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Original Article

Performance Evaluation and Enhancement of Geopolymer Concrete using Silica Fume

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Abstract *- This study investigates the effects of Silica Fume (SF) on Geopolymer Concrete (GPC) to evaluate its impact on key performance metrics, including workability, setting times, and mechanical properties. Geopolymer concrete mixes with varying SF/Fly Ash (FA) ratios were prepared and tested for the slump, initial and final setting times, compressive strength, and splitting tensile strength. Results indicate that increasing SF content decreases slump values, reflecting reduced workability due to the high surface area and water absorption of SF particles. Incorporating SF significantly accelerates setting times, which is advantageous for applications requiring rapid strength gain. Mechanical testing revealed a marked improvement in compressive and splitting tensile strengths with higher SF content, attributed to enhanced microstructural densification and reduced porosity. Despite these promising findings, the study identifies several knowledge gaps, including the need for research on long-term durability, optimization of mix proportions, standardization of production methods, exploration of additional industrial by-products, and comprehensive environmental and economic assessments. Addressing these gaps will advance the understanding and application of SF-blended GPC, supporting its broader adoption in sustainable construction practices.*

Keywords *- Geopolymer Concrete, Silica Fume, Workability, Compressive Strength, Splitting Tensile Strength, Sustainability.*

1. Introduction

The purpose of this paper is threefold: to establish a robust theoretical framework, to identify key findings and existing knowledge gaps in the current body of research, and to guide the direction of the present study. As per the kinds of literature, various research presents the evaluation of the performance of geopolymer-concrete with partial replacement of various additional materials. The property varies with respect to the different replaced materials in the different geographical regions. According to the Delhi geographic region, silica fume has been used in this research to develop a high-strength geopolymer concrete. Theoretical frameworks serve as the foundation upon which empirical research is constructed, providing the necessary context for understanding the underlying principles governing geopolymer concrete's mechanical properties and environmental impact. By systematically reviewing the relevant literature, this section seeks to delineate the evolution of research in the field, highlight the most significant contributions, and identify areas where further investigation is warranted. These efforts are essential in shaping the trajectory of the current study, ensuring that it builds upon existing knowledge while addressing unresolved questions and emerging challenges. Figure 1 represents some benefits of silica fume.

2. Overview of Geopolymer Concrete

2.1. Definition and Composition

Geopolymer Concrete (GPC) is an advanced material designed to address the environmental and performance limitations of traditional Portland cement concrete (OPC) [1]. Unlike OPC, which relies on the high-temperature calcination of limestone and other raw materials to produce cement, GPC is synthesized through the alkaline activation of aluminosilicate precursors. These precursors, such as fly ash, metakaolin, and blast furnace slag, are in the high proportion of alumina (Al_2O_3) as well as of silica (SiO_2), and they react with an alkaline activator to form a hardened binder [2].

The chemical process involved in GPC production begins with the dissolution of aluminosilicate minerals in an alkaline solution, typically composed of potassium hydroxide (KOH) or sodium hydroxide (NaOH), and a silicate activator such as potassium silicate (K_2SiO_3) or sodium silicate (Na_2SiO_3). This reaction generates a gel-like aluminosilicate matrix that forms the binding phase in GPC. Unlike OPC, where calcium silicate hydrate (C-S-H) is the primary binder, GPC's binding phase is an aluminosilicate gel characterized by a three-dimensional network of Si-O-Al bonds. This distinctive chemistry imparts GPC with unique mechanical and durability properties, setting it apart from conventional concrete materials [3].

The differences between GPC and OPC extend beyond their chemical composition. GPC typically exhibits enhanced resistance to chemical attacks, high temperatures, and acidic environments, making it particularly suitable for applications in harsh conditions. Furthermore, the production of GPC involves a lower carbon footprint compared to OPC, as it does not require the high-temperature kiln process essential for cement production. This makes GPC an appealing alternative in the context of sustainable construction practices [4]. Figure 2 illustrates the typical composition of geopolymers, highlighting the role of aluminosilicate materials like fly ash, metakaolin, and slag, along with alkali hydroxides and silicates, in the geopolymerization process.

