

Exploring Geopolymer Concrete In Archiving A Sustainable, Low Carbon Construction

Ololade Temitope Oduneye

Abstract

This report explores how to archive a sustainable, low-carbon construction with the use of Geopolymer concrete. Geopolymer Concrete (GPC) has gained much attraction over the past years due to its materials, which makes it sustainable and durable. This makes Geopolymer Concrete a sustainable alternative to traditional concrete. As an alternative to Portland cement, Geopolymer Concrete uses low-carbon materials that are rich in aluminosilicate such as fly ash and slag. This also improves Geopolymer Concrete durability, making it suitable for various applications like Building, Aquatic, Roads and bridge construction. This report explores the challenges of Geopolymer concrete which include cost, and material, future direction on how to reduce its cost, make materials available and integrate it with self-healing and fibre reinforced concrete technology. In conclusion, as the industry increasingly prioritizes sustainable and durable alternatives to Portland cement concrete, Geopolymer concrete use is expected to expand in future.

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I. Introduction

The construction industry, responsible for 39% of global greenhouse gas emissions, faces an urgent need to adopt sustainable practices and reduce its environmental footprint. Traditional Portland cement, a primary component of concrete, is a major contributor due to its energy-intensive production process and high CO₂ emissions. In this context, Geopolymer Concrete (GPC) emerges as an innovative solution, offering significant potential to achieve sustainability goals. Made from industrial by-products such as fly ash and slag, GPC not only reduces carbon emissions but also promotes a circular economy by recycling waste materials.

This investigation explores the role of GPC in achieving low-carbon construction, examining its composition, environmental advantages, performance, and challenges. By addressing critical issues such as cost, material availability, and standardization, the report aims to highlight pathways for optimizing GPC and its broader integration into the construction sector. Through this analysis, the study underscores the relevance of GPC as a cornerstone for innovation and sustainability in the built environment. This project also aligns with student design & sustainability competitions 2025, as it explores functionality and sustainability of concrete.

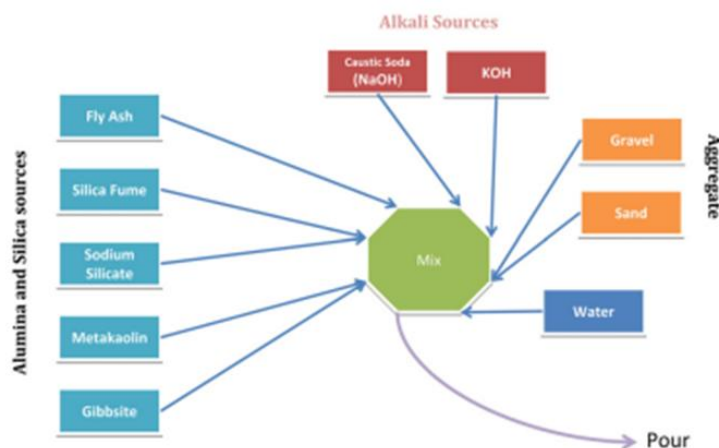


Figure 1. Production of geopolymer Concrete. From McLellan, B. C., et al (2011).

II. List Of Abbreviations

Abbreviation	Meaning
GPC	Geopolymer concrete
SI	Silicon
Al	Aluminium
Na	Sodium

H	Hydrogen
SDGs	Sustainable Development Goals
GCI	Global Change Institute
LCA	Life Cycle Assessment
GCI	The Global Change Institute
R&D	Research and Development

III. Context and Background

Geopolymer concrete (GPC) was introduced in the 1970s by French materials scientist Professor Joseph Davidovits as an innovative response to these environmental concerns. GPC is made by activating aluminosilicate-rich industrial by-products, such as fly ash, slag, and silica fume, with alkaline activators to create a binder that replaces Portland cement. This process significantly reduces carbon emissions, as it eliminates the need for the energy-intensive production of cement clinker (Davidovits, 1988). Additionally, the ability of GPC to utilize waste materials aligns with the principles of the circular economy, promoting resource efficiency and waste reduction (Rashad, 2013).

The construction industry is a significant contributor to global greenhouse gas emissions, responsible for 39% of worldwide CO₂ emissions (World Green Building Council, 2019). Traditional Portland cement, a core ingredient in concrete, is particularly problematic due to its energy-intensive production process, which involves significant CO₂ emissions during calcination (Davidovits., 1988). These challenges have fuelled the search for sustainable alternatives that can reduce the industry's environmental footprint while maintaining material performance and durability.

