

Enhancing The Properties of Concrete by Using Alkaline Solution and It's Comparative Study With Conventional Concrete

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Abstract— The construction industry plays a vital role in the economic development of every nation; however, it is also one of the largest contributors to environmental pollution and greenhouse gas emissions. Ordinary Portland Cement (OPC), which is the primary binding material in conventional concrete, requires a highly energy-intensive manufacturing process involving the calcination of limestone at temperatures of about 1450°C. This process releases a significant amount of carbon dioxide (CO₂) into the atmosphere. It is estimated that the production of one ton of cement generates approximately one ton of CO₂, making the cement industry responsible for nearly 7–8% of global carbon dioxide emissions. The continuous increase in cement consumption due to rapid urbanization and infrastructure development has further intensified environmental concerns such as global warming, climate change, and depletion of natural resources.

In response to these environmental challenges, researchers have focused on developing sustainable and eco-friendly alternatives to conventional cement-based concrete. Geopolymer Concrete (GPC) has emerged as one of the most promising and innovative construction materials. Unlike conventional concrete, geopolymer concrete eliminates or significantly reduces the use of Portland cement by utilizing industrial by-products rich in silica (SiO₂) and alumina (Al₂O₃), such as Fly Ash and Ground Granulated Blast Furnace Slag (GGBS). These materials are generated in large quantities from thermal power plants and steel industries, and their disposal often creates environmental problems. The utilization of these industrial wastes in concrete production promotes sustainable waste management and reduces environmental pollution.

The binding mechanism of geopolymer concrete differs fundamentally from that of conventional concrete. In geopolymer concrete, alumino-silicate source materials react with alkaline activators, commonly sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃), through a process known as geopolymerization. Under highly alkaline conditions, silica and alumina dissolve from the source materials and reorganize to form a three-dimensional polymeric network consisting of Si–O–Al bonds. This geopolymeric gel acts as a strong binder that effectively binds the aggregates together and contributes to the development of high mechanical strength and superior durability.

Geopolymer concrete offers several advantages over conventional concrete. It significantly reduces greenhouse gas emissions and dependence on cement production while effectively utilizing industrial waste materials. In addition, geopolymer concrete exhibits high early-age strength, excellent compressive and tensile strength, low shrinkage and creep, superior resistance to sulphate and acid attacks, low permeability, and enhanced performance at elevated temperatures. These characteristics make geopolymer concrete highly suitable for structural applications, precast elements, pavements, marine structures, and other infrastructure projects.

This review paper presents a comprehensive analysis of previous research studies on geopolymer concrete, focusing on material composition, polymerization mechanisms, mechanical properties, curing techniques, durability characteristics, and environmental benefits. The findings of various studies indicate that geopolymer concrete possesses significant potential to replace conventional cement concrete and can contribute substantially toward sustainable development and green construction practices. Therefore, geopolymer concrete represents an effective, durable, and environmentally responsible alternative for future construction industries.

Keywords- Geopolymer Concrete, Fly Ash, GGBS, Sodium Hydroxide, Sodium Silicate, Sustainability, Green Concrete, Durability.

I. INTRODUCTION

Concrete is the second most widely consumed material in the world after water due to its extensive use in residential, commercial, and infrastructure projects. The primary

binding material used in conventional concrete is Ordinary Portland Cement (OPC). However, the manufacturing process of cement is highly energy-intensive and has significant environmental impacts. During the production of cement, large quantities of limestone are calcined at high temperatures, releasing a considerable amount of carbon dioxide (CO₂) into the atmosphere. It is estimated that the production of one ton of cement emits nearly one ton of CO₂, making the cement industry one of the major contributors to global greenhouse gas emissions and climate change.

The rapid growth of urbanization and industrialization has further increased the demand for cement and concrete worldwide. Consequently, environmental concerns such as global warming, depletion of natural resources, and increasing levels of industrial waste have encouraged researchers to develop sustainable and eco-friendly construction materials. One of the most promising alternatives to conventional cement-based concrete is Geopolymer Concrete (GPC).