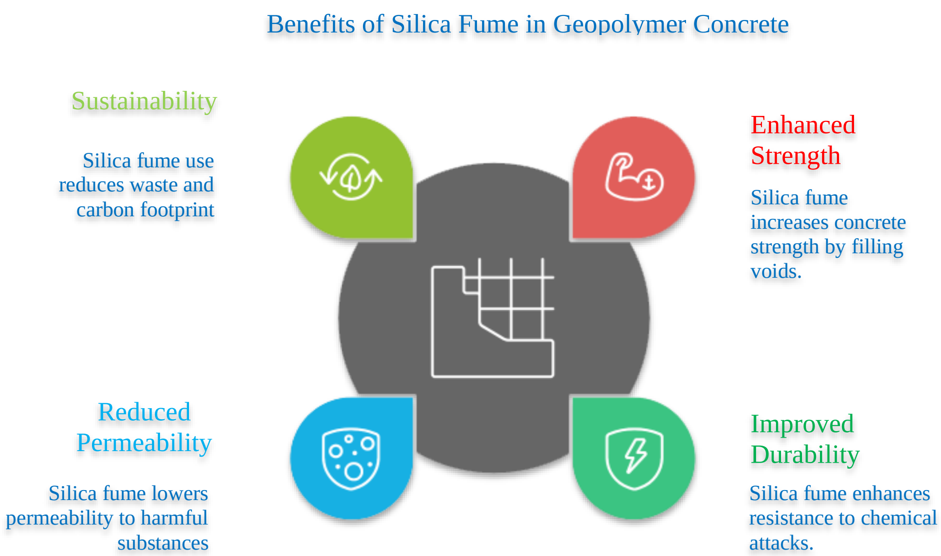

Fig. 1 Benefit of silica fume

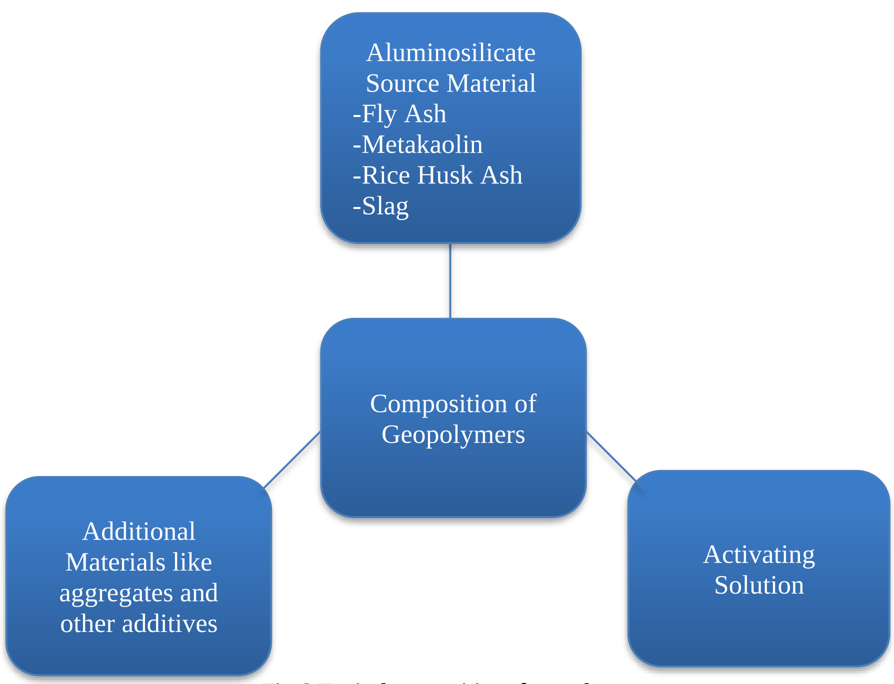

Fig. 2 Typical composition of geopolymers

2.2. Historical Development

The evolution of geopolymer technology dates back to the early 1970s, with the pioneering work of Professor Joseph Davidovits, who first introduced the concept of geopolymers. Davidovits's initial research focused on developing a new class of inorganic polymers, which he termed "geopolymers," to replace conventional cementitious materials. His early work demonstrated the potential of aluminosilicate materials to form durable and chemically resistant binders when activated with alkaline solutions [5].

Key milestones in the research and application of GPC include the refinement of precursor materials and activation methods, as well as the exploration of diverse applications. In the 1980s and 1990s, significant advancements were made in understanding geopolymers' structural and chemical properties, leading to the development of more refined and efficient activation techniques. The use of industrial by-products, such as fly ash and slag, as precursors for GPC gained prominence in the 2000s, reflecting a growing emphasis on sustainability and waste minimization in construction materials.

The 2010s marked a period of increased research into the optimization of GPC mixtures, with a focus on enhancing mechanical properties, workability, and long-term durability. Studies during this period also explored the potential of GPC in various structural and non-structural applications, including high-strength concrete, fire-resistant materials, and environmentally friendly construction solutions [7].