Currently, the adoption of GPC is gaining traction as global awareness of climate change intensifies. Many governments and industries are committing to ambitious carbon-neutrality targets, driving innovation in low-carbon technologies. The construction sector, as a cornerstone of the global economy, is under increasing pressure to adopt environmentally sustainable practices. GPC is recognized as a key player in achieving these goals, offering not only reduced carbon emissions but also enhanced durability and resistance to chemical attacks, such as those caused by chlorides and sulphates (Habert et al., 2011).

Despite these benefits, the widespread adoption of GPC is limited by several challenges, including high initial costs, variability in the quality of raw materials, and the absence of standard testing protocols (The Concrete Centre, n.d.).

IV. Literature Review

Composition and Properties of Geopolymer Concrete

Geopolymer concrete (GPC) is made from aluminosilicate materials activated by alkaline solutions such as aum or potassium hydroxide. The mixture's composition is crucial to its properties, such as mechanical strength, durability, and fire resistance (Rashad, 2013). Studies highlight the significance of raw material type and quantity, with alkali activator concentration being a key factor influencing performance. When optimized, GPC can match or even outperform traditional Portland cement concrete, particularly in high-temperature environments (Davidovits, 2013).

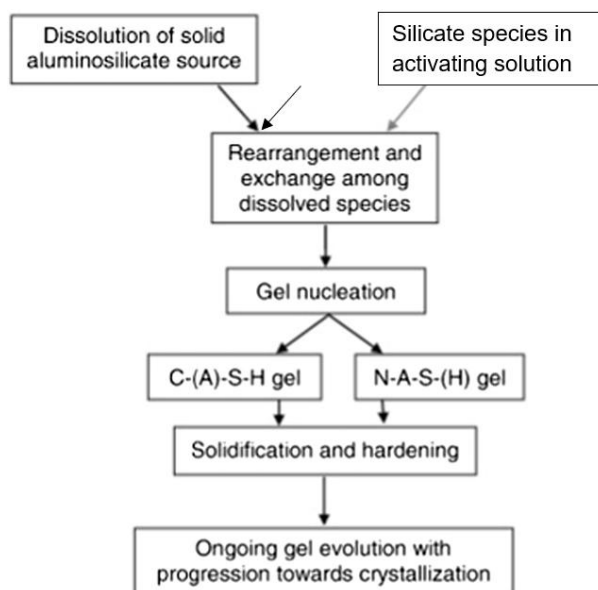


Figure 2. Alkali activation reaction process. From M.Mastali et al (2018)

Environmental Impact of Geopolymer Concrete

Geopolymer concrete (GPC) offers significant environmental benefits by reducing the carbon footprint of construction, compare to traditional Portland cement, which is energy-intensive to produce. In contrast, GPC requires lower temperatures, cutting energy consumption and greenhouse gas emissions. Additionally, GPC uses industrial by-products like fly ash and slag, reducing the need for virgin materials and promoting recycling. Research shows that GPC can reduce CO₂ emissions by up to 80% compared to conventional concrete. This aligns with global climate change mitigation efforts and supports a circular economy by recycling waste materials (McLellan et al., 2011).

Performance and Durability of Geopolymer Concrete

Research into the durability of geopolymer concrete (GPC) highlights its resilience in several key areas. GPC resists chemical attacks, including sulphate and chloride exposure, which commonly damage traditional concrete. It also provides superior protection against alkali-silica reactions (ASR), a frequent issue with conventional concrete. These properties make GPC particularly effective for use in aggressive environments such as marine structures and wastewater treatment plants, enhancing long-term performance in harsh conditions. However, further research is needed to address any potential weaknesses and optimize its application in diverse settings, on Issues such as carbonation resistance, shrinkage, and cracking under certain conditions (Provis & van Deventer, 2009).

