of any dirt. Let them dry before conducting additional testing.

4.3 Results

The following results were obtained for Setting Time and Compressive strength after testing cubes made by using Taguchi’s Method:

4.3.1 Compressive Strength

It is important to note that the specific mixing sequence may vary depending on the specific formulation, the desired properties, and the equipment used. Additionally, it is recommended to follow any manufacturer's guidelines or specific research protocols to ensure accurate and reproducible results. By following a wise mixing sequence, the GGBS-based Geo-polymer Concrete with partial replacement of bentonite can achieve a well-dispersed, homogeneous mixture with optimal geo-polymerization and binding properties. This approach helps in producing a high-quality and sustainable concrete material with improved mechanical and durability characteristics. Compressive strength is a fundamental mechanical property used to evaluate the performance and structural integrity of concrete.

The results are as shown in table:

Table.4.3. Compressive strength of concrete cubes.

TEST RESULTS				
MIX ID	**14 DAYS**		**28 DAYS**	
	CUBE 1 (Psi)	**CUBE 2 (Psi)**	**CUBE 1 (Psi**	**CUBE 2 (Psi)**
M1	632	643	843	857
M2	1475	1528	1967	2037
M3	1128	1244	1503	1658
M4	822	801	1096	1068
M5	685	696	913	927
M6	2255	2287	3007	3009
M7	1855	1876	2473	2501
M8	1465	1496	1953	1995
M9	495	548	660	731
M10	622	643	829	857
M11	696	717	927	955
M12	938	980	1251	1307
M13	717	738	955	984
M14	337	316	450	422
M15	390	400	520	534
M16	1971	2066	2628	2754
M17	864	833	1152	1110
M18	811	843	1082	1124
M19	390	432	520	576
M20	242	274	323	365
M21	790	769	1054	1026
M22	569	569	759	759
M23	580	590	773	787
M24	748	759	998	1012
M25	569	590	759	787

The M6 mix design gave us the only compressive strength greater than 3000psi.

The compressive strength test on all the GPC mixes Were performed at 14 and 28 days of ambient curing from the day of preparation and the results are shown also as graphical data in Figure 3.

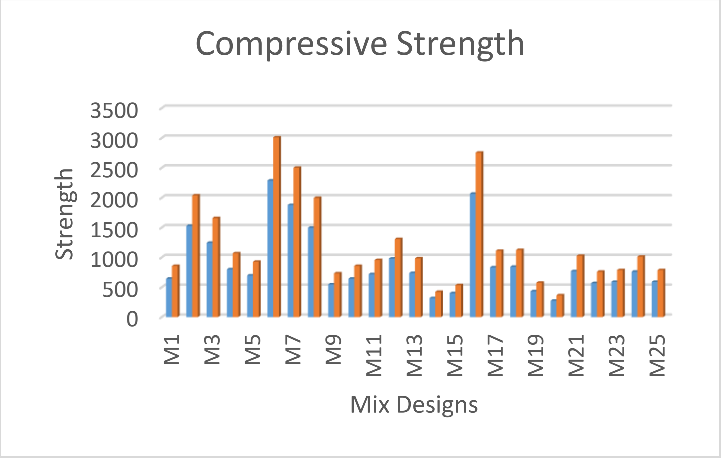


Fig.4.2. Compressive strength graph.

The inclusion of ceramic waste powder, bentonite, and GGBS in the combination affects the compressive strength of the ceramic waste powder-bentonite blended cement-less geo-polymer concrete. These components together with the ideal mixing proportions identified by Taguchi's method result in geo-polymer concrete with increased compressive strength, a practical and environmentally friendly substitute for conventional cement-based concrete.

4.3.2 Initial and Final Setting Time

Monitoring and controlling the initial and final setting time are important for ensuring proper workability, placement, and strength development of geo-polymer concrete. By understanding the effects of the binder materials, additives, and mixture proportions, researchers can manipulate the setting time to meet specific project requirements and optimize construction operations the initial and final setting time of ceramic waste powder-bentonite blended GGBS-based cement-less geo-polymer concrete are influenced by the presence of supplementary materials, such as ceramic waste powder and bentonite, as well as the mixture proportions determined using the Taguchi's method. The understanding and control of these setting characteristics contribute to achieving the desired workability, placement, and early strength development of geo-polymer concrete, making it a viable and sustainable alternative to traditional cement-based concrete.

The results for setting time are as follows:

Table.4.4. Setting Time of Concrete.