In recent years, the application of GPC has expanded beyond traditional concrete applications, with ongoing research investigating its use in novel contexts such as 3D printing, advanced structural composites, and infrastructure rehabilitation. The continued evolution of geopolymer technology reflects a growing recognition of its potential to contribute to sustainable development and address the environmental challenges associated with conventional cement-based materials [8].

The historical development of GPC underscores its transformative impact on the field of construction materials. From its inception as a theoretical concept to its current status as a viable and innovative alternative to OPC, GPC represents a significant advancement in materials science, driven by ongoing research and technological progress [9].

3. Mechanical Properties of Geopolymer Concrete

3.1. Compressive Strength

The compressive strength of Geopolymer Concrete (GPC) is a critical parameter influencing its suitability for various structural applications. This strength is influenced by several factors, including mixed proportions, curing conditions, and the nature of the alkaline activators used.

3.1.1. Mix Design Proportions

The proportions of the aluminosilicate precursor materials (such as fly ash, metakaolin, or slag) and the alkaline activator solutions are pivotal in determining the compressive strength of GPC. Variations in the SiO_2/Al_2O_3 ratio and the concentration of the alkaline activators can lead to significant differences in the final strength. Optimal mix proportions are necessary to achieve high compressive strength, and recent research has focused on fine-tuning these parameters to enhance performance [6]. Figure 3 represents the factors for mixed design proportions of geopolymer concrete using silica fume.

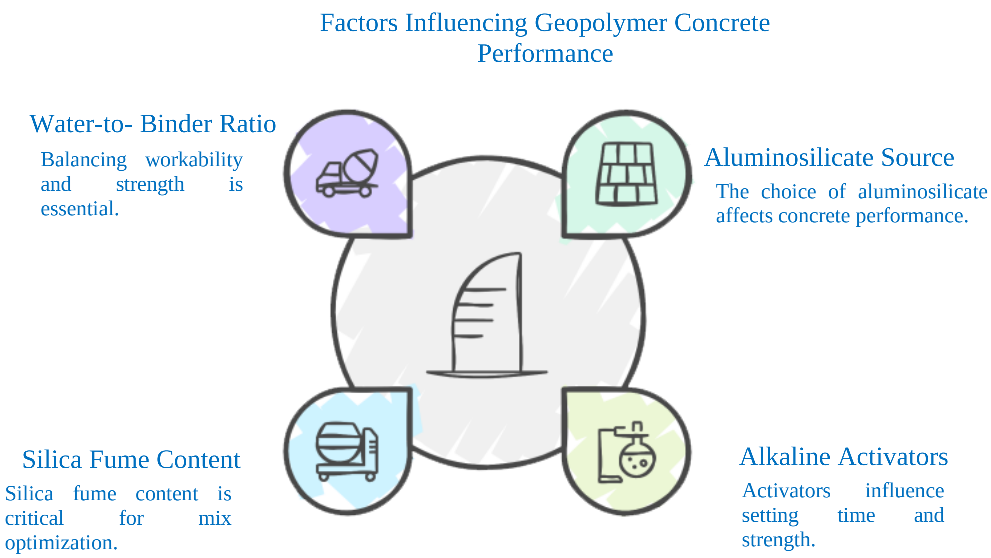

Fig. 3 Mix design properties

3.1.2. Curing Conditions

Curing conditions play a crucial role in developing compressive strength in GPC. Unlike OPC, which typically requires moist curing, GPC can benefit from elevated temperature curing, such as steam curing, to accelerate the geopolymerization process. The temperature and duration of curing affect the polymerization kinetics and, consequently, the final compressive strength. Understanding the influence of curing regimes helps in optimizing the performance of GPC in various environmental conditions [10].

3.1.3. Comparison with OPC

Compared with traditional Portland cement concrete (OPC), GPC often exhibits comparable or superior compressive strength. Studies have shown that GPC can achieve high compressive strengths, sometimes exceeding those of OPC, - depending on the mix design and curing conditions. This enhanced strength is attributed to the unique polymeric network formed during the geopolymerization process, which can provide greater load-bearing capacity and structural integrity [10].

3.1.4. Enhancements Through Additives

The tensile and flexural strengths of GPC can be improved by incorporating various additives, such as silica fumes and steel fibers. Silica fume, known for its high pozzolanic reactivity, contributes to the densification of the geopolymeric matrix, enhancing both tensile and flexural strengths. When added to GPC, steel fibres provide additional reinforcement, improving its resistance to cracking and enhancing overall mechanical performance.