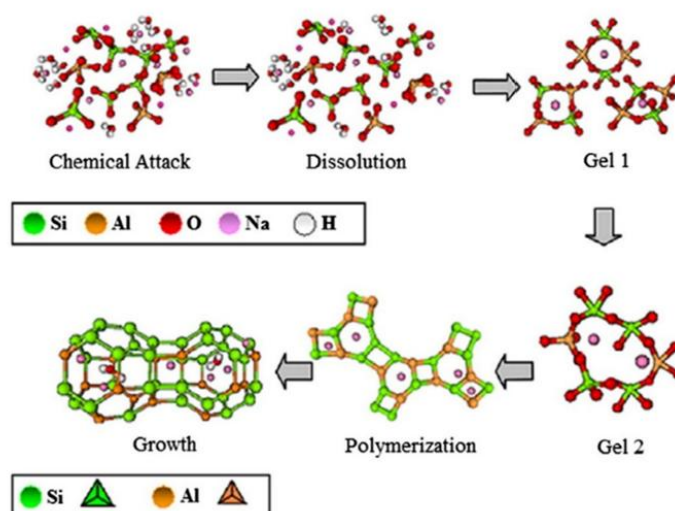


Figure 3. Graphic Model of Geopolymers reaction to chemical. From M.Mastali et al (2018)

Challenges and Future Directions

Despite its potential, GPC faces challenges like high initial costs due to alkaline activators and raw material processing, as well as variability in the availability of materials like fly ash and slag, complicating large-scale production. The complex chemistry and rheology of GPC mixtures also hinder consistency and scalability (Nath & Sarker, 2014).

Future research should focus on optimizing GPC's composition for better performance and cost-effectiveness. Standardized testing and life cycle assessments (LCA) are key for integrating GPC into building codes and comparing its environmental impact to traditional concrete. Additionally, combining GPC with advanced technologies, such as self-healing concrete and fibre reinforcement, could improve its durability for high-demand projects. Pilot testing is essential to validate these innovations and cement GPC's role in sustainable construction.

V. Critical Analysis

Geopolymer concrete (GPC) offers significant sustainability benefits but faces barriers requiring attention across economic, social, environmental, and ethical dimensions.

Economic Perspective

While GPC has high initial costs due to specialized materials like fly ash and alkaline activators, long-term maintenance savings and waste material utilization could offset expenses. However, inconsistent supply chains and cheaper traditional concrete in some regions remain obstacles. Expanding regional testing and refining production can enhance its economic viability (McLellan et al., 2011; Provis & van Deventer, 2009).

Social Perspective

The adoption of more sustainable building materials may also lead to the development of new construction techniques and standards. In terms of building performance, GPC has shown benefits such as enhanced fire resistance, thermal insulation, and long-term durability, which contribute to better living and working conditions (Nath & Sarker, 2014).

Environmental Perspective

GPC reduces CO₂ emissions compared to traditional cement, supports waste recycling, and promotes a circular economy. However, the environmental costs of raw material processing and disposal need deeper evaluation. Optimizing material sourcing is critical for sustainability (Davidovits, 2013; The Concrete Centre, n.d.).

Current Solutions and Limitations

GPC demonstrates effectiveness in pilot projects, showcasing durability and environmental benefits. However, adoption is constrained by high costs, material variability, and insufficient standards. Addressing these issues through research on composition optimization and standardization can drive its broader acceptance (Provis & van Deventer, 2009).

Ethical Perspective

The ethical implications of adopting geopolymer concrete are primarily related to its potential to reduce the environmental impact of the construction industry. By choosing sustainable materials and practices, the construction industry can contribute more, than just an equitable future. However, it is essential to ensure that the production and use of geopolymer concrete do not harm workers or communities.

Effectiveness and Limitations of Current Solutions

The effectiveness of GPC as a sustainable building material is evident in several pilot projects and studies demonstrating its superior mechanical properties and environmental benefits. GPC has proven effective in reducing the carbon footprint of construction projects while offering improved durability in certain conditions (Provis & van Deventer, 2009). However, its adoption is hindered by several limitations, these limitations can be addressed by focusing on optimizing the chemical composition of GPC to lower its cost and increase its accessibility.

VI. Case Study

The GCI at the University of Queensland, Australia, exemplifies sustainable construction using geopolymer concrete (GPC). As a hub for climate research and environmental management, the building showcases innovative low-carbon technologies, including geopolymer concrete, to minimize its environmental footprint.



