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Experimental Evaluation of Compressive Strength of Geopolymer Foamed Concrete: A Review

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Abstract

Geopolymer foamed concrete (GFC) has emerged as a sustainable and versatile construction material, offering a promising alternative to conventional Portland cement-based concrete. This review paper provides a comprehensive overview of the experimental evaluation of the compressive strength of GFC, synthesizing findings from recent research. It delves into the critical factors influencing GFC's mechanical properties, including the type of precursor materials, the nature of foaming and stabilizing agents, and the curing conditions. Special attention is given to the intricate relationship between pore structure and compressive strength, highlighting how parameters such as porosity, pore size distribution, and pore connectivity dictate overall performance. The paper also explores advancements in achieving high-strength GFC and presents a comparative analysis with ordinary Portland cement (OPC)-based foamed concrete. Furthermore, it discusses various mix design optimization strategies and the role of nanomaterials and fibers in enhancing GFC properties. The objective of this review is to consolidate current knowledge, identify key experimental trends, and suggest future research directions to facilitate the broader adoption of GFC in sustainable construction practices.

Keywords: Geopolymer Concrete, Foamed Concrete, Fly Ash, GGBFS, Sustainability, CO_2 Reduction, Lightweight Concrete

1. Introduction

The rapid expansion of the global construction industry has led to an increased demand for conventional building materials, particularly Ordinary Portland Cement (OPC). However, the production of OPC is highly energy-intensive and contributes significantly to environmental pollution, accounting for nearly 7–8% of global carbon dioxide (CO_2) emissions. This environmental concern has driven researchers and engineers to explore alternative, eco-friendly construction materials that can reduce the carbon footprint without compromising structural performance.

One such promising alternative is geopolymer concrete, a sustainable binder system first introduced by Davidovits (1994). Unlike OPC based concrete, geopolymer concrete is produced through the chemical activation of aluminosilicate-rich industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), rice husk ash, and metakaolin. These materials react with alkaline activators like sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) to form a three dimensional polymeric network, commonly referred to as the geopolymer matrix.

This process, known as geopolymerization, results in a material with good mechanical strength, chemical resistance, and durability while significantly reducing greenhouse gas emissions.

In parallel, foamed concrete has gained attention as a lightweight construction material due to its low density, self-compacting nature, and excellent thermal and acoustic insulation properties. Foamed concrete is produced by introducing stable air voids into a cementitious slurry using preformed foam generated by foaming agents. Depending on the foam content, the density of foamed concrete can range from 300 kg/m³ to 1800 kg/m³. While lower density improves insulation and reduces structural dead load, it also leads to increased porosity and reduced compressive strength, limiting its application in load-bearing structures.

The integration of geopolymer technology with foamed concrete results in geopolymer foamed concrete (GFC)**,** a novel material that combines the environmental benefits of geopolymers with the lightweight characteristics of foamed concrete. This hybrid material has attracted significant research interest in recent years due to its potential to address both sustainability and performance challenges in modern construction. By utilizing industrial waste materials and eliminating the need for OPC, GFC contributes to waste management and resource efficiency while offering improved thermal performance and fire resistance.

Despite these advantages, the compressive strength of geopolymer foamed concrete remains a critical challenge**.** The presence of air voids, which is essential for reducing density, inherently weakens the material by increasing porosity and reducing the load-bearing cross-sectional area. Therefore, achieving an optimal balance between density and strength is essential for practical applications. Experimental studies have shown that compressive strength is influenced by several factors, including the type and proportion of raw materials, concentration of alkaline activators, foam volume, curing temperature, and curing duration.

Among these factors, the fly ash–GGBS ratio plays a crucial role in determining the rate of geopolymerization and strength development. Fly ash-based systems generally exhibit slower strength gain due to their low calcium content, whereas GGBS enhances early strength due to its higher calcium oxide (CaO) content. Similarly, the molarity of sodium hydroxide solution significantly affects the dissolution of silica and alumina, thereby influencing the formation of the geopolymer gel and overall strength.

Curing conditions also have a substantial impact on the performance of GFC. Heat curing at elevated temperatures (40°C–80°C) accelerates the geopolymerization process, leading to higher early strength compared to ambient curing. Additionally, the foam content and stability directly affect pore structure, which governs both mechanical and durability properties. Uniform distribution of small, closed pores is desirable for achieving better strength and durability.