SETTING TIME		
MIX ID	**INITIAL SETTING**	**FINAL SETTING**
M1	20m 19s	2h 23m
M2	19m 21s	2h 11m
M3	21m 43s	3h 19m
M4	14m 33s	2h 56m
M5	17m 31s	3h 11m
M6	28m 11s	8h 21m
M7	19m 22s	6h 13m
M8	23m 22s	5h 29m
M9	11m 11s	3h 33m
M10	11m 46s	3h 43m
M11	19m 56s	3h 46m
M12	17m 33s	2h 58m
M13	17m 59s	2h 11m
M14	12m 13s	2h 13m
M15	11m 45s	3h 24m
M16	16m 23s	0h 13m
M17	06m 29s	0h 49m
M18	08m 52s	1h 45m
M19	11m 32s	1h 35m
M20	17m 19s	2h 22m
M21	12m 13s	1h 38m
M22	11m 45s	0h 58m
M23	16m 23s	1h 33m
M24	13m 19s	2h 44m
M25	19m 11s	1h 39m

The graphical representation of the Setting time is as shown:

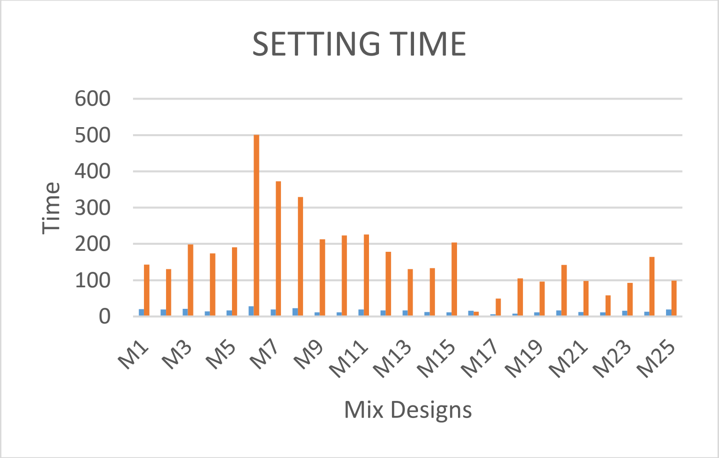


Fig.4.3. Setting Time Graph.

The graph shows the actual value of the initial and final setting time of the different types of mix ratios.

The presence of ceramic waste powder, bentonite, and GGBS in the geo-polymer concrete mixture can influence the initial setting time. These materials, especially bentonite, act as rheology modifiers and can affect the flow and workability of the fresh concrete.

4.4 Taguchi Optimization

After applying Taguchi’s Method we got optimized mix levels of parameters:

Table.4.5. Optimization Parameters for Taguchi.

Taguchi L25 Array matrix					
Experiment	**Level of Parameters**				
	Cement % Replacement	**W/B**	**Course Aggregate**	**Fine Aggregate**	**Binder Content**
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	1	5	5	5	5
6	2	1	2	3	5
7	2	2	3	4	1
8	2	3	4	5	2
9	2	4	5	1	3
10	2	5	1	2	4
11	3	1	3	4	2
12	3	2	4	5	3
13	3	3	5	1	4
14	3	4	1	2	5
15	3	5	2	3	1
16	4	1	4	5	3
17	4	2	5	1	4
18	4	3	1	2	5
19	4	4	2	3	1
20	4	5	3	4	2
21	5	1	5	2	4
22	5	2	1	3	5
23	5	3	2	4	1
24	5	4	3	5	2
25	5	5	4	1	3

4.4.1 Mix Design Composition

Mix design for geo-polymer concrete involves determining the proportions of various components to achieve the desired properties of the concrete. The mix design process for geo-polymer concrete is similar to that of traditional concrete but requires additional considerations for the geo-polymerization reaction.

The quantity of each of the ingredient of the mix design is given in the table:

Table.4.6.Used values calculation.