Figure 4. Image of The Global Change Institute, Brisbane, Australia. From Archdaily (2013)

Key Features:

The Global Change Institute (GCI), located at the University of Queensland in Brisbane, Australia, is a prime example of how geopolymer concrete is being used to reduce the environmental impact of construction. The building serves as a centre for research into climate change, sustainability, and environmental management, and it was built with a focus on showcasing innovative, low-carbon technologies.

Use of Geopolymer Concrete: One of the standout features of the GCI building is the use of geopolymer concrete in its construction. Geopolymer concrete, made from industrial by-products such as fly ash and slag, was utilized in key structural components of the building. This choice was made to significantly reduce the carbon footprint of the construction, as the production of geopolymer concrete emits less carbon dioxide than traditional Portland cement. The project is a concrete demonstration of how alternative materials can contribute to sustainable construction, supporting global efforts to mitigate climate change.

Alignment with UN SDGs:

- **SDG 13:** Reduces greenhouse gas emissions through low-carbon materials.
- **SDG 12:** Supports the circular economy by recycling industrial waste.
- **SDG 9:** Advances construction innovation with sustainable infrastructure solutions (Nath & Sarker, 2014).

Analysis:

The GCI project demonstrates the viability of integrating GPC in real-world construction, showcasing its environmental and societal benefits. Despite challenges like cost and standardization, it highlights how innovation can overcome barriers, supporting global climate goals (Scrivener et al., 2018). The case underscores the construction sector's potential to adopt sustainable practices through low-carbon materials (Bligh & Glasby, 2013).

VII. Future Directions And Recommendations

Geopolymer concrete (GPC) holds significant promise for contributing to sustainable construction by reducing carbon emissions and promoting the use of industrial by-products. However, several challenges need to be addressed to increase its widespread adoption. These include improving material properties, reducing costs, and establishing standards.

Material Optimization

Advancing mix designs and raw material use (e.g., fly ash, slag, metakaolin) can improve GPC's strength, durability, and resistance to issues like shrinkage and carbonation, making it viable for broader applications (Scrivener et al., 2018).

Cost Reduction

Although GPC costs more than traditional cement, evolving production methods, automation, and greater use of industrial waste can lower material and labour costs, enhancing scalability (Bakharev, 2005).

Standardization

Developing international standards for testing and performance criteria is essential. Clear regulations and inclusion in building codes will boost market confidence and adoption (Habert et al., 2011).

Public Awareness

Promoting GPC's benefits and training professionals will address misconceptions and encourage adoption. Education campaigns and training programs for workers and architects will smooth its integration (Duxson et al., 2007).

Practical Recommendations

- **Policymakers:** Offer incentives like tax credits and research funding, while updating building codes to include GPC.
- **Businesses:** Invest in R&D, collaborate with industrial by-product suppliers, and train staff to ensure efficient use of GPC.

Addressing these challenges positions GPC to transform construction practices, offering a low-carbon, high-performance alternative for diverse applications.

VIII. Conclusion

Geopolymer Concrete (GPC) demonstrates immense potential as a sustainable alternative to traditional Portland cement concrete. Its ability to significantly reduce CO₂ emissions, enhance material performance, and recycle industrial by-products positions it as a key innovation in low-carbon construction. This investigation highlights GPC's advantages, including its superior durability and environmental benefits, alongside challenges like high initial costs, variability in raw materials, and a lack of standardized testing protocols.

Addressing these challenges is vital for the broader adoption of GPC. Future research into material optimization, cost reduction strategies, and integration with advanced technologies, such as fiber reinforcement

and self-healing concrete, will further enhance its viability. As global demand for sustainable construction solutions grows, GPC can play a pivotal role in reshaping industry practices, driving innovation, and contributing to a more resilient and low-carbon future.

IX. Resources Required

Resources	Uses
ICT Devices	Laptops, desktops, and mobile phones were used for research, providing access to academic articles, databases, and other digital resources.
Web-based resources	<i>Coventry Locate</i> was the primary tool for accessing books and articles. Additional research came from platforms like <i>Google Scholar</i> , <i>JSTOR</i> , <i>PubMed</i> , and <i>ScienceDirect</i> .
Software	Microsoft Word was used for drafting and formatting the report, while Google Chrome was essential for accessing online resources.
Workspace	Research was conducted at <i>Coventry University library</i> and at my personal workspace at home.
Time Management Tools	<i>Microsoft Project</i> , calendar, and reminders helped track progress and ensure deadlines were met

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