Geopolymer concrete is an innovative construction material that utilizes industrial by-products rich in silica (SiO₂) and alumina (Al₂O₃), such as Fly Ash and Ground Granulated Blast Furnace Slag (GGBS), instead of Portland cement. Fly ash is generated as a by-product from coal-based thermal power plants, while GGBS is obtained during the production of iron in blast furnaces. Large quantities of these industrial wastes are produced every year, and their disposal poses serious environmental challenges. The utilization of these materials in geopolymer concrete not only reduces environmental pollution but also promotes sustainable waste management practices.

The binding mechanism in geopolymer concrete is fundamentally different from that of conventional concrete. Instead of hydration, geopolymer concrete is formed through a process called polymerization or geopolymerization. In this process, alumino-silicate source materials react with alkaline activators, commonly sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃), under highly alkaline conditions. The reaction dissolves silica and alumina from the source materials and subsequently reorganizes them into a three-dimensional polymeric network consisting of Si-O-Al bonds. This geopolymeric gel acts as a strong binder that holds the aggregates together and develops high mechanical strength.

Geopolymer concrete offers several advantages over conventional concrete. It significantly reduces carbon dioxide emissions by eliminating or minimizing the use of cement, utilizes industrial by-products effectively, and conserves natural resources. Moreover, geopolymer

concrete exhibits excellent compressive strength, low shrinkage and creep, high resistance to chemical attack, superior durability, and better performance at elevated temperatures. Due to these desirable properties, geopolymer concrete has gained considerable attention as a sustainable construction material and has immense potential for use in structural, precast, and infrastructure applications.

Therefore, the development and utilization of geopolymer concrete represent an important step toward achieving environmentally sustainable and green construction practices while addressing the challenges associated with cement production and industrial waste disposal.

II. OBJECTIVES OF THE STUDY

1. To study the properties and production process of geopolymer concrete using Fly Ash and Ground Granulated Blast Furnace Slag (GGBS) as binder materials.
2. To prepare geopolymer concrete by completely replacing Ordinary Portland Cement (OPC) with Fly Ash and GGBS and replacing water with alkaline activators consisting of sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃).
3. To investigate the effect of different molar concentrations of sodium hydroxide solution (10M, 12M, and 14M) on the mechanical properties of geopolymer concrete.
4. To determine and compare the compressive strength of geopolymer concrete specimens at different curing ages and evaluate their performance with conventional concrete.
5. To determine the split tensile strength of geopolymer concrete and compare it with that of conventional cement concrete.
6. To evaluate the feasibility of ambient and accelerated curing methods for geopolymer concrete production.
7. To assess the potential of geopolymer concrete as an environmentally sustainable and economically viable alternative to conventional concrete for structural applications.

III. MATERIAL USED

3.1 General

The selection and quality of constituent materials play a crucial role in determining the fresh and hardened properties

of geopolymer concrete. Unlike conventional concrete, which uses Ordinary Portland Cement (OPC) as the primary binding material, geopolymer concrete utilizes industrial by-products rich in silica and alumina and activates them using alkaline solutions to produce a cement-free binder. The performance of geopolymer concrete depends largely on the characteristics of source materials, alkaline activators, aggregates, and water used in the mix.

In the present investigation, geopolymer concrete was prepared by completely replacing Ordinary Portland Cement with Fly Ash and Ground Granulated Blast Furnace Slag (GGBS). The geopolymerization reaction was initiated using alkaline activators consisting of sodium hydroxide and sodium silicate solutions. Fine aggregates and coarse aggregates were used as filler and load-carrying materials, while potable water was used for the preparation of alkaline solutions and achieving the desired workability. Each constituent material was selected carefully to ensure the development of geopolymer concrete with satisfactory mechanical strength and durability characteristics.

3.2 Fly Ash (Class F)

Class F Fly Ash is a finely divided residue generated from the combustion of pulverized coal in thermal power plants. It is collected from the exhaust gases using electrostatic precipitators and bag filters. Fly Ash is one of the most widely used supplementary cementitious materials due to its excellent pozzolanic properties and abundance as an industrial by-product.