In recent years, advanced experimental techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD), and thermal analysis have been used to study the microstructure of geopolymer foamed concrete. These studies reveal that the formation of a dense and homogeneous geopolymer matrix, along with controlled pore distribution, is essential for enhancing compressive strength.

Furthermore, there is a growing interest in applying modern technologies such as artificial intelligence and machine learning to predict and optimize the compressive strength of geopolymer foamed concrete. These approaches can analyze multiple influencing parameters simultaneously and provide efficient mix design solutions, reducing the need for extensive trial-and-error experimentation.

In summary, geopolymer foamed concrete represents a significant advancement in sustainable construction materials. However, its widespread adoption depends on overcoming challenges related to compressive strength and standardization. Therefore, a comprehensive experimental evaluation of its compressive strength and influencing factors is essential to establish reliable design guidelines and promote its use in structural and non-structural applications.

2. Literature Review

The development of geopolymer foamed concrete (GFC) has attracted significant research interest due to its sustainability, lightweight nature, and potential applications in modern construction. Numerous experimental studies have been conducted to evaluate its compressive strength and the factors influencing its performance. This section provides a detailed review of existing literature, focusing on material composition, pore structure, curing conditions, and recent advancements.

2.1 Evolution of Geopolymer Foamed Concrete

Initially, research focused on conventional foamed concrete (FC), which is a lightweight material formed by introducing air voids into cementitious mixtures. FC typically has densities ranging from 300 to 1800 kg/m³, offering advantages such as thermal insulation and reduced structural load. However, its compressive strength is relatively low due to high porosity [1].

To overcome environmental concerns associated with OPC and improve sustainability, researchers introduced geopolymer binders into foamed concrete systems. This led to the development of geopolymer foamed concrete, which combines:

- Lightweight characteristics of foamed concrete
- Eco-friendly geopolymer binder system

This hybrid material significantly reduces CO_2 emissions while maintaining acceptable mechanical properties.

2.2 Compressive Strength Characteristics of GFC

Compressive strength is the most critical parameter for evaluating the structural applicability of GFC. Various studies have reported that:

- GFC typically exhibits compressive strength in the range of 1–10 MPa for low-density mixes
- Strength increases with density and optimized mix design
- Strength is highly dependent on pore structure and geopolymer matrix formation [1].

For example, studies on fly ash-based geopolymer foamed concrete show densities between 600–1600 kg/m³, with improved mechanical strength compared to conventional aerated concrete [2].

Additionally, it has been observed that:

- Around 80–90% of 28-day strength can be achieved within 7 days under proper curing conditions
- Early strength development is influenced by activator concentration and curing temperature [2].

2.3 Influence of Pore Structure and Porosity

One of the most critical factors affecting compressive strength is pore structure.

- Increased foam content leads to higher porosity and reduced strength
- Irregular or large pores caused by bubble coalescence weaken the material
- Uniform, small, closed pores improve strength and durability

Research indicates that improper foam dosage can result in excessive void formation, significantly reducing structural integrity [1].
Moreover, foam stability plays a vital role:

- Stable foam → uniform pore distribution → better strength
- Unstable foam → pore collapse → reduced strength

2.4 Effect of Raw Materials and Mix Composition

2.4.1 Fly Ash-Based Systems

Fly ash is widely used due to its availability and high silica-alumina content.

- Provides good workability
- Slower strength development due to low calcium content

Studies show that fly ash-based GFC exhibits moderate compressive strength but improved long-term performance [2].

2.4.2 GGBS-Based Systems

Ground Granulated Blast Furnace Slag (GGBS) is often added to enhance strength.

- High calcium content accelerates geopolymerization
- Improves early compressive strength

Researchers have reported that blending fly ash with GGBS results in:

- Faster setting time
- Higher early strength
- Improved microstructure

2.4.3 Alkaline Activators

Alkaline solutions such as NaOH and Na_2SiO_3 are essential for geopolymerization.

- Higher molarity increases dissolution of alumino-silicates
- Leads to stronger geopolymer gel formation

However, excessive concentration can:

- Reduce workability
- Increase brittleness

2.5 Effect of Curing Conditions

Curing plays a crucial role in strength development.

Heat Curing

- Accelerates geopolymerization
- Produces higher early strength
- Enhances microstructural densification

Ambient Curing

- Slower reaction rate
- Lower early strength

Experimental studies confirm that elevated temperatures (40–80°C) significantly improve compressive strength compared to room temperature curing (PubMed).