Exp. #	**Cement % Replacement**	**W/B**	**Course Aggregate**	**Fine Aggregate**	**Binder Content**
Exp. 1	20	0.45	1183	637	400
Exp. 2	20	0.5	1068	575	505
Exp. 3	20	0.55	1016	547	540
Exp. 4	20	0.6	1144	616	400
Exp. 5	20	0.65	1093	589	435
Exp. 6	37.5	0.45	1136	612	435
Exp. 7	37.5	0.5	1016	547	540
Exp. 8	37.5	0.55	1144	616	400
Exp. 9	37.5	0.6	1093	589	435
Exp. 10	37.5	0.65	1117	601	470
Exp. 11	55	0.45	1086	585	470
Exp. 12	55	0.5	1144	616	400
Exp. 13	55	0.55	1093	589	435
Exp. 14	55	0.6	1117	601	470
Exp. 15	55	0.65	1068	575	505
Exp. 16	90	0.65	1144	616	400
Exp. 17	72.5	0.5	1093	589	435
Exp. 18	72.5	0.55	1117	601	470
Exp. 19	72.5	0.6	1068	575	505
Exp. 20	72.5	0.65	1016	547	540
Exp. 21	90	0.45	981	528	540
Exp. 22	90	0.5	1117	601	470
Exp. 23	90	0.55	1068	575	505
Exp. 24	90	0.6	1016	547	540
Exp. 25	90	0.65	1144	616	400

4.4.2 Means Calculations For 14 Days

The means are calculated from the results of our cubed which we tested at 14 Days:

Table 4.7. Calculated means for 14 days.

MIX IDs	**Sample 1 (Mpa)**	**Sample 2 (Mpa)**	**Sample 3 (Mpa)**	**Mean**	**Var.**	**S/N**
1	35	38	95	56.00	382.50	30.92
2	95	98	26	73.00	554.50	30.72
3	65	66	34	55.00	110.50	31.77
4	39	43	33	38.33	11.11	29.75
5	24	24	43	30.33	40.11	26.98
6	112	112	33	85.67	693.44	32.69
7	116	112	14	80.67	1115.11	25.80
8	95	97	19	70.33	659.78	28.26
9	26	29	87	47.33	395.61	28.54
10	34	37	41	37.33	5.61	29.61
11	33	36	39	36.00	4.50	29.30
12	43	41	21	35.00	50.00	27.69
13	33	36	11	26.67	63.61	23.03
14	14	16	36	22.00	50.00	23.11
15	19	18	25	20.67	4.94	24.28
16	87	82	27	65.33	373.61	30.83
17	41	49	36	42.00	25.00	30.50
18	39	40	33	37.33	4.94	29.58
19	21	23	38	27.33	29.44	26.15
20	11	12	98	40.33	831.61	21.16
21	36	36	66	46.00	100.00	30.52
22	25	26	43	31.33	34.28	27.42
23	27	27	24	26.00	1.00	26.50
24	36	36	112	61.33	641.78	30.91
25	33	32	112	59.00	702.50	30.06

4.4.2.1 Mean of Mean

In the Taguchi method, the Mean-to-Mean (MTM) ratio is another important performance characteristic used for assessing the effectiveness of a design or process. The MTM ratio is a measure of the improvement achieved by optimizing the process or product based on the Taguchi method.

The MTM ratio is calculated by comparing the mean value of the response variable for a particular factor level or combination to the overall mean value of the response variable across all factor levels or combinations. It helps to quantify the improvement in performance achieved by using the Taguchi method.
There means are as given in table:

Table.4.8. Mean of means for 14 days.

Mean of Mean					
Parameter	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Cement % Replacement	50.53	28.07	42.47	44.73	44.73
W/B	40.08	54.50	48.08	36.58	131.08
Course Aggregate	59.83	51.50	35.58	48.00	112.73
Fine Aggregate	59.83	51.50	35.58	48.00	112.73
Binder Content	59.83	51.50	35.58	48.00	112.73

The graphical representation of the Mean to Mean ratio mean is as:

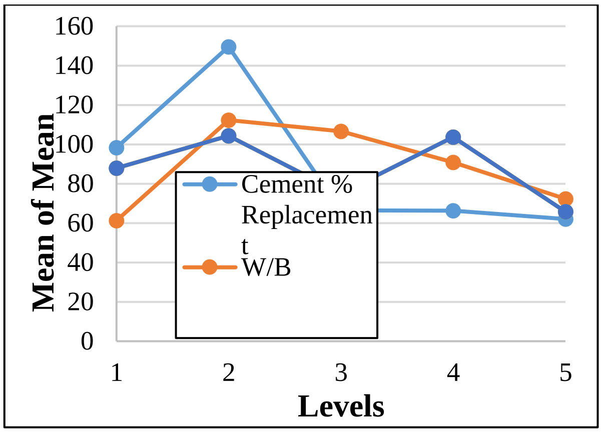


Fig.4.4. Mean of mean of 14 days graph.

