Research study on Effect of Geopolymers on Soil

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Abstract - Geopolymers are environmentally friendly, cement-free binders formed by the reaction of aluminosilicate materials with alkaline activators. Their application in soil stabilization enhances mechanical strength, durability, and resistance to environmental degradation. This study explores the geopolymerization mechanism, influence of alkaline activators, and the role of Fly Ash, Metakaolin, and GGBS in soil improvement. The mix design, curing methods, and performance evaluation are discussed with reference to IS codes and laboratory testing. The results indicate that geopolymer-stabilized soils provide superior strength, reduced permeability, and sustainable alternatives to conventional cement-based stabilization. The study highlights the economic and environmental benefits of using geopolymers in infrastructure projects, road bases, and contaminated soil remediation.

Keyword: Geopolymers, Soil Stabilization, Fly Ash, Metakaolin, GGBS, Alkaline Activators, Compressive Strength

I. INTRODUCTION

Geopolymers are inorganic, cementitious materials formed by activating aluminosilicate-rich materials with alkaline activators under moderate temperatures. Unlike Portland cement, geopolymers undergo a polymerization reaction, forming a three-dimensional network of Si-O-Al bonds. They offer high strength, chemical resistance, and environmental sustainability, making them an ideal alternative for soil stabilization.

A. Composition of Geopolymers

Primary Components:

- Aluminosilicate Sources: Materials rich in silica (SiO_2) and alumina (Al_2O_3).
- Alkaline Activators: Solutions like sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3).
- Water: Acts as a medium for dissolution and reaction but does not remain in the final hardened structure.

Common Aluminosilicate Sources:

- Natural Minerals:

Clay Minerals (Kaolinite, Bentonite, Laterite).

- Industrial By-Products:
- Fly Ash (Class F & Class C): A waste product from coal combustion.
- Ground Granulated Blast Furnace Slag (GGBS): A by-product from steel production.
- Metakaolin: A highly reactive calcined clay.

B. Geopolymerization Process

The formation of geopolymers involves three major steps:

Dissolution:

- The alkaline activator dissolves silica (SiO_2) and alumina (Al_2O_3) from the raw material.

Polymerization:

- The dissolved silica and alumina react to form a long-chain polymeric network.

II. THE NEED OF STUDY OF GEOPOLYMERS ON SOIL

Challenges with Natural Soils:

- Many natural soils, especially expansive clays, loose sands, and weak subsoils, lack the required strength for construction.
- These soils are prone to settlement, cracking, and instability, making them unsuitable for infrastructure projects.

Geopolymers as a Solution:

- Improve compressive strength, making weak soils suitable for load-bearing applications.
- Enhance durability by forming a strong, chemically stable matrix.
- Increase resistance to water infiltration, sulfate attack, and erosion, ensuring long- term soil stability.

Cost Issues with Conventional Stabilizers:

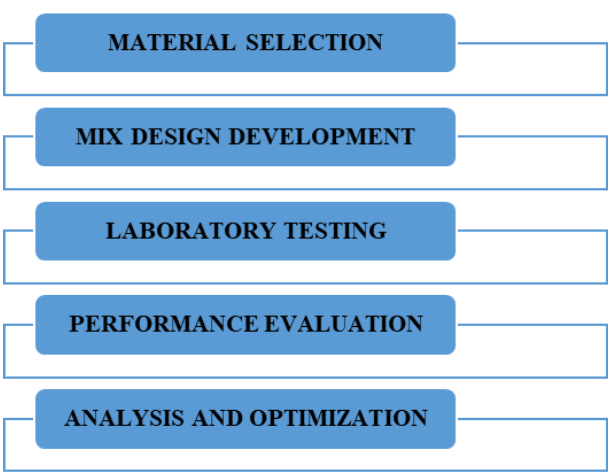
- Cement and lime stabilization increase construction costs due to high material and transportation expenses.
- Non-renewable materials contribute to long-term environmental and economic challenges.