3.1.5. Comparative Analysis with Conventional Concrete

Compared to conventional concrete, GPC, with appropriate additives, often demonstrates improved tensile and flexural strengths. The presence of silica fumes and steel fibers contributes to a more robust and ductile material capable of withstanding higher tensile stresses and flexural loads. The ability to tailor the mechanical properties of GPC through additive incorporation allows for its application in demanding structural scenarios where conventional concrete might fall short.

3.2. Durability

3.2.1. Resistance to Chemical Attacks

GPC exhibits exceptional resistance to chemical attacks, including acids, sulfates, and chlorides. This enhanced durability results from the dense aluminosilicate network, which minimizes the penetration of aggressive substances. The performance of GPC in environments with high chemical exposure makes it a suitable choice for applications such as marine structures and wastewater treatment facilities [11].

3.2.2. Thermal Effects

The thermal stability of GPC is another significant advantage. GPC can withstand elevated temperatures better than OPC, making it particularly valuable in fire resistance applications. The thermal properties of GPC, including its ability to maintain structural integrity at high temperatures, are a direct result of the geopolymeric matrix, which remains stable under thermal stress [12].

3.2.3. Environmental Stressors

GPC's durability extends to its performance under various environmental stressors, including freeze-thaw cycles and moisture fluctuations. The resistance to such stressors is attributed to the low permeability and high chemical stability of the geopolymeric binder. This resilience ensures long-term performance and reduces maintenance needs, contributing to the overall sustainability of GPC as a construction material [13].

3.2.4. Long-Term Performance and Sustainability Aspects

The long-term performance of GPC is characterized by its ability to maintain mechanical and durability properties over extended periods. Studies indicate that GPC can sustain its strength and resistance characteristics effectively throughout its service life.

Moreover, using industrial products as precursors in GPC production aligns with sustainability goals by reducing waste and lowering the carbon footprint associated with traditional cement production [14]. The performance characteristics of geopolymer concrete using silica fume are shown in Figure 4.

Table 1. Mechanical properties of geopolymer concrete

Property	Aspect	Details	References
Compressive Strength	Mix Proportions	Optimal ratios	[6]
	Curing Conditions	Elevated curing	[10]
	Comparison with OPC	Comparable or superior	[10]
Enhancements	Additives	Silica fume, steel fibers	
	Comparative Analysis	Improved strength	
Durability	Chemical Resistance	Acid, sulfate, and chloride resistance	[11]
	Thermal Effects	High-temperature stability	[12]
	Environmental Stressors	Freeze-thaw, moisture resistance	[13]
	Long-Term Performance	Sustained strength, eco-friendly	[14]

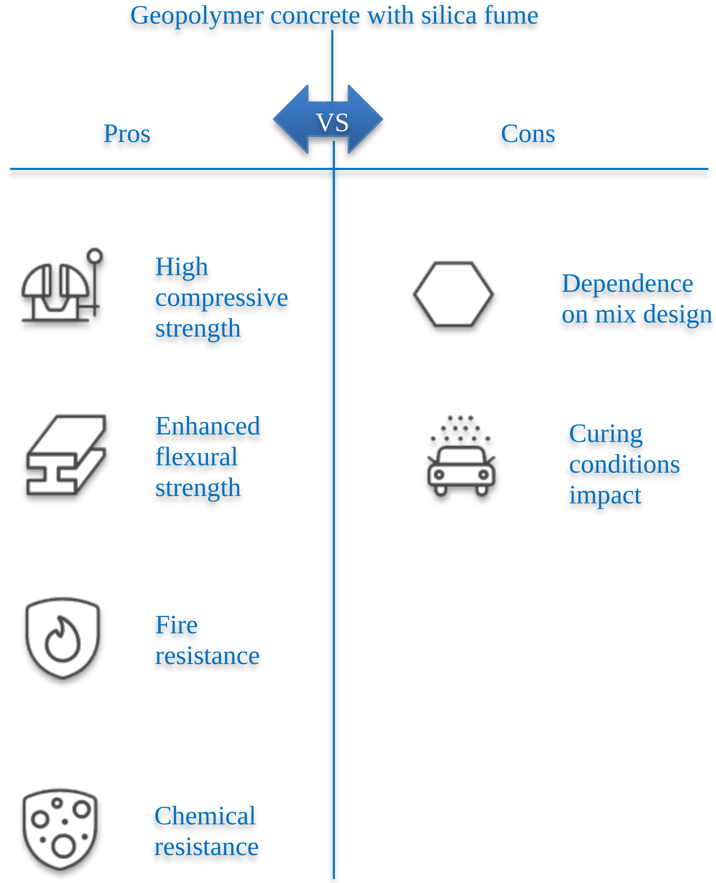

Fig. 4 Performance characteristics

The mechanical properties of geopolymer concrete, including compressive strength, tensile and flexural strength, and durability, underscore its potential as a robust and sustainable alternative to traditional Portland cement concrete. The advancements in mix design, additive incorporation, and understanding of curing conditions continue to enhance the performance of GPC, supporting its application in a wide range of structural and environmental contexts. The mechanical properties of Geopolymer Concrete (GPC), including compressive strength and durability factors, are summarized in Table 1.