4.4.2.2 Mean of SN

In the Taguchi method, the signal-to-noise (S/N) ratio is a critical concept used to assess the performance or quality of a product or process. It is a statistical metric that helps identify the effect of various factors or parameters on the variability of the response variable. The goal in the Taguchi method is to maximize or minimize the S/N ratio, depending on the type of response being considered (larger-the-better, smaller-the-better, or nominal-the-best)[59].

The formula for its calculation is as:

$$Y_{ij} = -10 \times \log \left[\frac{1}{r} \sum_{k=1}^{r} \frac{1}{v_{ijk}^{2}} \right]$$

There means are as given in table:

Table.4.9. Mean of S/N ratios for 14 days.

Mean of S/N					
Parameter	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Cement % Replacement	30.79	28.43	28.78	25.31	29.08
W/B	27.36	29.03	27.79	29.13	32.58
Course Aggregate	29.29	27.83	27.39	28.82	27.26
Fine Aggregate		27.83	27.39	28.82	27.26
Binder Content	29.29	27.83	27.39	28.82	28

The graphical representation of the S/N ratio mean is as:

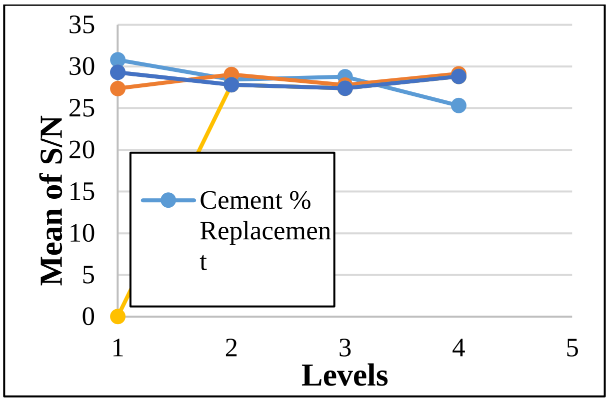


Fig.4.5.Mean of S/N ratios graph of 14 days.

4.4.2.3 Final Optimized Mix

The final optimized mix design from 14 days strength is as follows:

Table.4.10. Taguchi 14 Days Optimized Mix Design Parameter

Taguchi 14 Days Optimized Mix Design Parameter		
Maximum	**Level**	**Value**
30.79	Level 1	40
29.13	Level 1	0.45
29.29	Level 3	1183
28.82	Level 3	637
29.29	Level 3	400

4.4.3 Means Calculations For 28 Days

The means are calculated from the results of our cubed which we tested at 28 Days:

Table.4.11. Means calculation for 28 days.

MIX IDs	Sample 1 (Mpa)	Sample 2 (Mpa)	Sample 3 (Mpa)	Mean	Var.	S/N
1	60.00	61.00	62.00	61.00	0.50	33.94
2	140.00	143.00	145.00	142.67	3.61	41.32
3	107.00	113.00	118.00	112.67	16.11	39.25
4	78.00	77.00	76.00	77.00	0.50	35.97
5	65.00	66.00	67.00	66.00	0.50	34.63
6	214.00	216.00	217.00	215.67	1.44	44.91
7	174.00	176.00	178.00	176.00	2.00	43.15
8	139.00	141.00	142.00	140.67	1.44	41.20
9	47.00	50.00	52.00	49.67	3.61	32.14
10	59.00	60.00	61.00	60.00	0.50	33.80
11	63.00	66.00	68.00	65.67	3.61	34.57
12	89.00	90.00	93.00	90.67	1.61	37.38
13	67.00	68.00	70.00	68.33	0.94	34.93
14	32.00	31.00	30.00	31.00	0.50	28.06
15	37.00	37.00	38.00	37.33	0.11	29.68
16	187.00	191.00	196.00	191.33	9.44	43.87
17	82.00	76.00	79.00	79.00	9.00	36.18
18	77.00	81.00	80.00	79.33	4.11	36.22
19	37.00	41.00	41.00	39.67	4.44	30.18
20	23.00	25.00	26.00	24.67	1.44	26.05
21	75.00	74.00	73.00	74.00	0.50	35.62
22	52.00	56.00	54.00	54.00	4.00	32.88
23	55.00	55.00	56.00	55.33	0.11	33.10
24	71.00	72.00	74.00	72.33	0.94	35.42
25	54.00	55.00	56.00	55.00	0.50	33.04

4.4.3.1 Mean of Mean

There means are as given in table:

Table.4.12. Mean of means of 28 days strength.