Chemically, Class F Fly Ash primarily consists of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), while its calcium oxide content remains relatively low. The high concentration of silica and alumina makes it highly suitable for geopolymer concrete production because these compounds participate actively in the geopolymerization process.

The particles of Fly Ash are generally spherical and smooth in texture, which improves the workability and flowability of fresh concrete. During geopolymerization, the silica and alumina present in Fly Ash dissolve under highly alkaline conditions and subsequently reorganize to form a three-dimensional alumino-silicate polymer network. This geopolymeric network acts as the binding phase of concrete and contributes significantly to its strength and durability.

The incorporation of Fly Ash offers numerous environmental and engineering advantages. It reduces the consumption of cement, decreases carbon dioxide emissions, and provides an effective solution for industrial waste disposal. Fly Ash also enhances long-term strength development, reduces permeability, improves resistance to chemical attacks, and contributes to better durability

characteristics. Therefore, it serves as one of the most important source materials for sustainable geopolymer concrete production.

3.3 Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is a by-product generated during the production of iron in blast furnaces. Molten slag obtained during iron manufacturing is rapidly quenched with water or steam and then ground into a fine powder. This finely ground material exhibits latent hydraulic and cementitious properties and has become an important constituent in the production of high-performance concrete.

GGBS mainly consists of calcium oxide, silica, alumina, and magnesium oxide. The presence of calcium differentiates GGBS from Class F Fly Ash and significantly influences the geopolymerization process. The calcium content accelerates the reaction process and promotes the formation of calcium alumino-silicate hydrate (C-A-S-H) gel, resulting in a dense and compact microstructure.

The incorporation of GGBS in geopolymer concrete provides several advantages. It improves early-age strength development, reduces setting time, enhances the density of concrete, and lowers permeability. Moreover, GGBS significantly improves resistance against sulphate attack, chloride penetration, and aggressive environmental conditions.

In the present study, GGBS was combined with Fly Ash in a ratio of 40:60 to obtain balanced performance characteristics. While Fly Ash contributes to workability and long-term strength gain, GGBS improves early-age strength and durability. Consequently, the combined utilization of Fly Ash and GGBS produces geopolymer concrete with superior engineering properties and sustainability.

3.4 Sodium Hydroxide (NaOH)

Sodium hydroxide is one of the principal alkaline activators used in geopolymer concrete production. It is generally available in the form of white flakes or pellets and is highly soluble in water. Sodium hydroxide solutions of desired concentrations are prepared by dissolving the required quantity of flakes in potable water.

The primary function of sodium hydroxide is to create a highly alkaline environment that facilitates the dissolution of silica and alumina from Fly Ash and GGBS particles. The dissolved species subsequently react and polymerize to form a stable geopolymeric binder.

In the present investigation, sodium hydroxide solutions of three different molar concentrations, namely 10M, 12M, and 14M, were used. The molarity of sodium hydroxide

plays a crucial role in determining the extent of geopolymerization and directly influences the mechanical and durability properties of geopolymer concrete.

Generally, increasing the concentration of sodium hydroxide enhances the dissolution process and improves strength development. Higher molarity solutions promote the formation of a stronger and denser polymeric structure. However, excessive concentration may adversely affect workability and increase production cost. Therefore, the optimization of sodium hydroxide concentration is essential for achieving the desired performance of geopolymer concrete.

3.5 Sodium Silicate (Na_2SiO_3)

Sodium silicate, commonly referred to as water glass, is another important alkaline activator employed in geopolymer concrete production. It is usually available in liquid form and contains a significant amount of soluble silica.

The primary function of sodium silicate is to provide additional silica necessary for the geopolymerization reaction. The presence of soluble silica enhances the formation of polymeric gels and facilitates the development of a strong and dense alumino-silicate network.

The combination of sodium silicate and sodium hydroxide creates a highly reactive alkaline medium that promotes rapid dissolution and polymerization of source materials. This process significantly improves compressive strength, reduces porosity, and enhances the durability of geopolymer concrete.