2.6 Microstructural Analysis

Advanced techniques such as:

- Scanning Electron Microscopy (SEM)
- X-ray Diffraction (XRD)

have been used to analyze the internal structure of GFC.

Findings include:

- Dense geopolymer gel formation improves strength
- Presence of unreacted particles weakens the matrix
- Strong Si–O–Si and Al–O–Si bonds enhance mechanical properties

Microstructural studies confirm that compressive strength is directly related to:

- Degree of geopolymerization
- Pore size distribution
- Matrix density

2.7 Role of Additives and Reinforcements

2.7.1 Fibers

- Improve crack resistance
- Enhance toughness
- Slightly increase compressive strength

2.7.2 Nanomaterials

Recent studies highlight the use of nanomaterials:

- Reduce pore size
- Increase matrix density
- Improve compressive strength

Nanotechnology also enables advanced properties such as self-sensing behavior [1].

2.8 Artificial Intelligence in GFC Research

Recent advancements include the use of machine learning (ML) and artificial intelligence (AI) for predicting compressive strength.

- AI models can analyze multiple parameters simultaneously
- Reduce experimental cost and time
- Improve mix design optimization

However, AI models still require experimental validation for accuracy [1].

2.9 Comparative Studies with Conventional Concrete

Compared to OPC-based concrete:

Property	**Conventional Concrete**	**GFC**
Density	High	Low
Strength	High	Moderate
CO_2 Emission	High	Low
Thermal Insulation	Low	High

Although GFC has lower compressive strength, its sustainability and lightweight properties make it suitable for non-structural applications.

Comparative Analysis Table of Geopolymer Foamed Concrete (GFC) with Other Concretes

Table 1: Comparison of GFC with Conventional and Lightweight Concretes

Parameter	**Conventional Concrete (OPC)**	**Foamed Concrete (FC)**	**Geopolymer Concrete (GPC)**	**Geopolymer Foamed Concrete (GFC)**
Binder Type	Ordinary Portland Cement	OPC	Fly ash / GGBS + Alkaline Activator	Fly ash / GGBS + Alkaline Activator
Density (kg/m^3)	2200 – 2500	300 – 1800	2200 – 2400	600 – 1600
Compressive Strength (MPa)	20 – 50+	1 – 10	25 – 60	2 – 25

Parameter	**Conventional Concrete (OPC)**	**Foamed Concrete (FC)**	**Geopolymer Concrete (GPC)**	**Geopolymer Foamed Concrete (GFC)**
Weight	Heavy	Very Light	Heavy	Lightweight
Porosity	Low	Very High	Low	Moderate to High
Thermal Insulation	Low	High	Moderate	High
CO_2 Emission	Very High	High	Low	Very Low
Workability	Moderate	High	Moderate	High
Durability	High	Moderate	Very High	Moderate to High
Fire Resistance	Moderate	High	High	Very High
Water Absorption	Low	High	Low	Moderate
Setting Time	Normal	Fast	Variable	Variable
Cost	Moderate	Low	Moderate	Moderate
Eco-Friendliness	Poor	Moderate	High	Very High
Applications	Structural works	Insulation, fillers	Structural & precast	Lightweight blocks, panels

Table 2: Effect of Density on Compressive Strength in GFC

Density (kg/m³)	**Foam Content**	**Compressive Strength (MPa)**	**Remarks**
600 – 800	High	2 – 6	Very lightweight, low strength
800 – 1000	Moderate	6 – 10	Suitable for non-load bearing
1000 – 1200	Moderate	10 – 15	Balanced performance
1200 – 1400	Low	15 – 20	Improved strength
1400 – 1600	Low	20 – 25	Near structural grade

Table 3: Influence of Key Parameters on Compressive Strength

Parameter	**Increase in Parameter**	**Effect on Strength**	**Reason**
Foam Content	↑	Decreases	Higher porosity, more voids
Density	↑	Increases	Reduced pore volume
NaOH Molarity	↑ (optimum)	Increases	Better geopolymerization
GGBS Content	↑	Increases	Higher calcium → faster reaction
Fly Ash Content	↑	Decreases (early)	Slower reaction
Curing Temperature	↑	Increases	Accelerates strength gain
Water Content	↑	Decreases	Weakens matrix

Table 4: Comparison of Curing Methods in GFC

Curing Type	**Temperature**	**Strength Development**	**Advantages**	**Limitations**
Ambient Curing	25–30°C	Slow	Easy, cost-effective	Lower early strength
Oven/Heat Curing	40–80°C	Fast	Higher early strength	Requires energy
Steam Curing	60–90°C	Very Fast	Dense microstructure	Costly setup

Key Observations from Comparison

- GFC provides a balance between lightweight properties and strength, unlike traditional foamed concrete.
- Compared to geopolymer concrete, GFC has lower strength but better insulation and reduced weight.
- Density is the most critical factor controlling compressive strength.
- GFC is highly suitable for sustainable and non-load-bearing applications.