Mean of Mean					
Parameter	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Cement % Replacement	98.33	149.58	66.50	66.26	62.06
W/B	61.25	112.33	106.67	90.83	72.38
Course Aggregate	88.00	104.33	75.08	103.67	65.75
Fine Aggregate	88.00	104.33	75.08	103.67	65.75
Binder Content	88.00	104.33	75.08	103.67	65.75

The graphical representation of the Mean to Mean ratio mean is as:

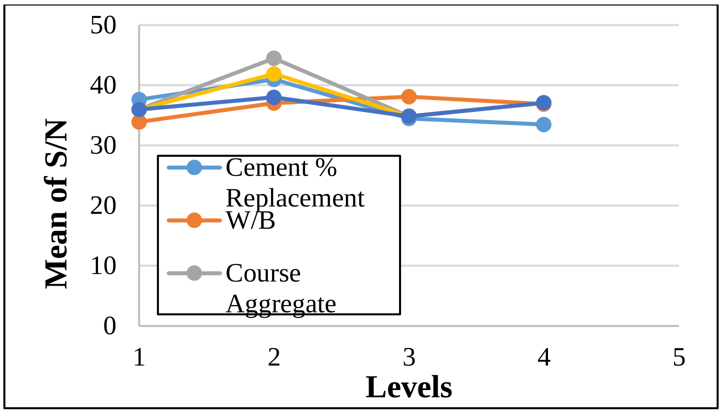


Fig.4.6.Mean of means graph of 28 days strength.

4.4.3.2 Mean of SN

There means are as given in table:

Table.4.13. Mean of S/N ratio for 28 days strength.

Mean of S/N					
Parameter	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Cement % Replacement	37.62	40.97	34.47	33.48	37.02
W/B	33.91	37.02	38.10	36.90	41.2
Course Aggregate	35.98	44.47	34.83	37.11	34.47
Fine Aggregate	35.98	41.9	34.83	37.11	34.47
Binder Content	35.98	38.01	34.83	37.11	34.47

The graphical representation of the S/N ratio mean is as:

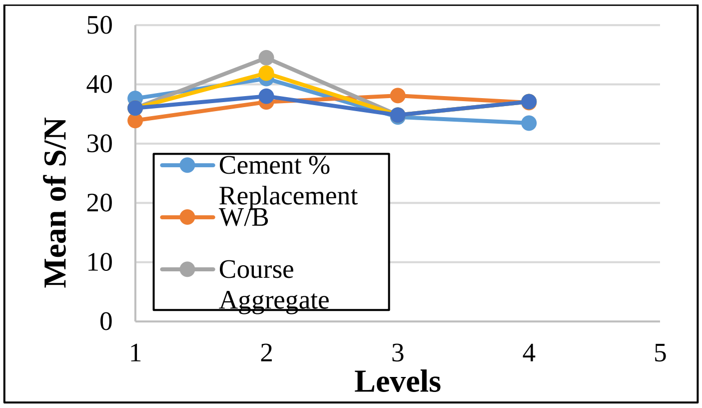


Fig.4.7.S/N ratio graph for 28 days strength.

4.4.3.3 Final Optimized Mix

The final optimized mix design from 28 days strength is as follows:

Table.4.14. Taguchi 28 Days Optimized Mix Design Parameter

Taguchi 28 Days Optimized Mix Design Parameter		
Maximum	**Level**	**Value**
40.97	Level 2	40
41.20	Level 5	0.32
44.47	Level 2	770
41.90	Level 2	690
38.01	Level 1	450

4.5 Results

The table below contains the final optimum blend that was created using the Taguchi approach. The Taguchi mix design table's levels are represented by the mix, which represents the optimal values in accordance with them. 3007 Psi is the highest possible strength for this optimized composition. The final optimal mix that was produced using the Taguchi optimization process is displayed in Table above. This Table displays the final parameter results following Taguchi's optimum mix testing.

Table.4.15. Taguchi’s Final Results of optimized mix.

Taguchi FINAL RESULTS	
Compressive Strength (Psi)	3200
Initial Setting Time (min.)	32.25
Final Setting Time (hr.)	9.5

The maximum value for compressive strength achieved using Taguchi is 3200 Psi and for the Setting time is 32.25 minutes and 9.5 hours for Initial and Final setting time respectively.