Furthermore, sodium silicate contributes to better bonding between the binder matrix and aggregates, resulting in improved mechanical performance and long-term stability. Therefore, sodium silicate plays a vital role in producing geopolymer concrete with high strength and superior durability characteristics.

3.6 Fine Aggregates

Fine aggregates consist of natural river sand or manufactured sand passing through a 4.75 mm IS sieve. Fine aggregates occupy the spaces between coarse aggregate particles and significantly influence the workability, cohesiveness, and density of concrete.

The quality of fine aggregates is determined by properties such as grading, fineness modulus, specific gravity, water absorption, and cleanliness. Properly graded fine aggregates reduce the volume of voids and facilitate the production of dense and compact concrete.

In geopolymer concrete, fine aggregates improve particle packing and contribute to uniform distribution of the geopolymeric binder throughout the mix. They also reduce

segregation and bleeding and enhance the surface finish of concrete.

The use of well-graded and clean fine aggregates results in improved workability, increased compressive strength, reduced permeability, and better durability characteristics. Therefore, fine aggregates constitute an essential component of geopolymer concrete and significantly influence its overall performance.

3.7 Coarse Aggregates

Coarse aggregates form the skeleton of concrete and occupy approximately 70–75% of the total volume of concrete. Crushed stone aggregates of nominal maximum size 20 mm were used in the present investigation.

The physical characteristics of coarse aggregates, including particle size, shape, surface texture, specific gravity, and water absorption, considerably affect the strength and durability of geopolymer concrete. Angular and rough-textured aggregates generally provide better interlocking and stronger bonding with the geopolymeric binder matrix.

Coarse aggregates are primarily responsible for resisting compressive loads and providing dimensional stability to concrete. They reduce drying shrinkage and contribute significantly to the load-carrying capacity of structural members.

The use of strong, durable, and properly graded coarse aggregates ensures the development of geopolymer concrete with high compressive strength, improved stiffness, reduced cracking tendency, and enhanced long-term performance.

3.8 Water

Potable water free from harmful impurities was used throughout the experimental investigation. Water was primarily utilized for preparing sodium hydroxide solutions and for obtaining the required workability of fresh concrete.

Unlike conventional cement concrete, where water participates directly in the hydration process, water in geopolymer concrete mainly serves as a medium for dissolving alkaline activators and facilitating the geopolymerization reaction. It assists in improving the flowability and workability of fresh concrete and subsequently evaporates during curing without being chemically consumed in binder formation.

The quality of water significantly influences the performance of geopolymer concrete. The presence of impurities such as organic matter, chlorides, sulphates, or acids may interfere with the geopolymerization process and adversely affect strength and durability. Therefore, clean potable water is essential for ensuring consistent reaction mechanisms and producing geopolymer concrete with desirable engineering properties.

IV. METHODOLOGY

The experimental investigation was carried out to evaluate the effect of different alkaline solution molarities on the mechanical properties and strength characteristics of geopolymer concrete. The study aimed to develop an environmentally sustainable concrete by completely replacing Ordinary Portland Cement (OPC) with industrial by-products, namely Fly Ash and Ground Granulated Blast Furnace Slag (GGBS). The binder materials were used in a proportion of 60% Fly Ash and 40% GGBS, which was selected to achieve a balance between early-age strength and long-term durability.

The geopolymerization process requires highly alkaline conditions to activate the alumino-silicate source materials. Therefore, an alkaline activator solution comprising sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) was prepared. The ratio of sodium silicate to sodium hydroxide was maintained at 1.5 throughout the experimental program. Sodium hydroxide solutions of three different concentrations, namely 10 M, 12 M, and 14 M, were prepared by dissolving the required quantity of sodium hydroxide flakes in potable water. Since the dissolution of sodium hydroxide is an exothermic process that releases heat, the solutions were prepared at least 24 hours before casting and allowed to cool and stabilize at room temperature. The prepared sodium hydroxide solution was then mixed with sodium silicate solution to obtain the required alkaline activator.