4. Utilization of Industrial By-products in Geopolymer Concrete

4.1. Fly Ash-Based Geopolymer Concrete

4.1.1. Environmental Benefits and Potential for Reducing Greenhouse Gas Emissions

Fly ash, a by-product of coal combustion in power plants, has emerged as a prominent material in the production of Geopolymer Concrete (GPC). The utilization of fly ash in GPC offers significant environmental benefits. The incorporation of fly ash reduces the reliance on virgin raw materials, thereby decreasing the overall environmental footprint of concrete production [15].

Greenhouse Gas Emission Reductions

The production of traditional Portland cement is a major contributor to greenhouse gas emissions, primarily due to the high temperatures required for its calcination. In contrast, the geopolymerization process, which utilizes fly ash, involves lower temperatures and consequently results in reduced carbon dioxide emissions. By substituting a significant portion of Portland cement with fly ash, GPC contributes to a lower carbon footprint, aligning with global sustainability goals.

Reduction of Landfill Waste

The use of fly ash in GPC also addresses the issue of waste management. Fly ash is often disposed of in landfills, where it can pose environmental hazards. By incorporating fly ash into GPC, the volume of waste directed to landfills is minimized, providing a beneficial use for this industrial by-product and contributing to waste reduction efforts[16].

4.1.2. Key Studies on the Mechanical and Durability Properties of Fly Ash-Based GPC

Numerous studies have examined the mechanical and durability properties of fly ash-based GPC, highlighting its performance and potential applications.

Mechanical Properties

Research indicates that fly ash-based GPC can achieve comparable or superior mechanical properties compared to traditional concrete. Studies have demonstrated that fly ash-based GPC can attain high compressive strength, tensile strength, and flexural strength, depending on the mix design and curing conditions.

The pozzolanic reaction of fly ash with alkaline activators enhances the formation of a dense geopolymeric matrix, contributing to its mechanical robustness.

Durability Properties

Fly ash-based GPC exhibits excellent durability characteristics, including resistance to chemical attacks, moisture infiltration, and high temperatures. Studies have shown that fly ash-based GPC has superior resistance to sulfate attacks, chloride ingress, and acid exposure compared to conventional concrete.

This durability makes fly ash-based GPC suitable for aggressive environments, such as marine structures and industrial applications [17].

4.2. Other By-Products

4.2.1. Use of Ultra-Fine Slag, Rice Husk Ash, Ferrochrome Slag, Red Mud, and Silica Fume

In addition to fly ash, several other industrial by-products have been explored for their use in geopolymer concrete. These by-products offer varying benefits in terms of mechanical performance and sustainability [19].

Ultra-Fine Slag

Ultra-fine slag, a by-product of steel manufacturing, has been used as a supplementary material in GPC. Its fine particle size and high reactivity contribute to improved mechanical properties and durability. Research indicates that ultra-fine slag can enhance the compressive strength and resistance to chemical attacks of GPC, making it a valuable addition to geopolymer mixtures [20].

Rice Husk Ash

Rice husk ash, derived from the agricultural waste of rice milling, is another by-product used in GPC. The high silica content of rice husk ash contributes to forming a dense and durable geopolymeric matrix. Studies have demonstrated that rice husk ash-based GPC exhibits good mechanical properties and resistance to environmental stressors [21].

Ferrochrome Slag

Ferrochrome slag, a by-product of the ferrochrome industry, has been investigated for its use in GPC. This by-product can enhance the mechanical properties of GPC, particularly in terms of compressive strength. Research also highlights its potential benefits in improving the sustainability of GPC by reducing reliance on conventional raw materials [22].

Red Mud

Red mud, a waste product from the alumina extraction process, has been studied for its application in GPC. The incorporation of red mud in GPC can contribute to improved strength and durability.

However, challenges related to red mud's high alkalinity and variability need to be addressed to optimize its performance in geopolymer mixtures [23].