Chapter 5

Conclusions and Recommendations

5.1 Outline

This chapter presents the findings and suggestions we came to after conducting study on our subject. This study's major objective was to create and assess the performance of geo-polymer concrete built in various CWP and GGBS ratios. This thesis investigated the feasibility of using CWP and GGBFS in geo-polymer concrete at various ratios to create sustainable concrete mixtures. This proposed geo-polymer concrete will offer a cutting-edge sustainable solution to two well-known environmental problems, the exhaustion of natural resources and carbon dioxide emissions. Additionally, instead of throwing away industrial waste in landfills and stockpiles, it will recycle it for use in building materials and other applications.

5.2 Conclusions

The ideal set of mix parameters for the creation of geo-polymer concrete will be chosen with the aid of the experimental results from the current study effort and the Taguchi method. In light of the gathered data and debate, the following conclusions were drawn

- The replacement amount of GGBS (% by mass of binder) has a significant impact on the compressive strength of GPC mixtures in ambient circumstances.
- The research has successfully explored the development and characterization of ceramic waste powder-bentonite blended GGBS-based cement-less geo-polymer concrete using the Taguchi's method. The findings contribute to the existing knowledge on sustainable construction materials and highlight the potential of geo-polymer concrete in reducing the environmental impact of concrete production.

Following results were seen during testing which differ from predicted values as shown in table:

Table.5.1. Predicted vs Experimental Strength values.

	Compressive Strength (psi)	
Mix Ids	**Experimental**	**Prediction**
M1	857	833
M2	2037	2300
M3	1658	1322
M4	1068	1110
M5	927	1011
M6	3049	2800
M7	2501	2160
M8	1995	2400
M9	731	458
M10	857	980
M11	955	868
M12	1307	1530
M13	984	899
M14	422	402
M15	534	580
M16	2754	2600
M17	1110	1090
M18	1124	1200
M19	576	469
M20	365	460
M21	1026	1001
M22	759	700
M23	787	750
M24	1012	982
M25	787	710

Following graph shows the Actual and Predicted values variation of all mix designs.

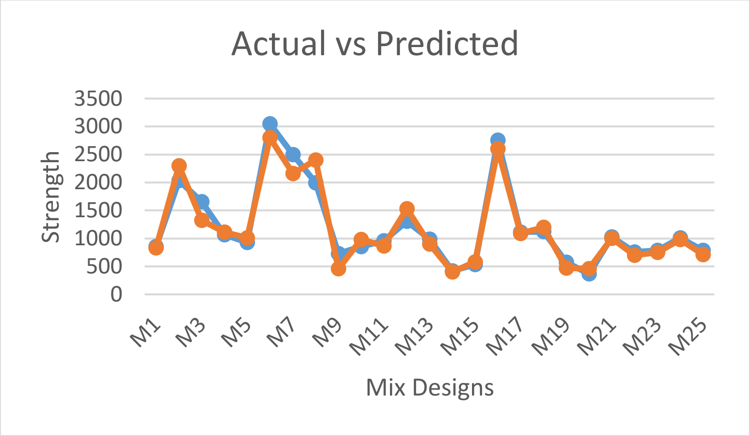


Fig.5.1.Graph between Actual and Predicted values.

Blue shows the Actual values and Orange shows the predicted values.

5.3 Recommendations

The characteristics of geopolymer concrete are reportedly influenced by a number of factors in both their fresh and hardened states. Thus, geopolymer concrete mix proportioning lacks a specialized mix design approach. The Taguchi optimization approach can assist in figuring out the ideal combination of the control parameters for the composition of geopolymer concrete, saving time and money on the experiment.

Further research and experimentation are needed to refine the mixture design, optimize the performance characteristics, and explore wider applications of this innovative geopolymer concrete in the construction industry.

CHAPTER 6

Sustainable Development Goals

6.1 Outline

The introduction to the sustainable development goals and an explanation of

they align with our findings are explained in this chapter. The main goal of this study was to produce geo-polymer concrete and evaluate its performance using different CWP and GGBS concentrations. In order to generate sustainable concrete mixtures, this thesis examined the viability of utilizing CWP and GGBFS in geo-polymer concrete at various ratios. With the suggested geo-polymer concrete, two well-known environmental issues—the depletion of natural resources and carbon dioxide emissions—will be addressed in a cutting-edge, sustainable manner.