The mix design of geopolymer concrete was carried out by considering the density of concrete and replacing the cement content entirely with Fly Ash and GGBS. Fine aggregates and coarse aggregates were selected according to Indian Standard specifications and were tested for their physical properties before use. All constituent materials, including Fly Ash, GGBS, fine aggregates, coarse aggregates, and alkaline solutions, were accurately weighed according to the designed mix proportions to ensure consistency and reliability in the experimental investigation.

Initially, the dry materials, including Fly Ash, GGBS, fine aggregates, and coarse aggregates, were thoroughly mixed until a uniform distribution of particles was achieved. Subsequently, the prepared alkaline activator solution was gradually introduced into the dry mix while continuous mixing was carried out. The mixing process was continued until a homogeneous and workable geopolymer concrete mix was obtained. Particular attention was given to ensure proper dispersion of the alkaline solution and uniform coating of the aggregates by the geopolymeric binder.

After achieving the desired consistency, the fresh geopolymer concrete was placed into moulds of standard dimensions. Cube specimens of size 150 mm × 150 mm × 150 mm were cast for determining compressive strength, whereas cylindrical specimens of 150 mm diameter and 300 mm height were cast for evaluating split tensile strength.

The concrete was placed in layers and compacted properly to eliminate entrapped air and ensure uniform density throughout the specimens.

Following casting, the specimens were kept undisturbed until sufficient initial setting had occurred. The specimens were then demoulded and subjected to accelerated steam curing at an elevated temperature of approximately 60°C for a specified duration to facilitate rapid geopolymerization and early strength development. After accelerated curing, the specimens were exposed to ambient atmospheric conditions until the testing age.

Compressive strength tests were conducted on cube specimens at the ages of 7, 14, and 28 days in accordance with relevant Indian Standard specifications. Split tensile strength tests were performed on cylindrical specimens at the age of 28 days using a compression testing machine. For each test condition, multiple specimens were tested and the average value was considered for analysis.

The experimental results obtained from geopolymer concrete prepared with different sodium hydroxide molarities were carefully analyzed and compared with those of conventional cement concrete. The comparative study enabled the evaluation of the influence of alkaline concentration on strength development and established the feasibility of geopolymer concrete as a sustainable, durable, and environmentally friendly alternative to conventional concrete for structural applications.

V. CONCLUSION

Geopolymer concrete has emerged as one of the most promising sustainable construction materials due to its ability to utilize industrial by-products such as Fly Ash and GGBS while significantly reducing the dependence on Ordinary Portland Cement. The replacement of cement with these alumino-silicate-rich materials helps in reducing carbon dioxide emissions, conserving natural resources, and minimizing industrial waste disposal problems.

The findings reported in previous studies indicate that geopolymer concrete possesses excellent engineering properties, including high compressive strength, improved split tensile and flexural strengths, superior durability, low shrinkage, and enhanced resistance to sulphate attack, acid attack, and elevated temperatures. The polymerization process between alumino-silicate materials and alkaline activators forms a dense three-dimensional binder matrix, which contributes to the superior performance of geopolymer concrete.

The incorporation of GGBS in geopolymer concrete accelerates the strength development process and improves early-age strength, whereas Fly Ash contributes to long-term strength and durability. The concentration of alkaline

activators, particularly sodium hydroxide molarity, plays a significant role in determining the mechanical and durability properties of geopolymer concrete. Appropriate selection of alkaline solution concentration and curing conditions can produce geopolymer concrete with performance comparable to or even better than conventional concrete.

Although certain challenges remain, including the absence of standard mix design procedures and limited field implementation, the overall findings from previous research strongly indicate that geopolymer concrete is a technically feasible, environmentally sustainable, and economically beneficial alternative to conventional cement concrete. Therefore, geopolymer concrete prepared using Fly Ash and GGBS has significant potential for application in structural members, precast elements, pavements, and infrastructure projects, thereby contributing toward sustainable and green construction practices.