Silica Fume

Silica fume, a by-product of silicon and ferrosilicon alloy production, is frequently used to enhance the properties of GPC. The fine particles of silica fume contribute to a dense microstructure and improved mechanical performance. Silica fume can significantly enhance the compressive strength, tensile strength, and durability of GPC [18].

4.2.2. Impact on Mechanical Properties and Sustainability

The inclusion of these industrial by-products in GPC not only enhances its mechanical properties but also contributes to its sustainability. Using by-products reduces the demand for virgin raw materials, decreases waste generation, and lowers the carbon footprint associated with concrete production [24, 25].

Mechanical Properties

Each by-product has unique effects on the mechanical properties of GPC. For instance, silica fume and ultra-fine slag typically enhance strength, while rice husk ash and ferrochrome slag contribute to both strength and durability. The choice of by-product and its proportion in the geopolymer mixture can be optimized based on the specific requirements of the application [26].

Sustainability

Using industrial by-products in GPC aligns with sustainability goals by promoting resource efficiency and reducing environmental impacts. By leveraging waste materials from other industries, GPC supports circular economy principles and contributes to a more sustainable construction practice [27, 28].

In conclusion, integrating industrial by-products such as fly ash, ultra-fine slag, rice husk ash, ferrochrome slag, red mud, and silica fume into geopolymer concrete offers significant mechanical performance and sustainability advantages. These materials not only enhance the properties of GPC but also contribute to environmental conservation by minimizing waste and reducing greenhouse gas emissions [29].

Table 2 summarizes the use of various industrial by-products in geopolymer concrete, highlighting their impacts on mechanical properties and sustainability.

Table 2. Use of industrial by-products in geopolymer concrete

Category	Aspect	Details	Reference
Fly Ash-Based Geopolymer Concrete	Benefits	Reduced footprint	[15]
	Emissions	Lower CO_2	[15]
	Waste	Landfill reduction	[16]
	Strength	Comparable or superior	[17]
	Durability	Chemical, moisture, and heat resistance	[17]
Other By-products	Ultra-Fine Slag	Enhanced properties	[20]
	Rice Husk Ash	Dense matrix	[21]
	Ferrochrome Slag	Improved strength	[22]
	Red Mud	Strength, durability	[23]
	Silica Fume	Enhanced performance	[18]
Impact on Mechanical Properties and Sustainability	Strength	Improved by by-products	[26]
	Sustainability	Resource efficiency, reduced waste	[24, 25]

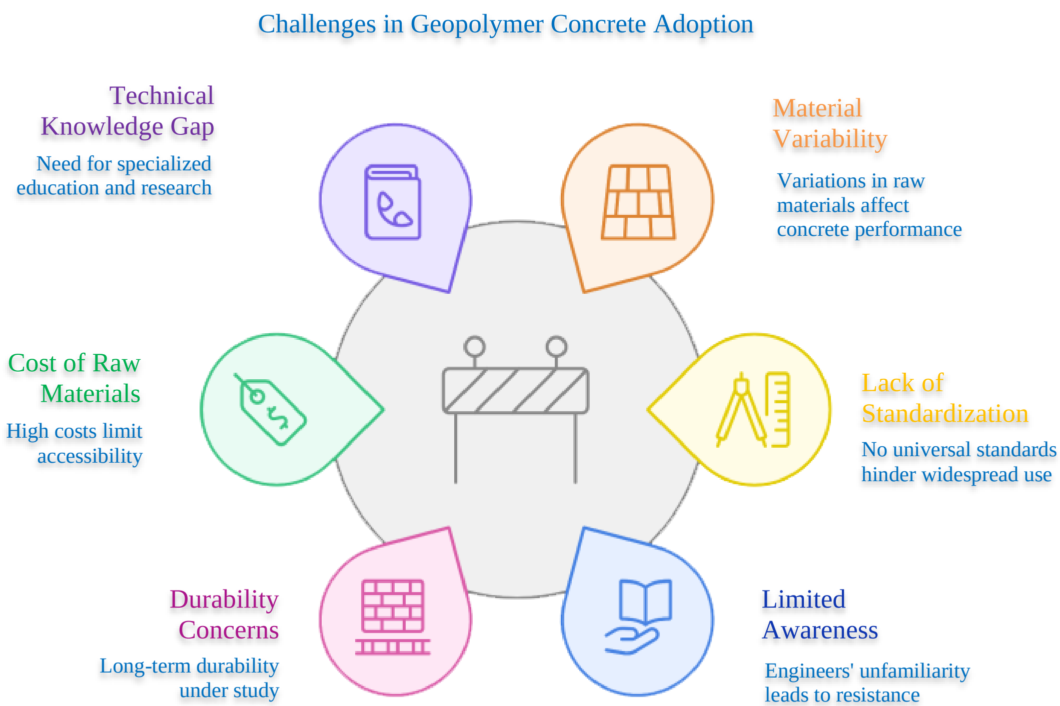

Fig. 5 Challenges in geopolymer concrete research

4.3. Environmental and Sustainability Considerations

The Life Cycle Assessment (LCA) of Geopolymer Concrete (GPC) compared to traditional Ordinary Portland Cement (OPC) concrete reveals a substantial reduction in environmental impact, primarily due to the lower CO2 emissions and global warming potential associated with GPC production.