6.2 Introduction

The Sustainable Development Goals (SDGs) are a collection of 17 global objectives that were established by the United Nations in September 2015 as part of the 2030 Agenda for Sustainable Development. These goals, which go beyond the Millennium Development Goals (MDGs), aim to address a variety of international social, economic, and environmental problems. The SDGs seek to guarantee peace and well-being for all, advance prosperity, and protect the environment by the year 2030. These two objectives are connected to this research:

Sustainable Cities and Communities.
Decent work and economic Growth.
Infrastructure and industry innovation.

These goals provide a framework for collaboration between governments, businesses, civil society, and people in order to address many global concerns and create a more just and sustainable world for both the present and the future. Coordination of efforts and a commitment to fusing social, economic, and environmental concerns are required to achieve the SDGs.

6.3 Mapped SDGs

6.3.1 Sustainable Cities and Communities

SDG 11, "Sustainable Cities and Communities," is one of the 17 Sustainable Development Goals adopted by the United Nations as part of the 2030 Agenda for Sustainable Development. This goal recognizes the significant global challenges related to urbanization, rapid population growth in cities, and the need to create sustainable and inclusive urban environments. SDG 11 aims to make cities and human settlements more inclusive, safe, resilient, and sustainable while promoting social, economic, and environmental well-being for all residents.

6.3.1.1 Key Objectives of SDG 11

Inclusive and Equitable Urbanization: Ensure that cities and human settlements are inclusive and offer equal opportunities for all residents, regardless of their income, gender, age, or other characteristics.

Safe and Resilient Cities: Build urban areas that are resilient to disasters, climate change, and other shocks while providing safe living conditions for their inhabitants.

Access to Basic Services: Ensure access to adequate housing, clean water, sanitation, energy, transportation, and other essential services for urban residents.

Sustainable Urban Planning and Design: Implement sustainable urban planning and design principles that promote efficient land use, mixed land-use development, and well-connected infrastructure to reduce environmental impact.

Environmental Protection and Biodiversity: Protect and enhance green spaces, natural habitats, and biodiversity within urban areas to improve the quality of life and foster ecological sustainability.

Sustainable Transport and Mobility: Develop sustainable transportation systems, including public transportation, cycling, and pedestrian infrastructure, to reduce congestion, air pollution, and greenhouse gas emissions.

Cultural and Historical Preservation: Safeguard and promote cultural heritage, historical landmarks, and traditional knowledge to maintain the cultural identity of communities.

6.3.1.2 Importance of SDG 11

Environmental Impact: Cities are major contributors to environmental issues, such as air and water pollution, waste generation, and high energy consumption. Sustainable cities focus on reducing their ecological footprint and promoting renewable energy sources.

Rapid Urbanization: The world is experiencing significant urbanization, with more people living in cities than ever before. Sustainable urban development is crucial to address the challenges of overcrowding, inadequate housing, and pressure on resources.

Social Inclusion: Sustainable cities prioritize social equity and ensure that all residents have access to basic services, education, healthcare, and job opportunities, irrespective of their socioeconomic status.

Resilience to Climate Change: As climate change intensifies, cities are vulnerable to extreme weather events. Sustainable urban planning helps build resilience and adaptation measures to protect communities from climate-related risks.

Global Agenda: SDG 11 aligns with international agreements such as the New Urban Agenda and the Paris Agreement, which emphasize sustainable urbanization and climate action.

To achieve SDG 11, it is essential for cities and communities to collaborate with various stakeholders, develop long-term plans, and integrate sustainability principles into urban development policies and practices. By promoting sustainable cities, we can create healthier, more inclusive, and resilient communities while contributing to global efforts to achieve the broader sustainable development agenda.

6.3.2 Decent Work and Economic Growth

SDG 8, "Decent Work and Economic Growth," is one of the 17 Sustainable Development Goals adopted by the United Nations as part of the 2030 Agenda for

Sustainable Development. This goal addresses the need for inclusive economic growth that provides opportunities for productive employment and decent work for all, while ensuring that this growth is sustainable and supports the well-being of individuals and communities.

6.3.2.1 Key Objectives of SDG 8

Full and Productive Employment: Promote sustained, inclusive, and sustainable economic growth that leads to full and productive employment for all, including women and youth.

Decent Work for All: Ensure that all workers have access to safe and secure working conditions, fair wages, social protection, and opportunities for personal and professional development.

Youth Employment: Address the challenges of youth unemployment and underemployment by creating opportunities for young people to access decent jobs and skills development.

Eradication of Forced Labor and Modern Slavery: Take immediate and effective measures to eradicate forced labor, human trafficking, and all forms of modern slavery.

