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A REVIEW ON 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 (CO_2) into the atmosphere. It is estimated that the production of one ton of cement generates approximately one ton of CO_2, 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 (SiO_2) and alumina (Al_2O_3), 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 (Na_2SiO_3), 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 (CO_2) into the atmosphere. It is estimated that the production of one ton of cement emits nearly one ton of CO_2, 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 (SiO_2) and alumina (Al_2O_3), 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 (Na_2SiO_3), 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. LITERATURE REVIEW

2.1 Davidovits (1995) conducted one of the earliest studies on geopolymerization and explained the chemical process involved in the formation of geopolymers from alumino-silicate materials activated by alkaline solutions. The study established that fly ash and other silica-rich materials can react with alkaline activators to produce a three-dimensional polymeric structure possessing excellent mechanical properties and chemical resistance.

2.2 Palomo, Grutzeck, and Blanco (2007) investigated the development and opportunities of geopolymer concrete as an alternative to Ordinary Portland Cement. Their study reported that geopolymer concrete significantly reduces carbon dioxide emissions and exhibits high compressive strength and durability. The authors concluded that geopolymer technology has considerable potential for sustainable construction applications.

2.3 Basheer, Milestone, and Matthys (2008) reviewed the potential use of geopolymers in marine concrete applications. Their research demonstrated that geopolymer concrete possesses superior resistance to chloride penetration, sulphate attack, and aggressive environmental conditions, making it suitable for marine and coastal structures.

2.4 Sarker and Islam (2008) studied the influence of particle size distribution and curing conditions on the compressive strength of fly ash-based geopolymers. They observed that finer fly ash particles and elevated-temperature curing significantly enhanced geopolymerization and increased compressive strength.

2.5 Lloyd and Rangan (2010) investigated fly ash-based geopolymer concrete and evaluated the effects of alkaline activator concentration and curing conditions on concrete properties. Their study revealed that increasing sodium hydroxide molarity and sodium silicate-to-sodium hydroxide ratio improved compressive strength and workability. They concluded that geopolymer concrete can successfully replace conventional concrete in structural applications.

2.6 Provis and Van Deventer (2012) reviewed recent developments in geopolymer technology and highlighted advancements in material formulation, production methods, and engineering applications. Their research concluded that geopolymer concrete exhibits excellent durability, low shrinkage, and high resistance to elevated temperatures and chemical attacks.

2.7 Sathish Kumar, Ramasamy, and Ngo (2012) investigated the properties of fly ash geopolymeric concrete using the Taguchi optimization method. The study reported that the compressive strength of geopolymer concrete depends significantly on alkaline solution concentration, curing temperature, and mix proportions. The optimized mixes demonstrated excellent mechanical performance.

2.8 B. Vijaya Rangan (2014) presented geopolymer concrete as a sustainable material for green construction. The study emphasized that the utilization of fly ash-based geopolymer concrete can reduce carbon dioxide emissions by approximately 80% compared to conventional cement concrete. The author also reported satisfactory structural performance and durability characteristics.

2.9 Krishnan, Karthikeyan, Nathiya, and Suganya (2014) investigated geopolymer concrete as an eco-friendly construction material. Their study showed that geopolymer concrete produced using fly ash and GGBS develops high early-age strength and exhibits superior resistance to chemical attacks and adverse environmental conditions.

2.10 Maria Rajesh, Adams Joe, and Roy Mammen studied the effect of varying molar concentrations of alkaline solutions on the strength properties of geopolymer concrete. The researchers observed that increasing sodium hydroxide molarity from lower to higher concentrations resulted in improved compressive, split tensile, and flexural strengths due to enhanced geopolymerization.

2.11 Islam and Rahman (2016) developed geopolymer concrete using fly ash for sustainable construction and reported that geopolymer concrete provides high strength and long-term durability while effectively utilizing industrial waste materials. The study highlighted its potential as a sustainable alternative to conventional concrete.

2.12 Rostami, Behfarnia, and Aslani (2018) reviewed various aspects of geopolymer concrete, including material composition, mechanical properties, and durability performance. Their study concluded that geopolymer concrete exhibits excellent resistance to sulphate attack, acid exposure, and high temperatures, making it suitable for aggressive environments.

2.13 Saafi, Tang, and Wang (2019) presented a state-of-the-art review of geopolymer concrete and summarized recent advancements in material development and practical applications. The authors reported that geopolymer concrete possesses high compressive strength, low permeability, and excellent durability characteristics while significantly reducing environmental impacts associated with cement production.

2.14 Marathe, Mithanthaya, and Bhavani Shankar Rao reviewed strength and durability studies on geopolymer concrete and concluded that geopolymer concrete demonstrates lower shrinkage, reduced creep, and superior durability compared to conventional concrete. The study further emphasized its potential use in sustainable infrastructure development.

III. 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 (Na_2SiO_3).
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. FUTURE SCOPE

1. Further studies can be conducted to establish standardized mix design procedures and codal provisions for geopolymer concrete.
2. Long-term durability studies involving sulphate attack, chloride penetration, carbonation, acid resistance, and freeze-thaw cycles can be carried out.
3. The influence of different source materials such as rice husk ash, silica fume, metakaolin, and other industrial by-products can be investigated for geopolymer concrete production.
4. Research can be extended to study the behavior of reinforced geopolymer concrete members such as beams, columns, slabs, and shear walls under various loading conditions.
5. The performance of geopolymer concrete in marine structures, pavements, precast elements, bridges, and high-rise buildings can be evaluated.
6. Studies can be conducted on self-compacting geopolymer concrete and fiber-reinforced geopolymer concrete to improve ductility and crack resistance.
7. Detailed life-cycle assessment and cost-benefit analysis can be performed to evaluate the environmental and economic advantages of geopolymer concrete on a commercial scale.
8. Further research on optimizing alkaline solution concentration, curing temperature, and Fly Ash-GGBS proportions can help in developing geopolymer concrete suitable for large-scale construction applications.
9. The utilization of geopolymer concrete in disaster-resistant and sustainable infrastructure projects can be explored to promote green construction practices and reduce global carbon emissions.

IV. RESEARCH GAP

Although numerous studies have demonstrated the potential of geopolymer concrete as an eco-friendly alternative to conventional concrete, several research gaps still exist. Most previous investigations have primarily focused on fly ash-based geopolymer concrete under controlled laboratory conditions and have not extensively explored the combined use of Fly Ash and Ground Granulated Blast Furnace Slag (GGBS) under varying alkaline concentrations.

The effect of different molarities of sodium hydroxide solution on the mechanical properties and long-term performance of geopolymer concrete has not been fully established. Limited research is available on determining the optimum molarity and Fly Ash-GGBS proportion that can provide maximum strength and durability while maintaining workability and economic feasibility.

Furthermore, there is a lack of standardized mix design procedures and codal provisions for geopolymer concrete, unlike conventional cement concrete. The influence of curing methods, ambient curing conditions, and practical field applications also requires further investigation. In addition, comparative studies evaluating the performance of geopolymer concrete and conventional concrete in terms of compressive strength, split tensile strength, and durability characteristics are still limited.

Therefore, the present study aims to investigate geopolymer concrete prepared using Fly Ash and GGBS with different molarities of alkaline solution and compare its strength characteristics with those of conventional concrete. The study intends to contribute toward the development of sustainable and practical geopolymer concrete suitable 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.

REFRENCES

[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)