Unlike OPC, which is responsible for approximately 5-7% of global anthropogenic CO2 emissions due to the calcination of limestone, GPC employs a chemical reaction between aluminosilicate materials and alkaline activators at significantly lower temperatures. This process not only reduces CO2 emissions but also utilizes industrial by-products, contributing to a notable decrease in greenhouse gas emissions [30]. LCA studies indicate that GPC can reduce global warming potential by up to 80% compared to OPC, depending on the specific mix design and the source of by-products. Regarding sustainable development, GPC is pivotal in advancing clean technology and promoting sustainable construction practices [31].

Its adoption aligns with circular economy principles by repurposing waste materials and minimizing the demand for virgin resources. The lower energy requirements for GPC production and its reduced carbon footprint underscore its contribution to mitigating climate change and achieving sustainability goals within the construction sector [33].

4.4. Challenges and Opportunities in Geopolymer Concrete Research

Despite its benefits, the research and application of geopolymer concrete face several challenges. One major issue is the lack of standardized mix designs and curing protocols, which complicates the consistent production and performance of GPC. Variability in raw material properties and the complexity of the geopolymerization process necessitate the development of universal guidelines to ensure reliable results. Additionally, the intricate chemical reactions involved in geopolymerization present a challenge in optimizing GPC formulations [36]. Addressing these complexities requires a deeper understanding of the reaction mechanisms and practical strategies for scaling up production from laboratory to industrial scale. Nonetheless, there are significant opportunities for advancing GPC research. Further optimization of mix proportions can enhance performance characteristics such as compressive strength and durability while reducing costs [37]. Exploring new applications in construction and infrastructure, including high-performance and specialized uses, offers potential for expanding GPC's market presence. Research into cost-effective production methods and innovative applications will support the broader adoption of GPC, ultimately contributing to more sustainable construction practices and infrastructure development [38]. Figure 5 represents some challenges in geopolymer concrete research.

Figure 6 represents the opportunities in geopolymer concrete research.

5. Methodology

The methodology involved preparing geopolymer concrete mixes with varying Silica Fume (SF) content while keeping other materials constant to evaluate workability, setting time, compressive strength, and splitting tensile strength. The mixes, labeled GPSF0 to GPSF3, had SF/FA ratios of 0/100, 10/90, 20/80, and 30/70, respectively. The workability was assessed using the slump test, setting times were measured with a Vicat apparatus, and compressive strength was tested on cube specimens after 28 days of curing.

Splitting tensile strength was determined using cylindrical specimens. The results were analyzed to determine the impact of SF on the concrete's performance, revealing its effectiveness in enhancing mechanical properties and reducing workability with increasing SF content.

Fig. 6 Opportunities in geopolymer concrete research

6. Presentation and Discussion of Results

Table 3. Slump values for geopolymer concrete with silica fume

Mix Name	SF/FA Ratio	Slump (mm)
GPSF0	0/100	120
GPSF1	10/90	105
GPSF2	20/80	90
GPSF3	30/70	75

Table 4. Setting times for geopolymer concrete with silica fume

Mix Name	SF/FA Ratio	Initial Setting Time (min)	Final Setting Time (min)
GPSF0	0/100	250	480
GPSF1	10/90	210	430
GPSF2	20/80	180	390
GPSF3	30/70	150	340

The workability of the geopolymer concrete was measured using the slump test, as presented in Table 3. The slump values indicate the flowability and ease of placement of the concrete. The mix labeled GPSF0, with no silica fume and fly ash (FA) to silica fume (SF) ratio of 0/100, exhibited the highest slump value of 120 mm, indicating a more fluid and workable mix. As the SF content increased, the slump values decreased progressively, with GPSF1 (10/90) showing a slump of 105 mm, GPSF2 (20/80) showing 90 mm, and GPSF3 (30/70) showing 75 mm. This reduction in workability with increasing SF content can be attributed to the higher surface area and amorphous nature of silica fume particles, which tend to absorb more water, leading to a stiffer mix.