Child Labor Elimination: End child labor in all its forms and ensure the protection of children from exploitation in the workforce.

Equal Pay and Gender Equality: Promote gender equality in the workplace, ensuring equal pay for equal work and equal opportunities for career advancement.

Sustainable Economic Growth: Encourage policies and investments that promote sustainable economic growth, productive activities, and job creation in various sectors, including green industries.

Support for Micro, Small, and Medium-sized Enterprises (MSMEs): Strengthen the capacity of MSMEs to access financial services, markets, and technology, recognizing their role as drivers of economic growth and job creation.

6.3.2.2 Importance of SDG 8

Poverty Reduction: Sustainable economic growth and decent work opportunities are critical for lifting people out of poverty and improving their living standards.

Social Inclusion: Decent work ensures that individuals, regardless of their backgrounds, have the opportunity to participate in the workforce and contribute to society's progress.

Economic Stability: Sustainable economic growth provides a stable foundation for a country's development and resilience to economic shocks.

Labor Rights and Human Dignity: Decent work promotes respect for labor rights, human dignity, and fair treatment in the workplace.

Youth Empowerment: Youth unemployment is a pressing global issue. Creating decent work opportunities for young people not only benefits them but also contributes to social stability and development.

Gender Equality: SDG 8 emphasizes the importance of gender equality in the workplace, ensuring that women have equal access to opportunities and fair treatment.

To achieve SDG 8, countries need to implement policies that foster sustainable economic growth, promote decent work, and address labor market challenges. This includes investing in education and skills development, supporting MSMEs, and ensuring equal opportunities for all workers. Governments, businesses, and civil society must collaborate to create an enabling environment for inclusive economic growth and decent work, thereby contributing to the overall progress towards the 2030 Agenda for Sustainable Development.

6.3.3 Industry, Innovation, and Infrastructure

"Industry, Innovation, and Infrastructure" is the ninth of the 17 Sustainable Development Goals (SDGs) established by the United Nations. In order to support sustainable development on a global scale, this target seeks to increase innovation, improve infrastructure, and advance inclusive and sustainable industrialization by 2030.

The following are crucial components of the study's goal of "Decent Work and Economic Growth" that are connected.

- Improving access to reliable, modern infrastructure is essential for social well-being, economic development, and the production of energy.
- Geo-polymer concrete can be used to construct infrastructure that is sturdy, sustainable, and adaptable to the effects of climate change. This entails

making investments in eco-friendly urban planning, efficient public transportation, and sustainable energy sources.

- The replacement of infrastructure materials with less expensive and safer alternatives can increase economic stability and resilience.
- Increasing investment on research and development to foster innovation and advance technical advancements across a range of industries.
- To lessen the harmful environmental effects of economic activity, Geo-polymer Concrete is being used to promote sustainable and moral manufacturing and consumption behaviors. Geo-polymer Concrete can result in a reduction in the environmental effect because it lead to a positive infrastructure innovation.
- Introducing Geo-polymer Concrete, which promotes the growth of environmentally friendly enterprises and generates economic and industrial growth without damaging the environment. Cleaner production methods are required for this.
- • Fostering innovation in business, science, and technology by enhancing Geo-polymer Concrete's properties in order to advance the world economy, increase productivity, and address a variety of problems. There will be solutions to issues like poverty, health, and climate change. So, innovation and technological advancement are made possible.

By putting an emphasis on industry, innovation, and infrastructure, the creation of an optimum mix of Geo-polymer Concrete with all the characteristics enhanced seeks to promote economic development, social advancement, and environmental sustainability. Building resilient infrastructure with materials like Geo-polymer Concrete that will support and promote sustainable industry is crucial to achieving the bigger objectives of the 2030 Agenda for Sustainable Development and building a more just and prosperous world for all.

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ABBREVIATIONS

CWP : Ceramic Waste Powder

GGBS : Ground Granulated Blast Furnance Slag

CBC : Cement Based Concrete

BRC : Burned Red Clay

GPC : Geo-polymer Concrete

SH : Sodium Hydroxide

SS : Sodium Silicate

Al/Binder : Alkaline Binder

TOM : Taguchi Optimization Methods

SCMs : Supplementary cementitious materials

CED : Conventional Experimental Design

DOE : Design of experiments

OA : Orthogonal Array

OPC : Ordinary Portland Cement

CB : Ceramic Bricks

S/N : Signal to Noise Ratio

TGA : Thermo-gravimetric Analysis

FA : Fly Ash