Geopolymer-Based Cost Savings:

- Uses abundant, low-cost materials like Fly Ash, GGBS, and locally available soils, reducing raw material expenses.
- Supports circular economy principles by converting waste materials into valuable construction resources.
- Minimizes waste disposal costs, as industrial by-products are repurposed instead of dumped in landfills.

III. METHODOLOGY AND ANALYSIS

The methodology for applying geopolymers on soil involves several steps, ranging from material selection to laboratory testing and field application. Below is a detailed framework.



A. Materials Used in Soil Geopolymers

Soil Types

- ➢ Expansive Soils: Stabilized to reduce swelling and shrinkage.
- ➢ Loose Sandy Soils: Treated to increase cohesion and load-bearing capacity.

B. Components Breakdown

Each mix is designed with a binder (Fly Ash, Metakaolin, or GGBS) and an alkaline activator solution ($NaOH + Na_2SiO_3$).

Table 1 Geopolymer Binder Mix Composition with Alkaline Activators

Component	Fly Ash (Class F) - 0.5 Ratio	Metakaolin - 0.5 Ratio	GGBS - 0.5 Ratio
Binder	1000 g	1000 g	1000 g
Alkaline Solution ($NaOH + Na_2SiO_3$)	500 g	500 g	500 g
NaOH Solution (1/3 of Alkaline Solution)	167 g	167 g	167 g
Na_2SiO Solution (2/3 of Alkaline Solution)	333 g	333 g	333 g
Water (if needed)	Small amount	Small amount	Small amount

Table 2 Curing Conditions for Different Geopolymer Binders

Curing Condition	Fly Ash	Metakaolin	GGBS
Heat Curing	24 hrs. at 60–90°C	24 hrs. at 60–90°C	24 hrs. at 60–90°C
Ambient Curing	7 days at room temp	7 days at room temp	7 days at room temp

C. Compressive Strength Results

Table 3 Compressive Strength of Different Geopolymer Binders

Binder Type	Compressive Strength (MPa)
Fly Ash-Based	20–40 MPa
Metakaolin-Based	30–50 MPa
GGBS-Based	35–60 MPa

Compressive Strength Analysis:

- Fly Ash: Moderate strength (20–40 MPa), good for general soil stabilization.
- Metakaolin: High strength (30–50 MPa), ideal for high-performance applications.
- GGBS: Highest strength (35–60 MPa), suitable for structural applications.

Recommended Applications

- Fly Ash-Based Geopolymer → Soil stabilization, pavement subbase, lightweight blocks.
- Metakaolin-Based Geopolymer → Precast elements, high-strength concrete, marine structures.
- GGBS-Based Geopolymer → Road base, bridges, structural applications.

IV. CONCLUSION

1. Geopolymers are an eco-friendly and sustainable alternative to cement, significantly reducing carbon emissions by utilizing industrial by-products such as Fly Ash, Metakaolin, and GGBS. This helps in waste management and environmental conservation.

Each binder has unique properties and applications:

- Fly Ash-Based Geopolymer: Low-cost, moderate strength, ideal for soil stabilization and lightweight structures.
- Metakaolin-Based Geopolymer: High reactivity and strength, suitable for high-performance concrete and marine structures.
- GGBS-Based Geopolymer: Develops early strength, making it ideal for road bases, bridges, and structural applications.

2. Geopolymers are highly durable, resistant to chemical attacks, and suitable for harsh environmental conditions. They outperform ordinary Portland cement (OPC) in acidic, sulfate-rich, and marine environments.
3. The use of geopolymers in soil stabilization improves soil strength, reduces settlement, and enhances durability, making them ideal for pavement subbases, embankments, and load-bearing soils.
4. Future research and industrial adoption of geopolymer technology can lead to more sustainable construction practices, reducing dependence on cement-based materials and promoting greener infrastructure.

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IS Codes

- IS 1725:2013 - Fly Ash-Based Binders.
- IS 2720 (Part 10):1991 - UCS Test for Soil.
- IS 4332 (Part 4):1968 - Durability Test for Stabilized Soil.
- IS 14767:1999 - Sustainability Guidelines
- IS 3812:2013 - Fly Ash Usage.