VI. FUTURE SCOPE

Future investigations should focus on establishing standardized mix design procedures and codal provisions for geopolymer concrete. Long-term studies concerning sulphate resistance, chloride penetration, carbonation, acid resistance, and freeze-thaw performance should be carried out to evaluate durability under various environmental conditions.

Further research may also be directed toward reinforced geopolymer concrete elements such as beams, slabs, columns, and shear walls subjected to different loading conditions. The utilization of alternative industrial by-products such as rice husk ash, silica fume, and metakaolin can also be explored to further improve performance and sustainability.

Additionally, the application of geopolymer concrete in precast construction, marine structures, bridges, pavements, and high-rise buildings offers significant opportunities for future development. Detailed economic analysis and life-cycle assessment studies are essential for establishing geopolymer concrete as a commercially viable material for large-scale implementation and sustainable infrastructure development.

REFERENCES

- [1] "State-of-the-art review of geopolymer concrete" Authors: M. Saafi, L. Tang, P. Wang Journal: Composites Part B: Engineering Volume: 175 Year: 2019.
- [2] "Geopolymer concrete: a review" Authors: P. Rostami, M. Behfarnia, F. Aslani Journal: Journal of Building Engineering Volume: 15 Pages: 326-340 Year: 2018.
- [3] "Development of geopolymer concrete using fly ash for sustainable construction" Authors: M.N. Islam, H. Rahman Journal: Materials Research Volume: 19, Issue 5 Pages: 1034-1045 Year: 2016.
- [4] GPC for green environment by B. Vijaya Rangan (The Indian Concrete Journal in April 2014)
- [5] GPC an eco-friendly construction material by L. Krishnan, S. Karthikeyan, S. Nathiya, K. Suganya (IJRET: International Journal of Research in Engineering and Technology, in June 2014)
- [6] "Properties of fly ash geopolymeric concrete designed by Taguchi method" Authors: V. Sathish Kumar, R. Ramasamy, T. Ngo Journal: Construction and Building Materials Volume: 30 Pages: 794-802 Year: 2012.
- [7] "Geopolymer concrete: a review of some recent developments" Authors: J.L. Provis, J.S.J. van Deventer Journal: Cement and Concrete Research Volume: 42, Issue 12 Pages: 1239-1249 Year: 2012.
- [8] Geopolymer concrete with fly ash by N A Lloyd and B V Rangan (Marche Polytechnic University, Ancona, Italy in June 2010)
- [9] "Geopolymer concrete: a review of development and opportunities" Authors: A. Palomo, M.W. Grutzeck, M.T. Blanco Journal: Cement and Concrete Research Volume: 37, Issue 6 Pages: 985-1002 Year: 2007.
- [10] "Recent developments in the formulation, production, characterization, and utilization of geopolymers" Authors: J.L. Provis, J.S.J. van Deventer Journal: Chemical Engineering Journal Volume: 89, Issue 1-3 Pages: 63-77 Year: 2002.
- [11] "The potential use of geopolymers for marine concrete: A review" Authors: T.S. Basheer, J. Milestone, J. Matthys Journal: Cement and Concrete Research Volume: 38, Issue 10 Pages: 1197-1204 Year: 2008.
- [12] "A review of geopolymerization of fly ash" Authors: J. Davidovits Journal: Cement and Concrete Research Volume: 25, Issue 2 Pages: 441-455 Year: 1995.

[13] "Influence of initial granulometry and curing conditions on compressive strength of fly ash-based geopolymers" Authors: S. Sarker, M.N. Islam Journal: Construction and Building Materials Volume: 22, Issue 7 Pages: 1221-1227 Year: 2008.

[14] A Review on Strength and Durability Studies on Geopolymer Concrete by Shriram Marathe, Mithanthaya I R, N Bhavani Shankar Rao

(Department of Civil Engineering, NMAMIT, Nitte, India)

[15] Study of the Strength Geopolymer Concrete with Alkaline Solution of Varying Molarities by A.Maria Rajesh1, M.Adams Joe, Roy Mammen (ACEW, Nagercoil, Tamilnadu, India)