Table 4 presents the initial and final setting times for geopolymer concrete mixes with varying SF content. The initial setting time for GPSF0 (0/100) was recorded at 250 minutes, and the final setting time at 480 minutes, representing the baseline for the setting behavior without any SF. As the SF content increased, the setting times shortened, reflecting the pozzolanic reactivity of SF, which accelerates the geopolymerization process. For the GPSF1 (10/90) mix, the initial and final setting times were 210 and 430 minutes, respectively. This trend continued with GPSF2 (20/80) showing setting times of 180 and 390 minutes and GPSF3 (30/70) showing the shortest setting times of 150 and 340 minutes, respectively. The faster setting times with higher SF content are beneficial in applications where rapid strength gain is desired, such as precast concrete production.

Table 5. Compressive strength of geopolymer concrete with silica fume

Mix Name	SF/FA Ratio	Compressive Strength (MPa)
GPSF0	0/100	15
GPSF1	10/90	18
GPSF2	20/80	25
GPSF3	30/70	33

Table 6. Splitting tensile strength of geopolymer concrete with silica fume

Mix Name	SF/FA Ratio	Splitting Tensile Strength (MPa)
GPSF0	0/100	1.2
GPSF1	10/90	1.6
GPSF2	20/80	2.2
GPSF3	30/70	2.7

The compressive strength of geopolymer concrete, a critical measure of its load-bearing capacity, is detailed in Table 5. At a curing age of 28 days, the GPSF0 (0/100) mix exhibited a compressive strength of 15 MPa. The introduction of SF significantly enhanced the compressive strength, with GPSF1 (10/90) achieving 18 MPa, GPSF2 (20/80) achieving 25 MPa, and GPSF3 (30/70) reaching 33 MPa. This marked increase in compressive strength with higher SF content is due to the densification of the concrete's microstructure and the formation of Calcium-Alumino-Silicate-Hydrate (C-A-S-H) gels, which reduce porosity and enhance the overall mechanical properties of the concrete.

Table 6 illustrates the splitting tensile strength, which measures the concrete's resistance to tensile stress, an important parameter for structural integrity. The GPSF0 (0/100) mix exhibited a tensile strength of 1.2 MPa at 28 days. The inclusion of SF progressively improved the tensile strength, with GPSF1 (10/90) showing 1.6 MPa, GPSF2 (20/80) reaching 2.2 MPa, and GPSF3 (30/70) achieving the highest value of 2.7 MPa. The enhancement in tensile strength with increasing SF content can be attributed to the improved interfacial transition zone (ITZ) between the aggregate and the binder and the reduced porosity resulting from the high pozzolanic activity of SF. This improvement is crucial for concrete structures where tensile forces are significant, as it enhances the durability and service life of the concrete.

7. Knowledge Gaps and Future Research Directions

Despite the promising results, several knowledge gaps remain in the field of Geopolymer Concrete (GPC) with Silica Fume (SF). Long-term durability and performance data are limited, particularly regarding resistance to environmental factors like chemical attack and freeze-thaw cycles. Future research should explore these aspects and optimize the SF/FA ratio to balance strength, durability, and workability. Additionally, the absence of standardized production protocols hinders broader adoption, highlighting the need for research to develop consistent methods for producing and curing SF-blended GPC.

Moreover, there is potential to explore other industrial by-products, such as rice husk ash and recycled concrete aggregates, in combination with SF to enhance GPC's mechanical properties and sustainability. Comprehensive life-cycle assessments and cost-benefit analyses are also needed to fully understand the environmental and economic impacts of GPC. Research should further investigate the application of SF-blended GPC in both structural and non-structural components to broaden its use in construction. Addressing these gaps will advance GPC technology and promote more sustainable construction practices.

8. Conclusion

The study highlights the significant impact of Silica Fume (SF) content on the performance of Geopolymer Concrete (GPC), demonstrating its potential to enhance key mechanical properties. As the SF/FA ratio increased, the workability of the concrete decreased while both compressive and splitting tensile strengths improved notably. The reduced setting times with higher SF content indicate accelerated geopolymerization, making these mixes suitable for applications requiring rapid strength gain. These findings align with the growing interest in geopolymer technology as a sustainable alternative to traditional Portland cement concrete, offering improved durability and lower environmental impact. However, the study also underscores the need for further research to optimize GPC mix designs and better understand long-term performance, particularly in relation to durability and the exploration of additional industrial by-products. By advancing knowledge in these areas, the study contributes to the broader adoption of GPC, promoting more sustainable and efficient construction practices.

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