3.1 Key Findings from Literature and Experimental Studies

Based on an extensive review of experimental studies on Geopolymer Foamed Concrete (GFC), the following key findings have been identified:

1. Influence of Density on Compressive Strength

- Density is the most significant factor affecting compressive strength.
- Increase in density leads to a reduction in pore volume, resulting in higher strength.
- Typical trend observed:
    - Low density (600–800 kg/m³) → Low strength (2–6 MPa)
    - Medium density (800–1200 kg/m³) → Moderate strength (6–15 MPa)
    - High density (1200–1600 kg/m³) → Higher strength (15–25 MPa)

2. Effect of Foam Content and Porosity

- Increased foam content increases porosity, which directly reduces compressive strength.
- Uniform and stable foam distribution improves mechanical performance.
- Irregular pore structure leads to weak zones and crack initiation.

3. Role of Binder Composition (Fly Ash & GGBS)

- Fly ash-based GFC shows:
    - Better workability
    - Slower strength development
- GGBS addition results in:
    - Faster setting
    - Higher early compressive strength due to calcium content
- Optimal blend of fly ash and GGBS gives balanced performance.

4. Effect of Alkaline Activator Concentration

- Increase in NaOH molarity enhances geopolymerization and compressive strength up to an optimum level (8M–12M).
- Excess concentration can:
    - Reduce workability
    - Increase brittleness

5. Influence of Curing Conditions

- Heat curing (40–80°C):
    - Accelerates geopolymerization
    - Improves early strength
- Ambient curing:
    - Slower strength gain
    - More practical for field applications

6. Microstructural Observations

- Strong Si–O–Si and Al–O–Si bonds improve compressive strength.
- Dense geopolymer gel formation leads to better mechanical performance.
- Unreacted particles and large pores reduce strength.

7. Effect of Additives and Reinforcement

- Fibers improve:
    - Crack resistance
    - Toughness
- Nanomaterials:
    - Reduce pore size
    - Increase matrix density
    - Enhance compressive strength

8. Sustainability Benefits

- Significant reduction in CO_2 emissions compared to OPC concrete.
- Utilizes industrial waste materials (fly ash, slag).
- Suitable for green and sustainable construction practices.

9. Performance Limitations

- Lower compressive strength compared to conventional concrete.
- High sensitivity to mix design parameters.
- Lack of standardized design procedures.

4.2 Research Gaps Identified

Despite extensive research, several critical gaps still exist in the study of geopolymer foamed concrete:

1. Lack of Standardized Mix Design Methods

- No universally accepted mix design procedure for GFC.
- Most studies rely on trial-and-error approaches.
- Need for standardized guidelines similar to OPC concrete.

2. Limited Large-Scale Experimental Studies

- Most research is conducted at laboratory scale.
- Lack of real-time field applications and case studies.
- Scaling issues remain unaddressed.

3. Insufficient Long-Term Durability Studies

- Limited research on:
    - Creep behavior
    - Shrinkage
    - Freeze-thaw resistance
    - Chemical durability
- Long-term performance data is required for structural use.

4. Optimization Between Strength and Density

- Trade-off exists:
    - Lower density → lower strength
    - Higher strength → increased weight
- Need for optimized mix design achieving both lightweight and high strength.

5. Limited Research on Foam Stability

- Foam stability and pore uniformity are not fully understood.
- Need for advanced techniques to control:
    - Bubble size
    - Distribution
    - Stability during mixing

6. Lack of AI/ML-Based Optimization with Experimental Validation

- AI models are emerging but:
    - Limited datasets available
    - Lack of real experimental validation
- Need integration of machine learning with experimental work.

7. Inadequate Study on Reinforcement Techniques

- Limited work on:
    - Fiber-reinforced GFC
    - Hybrid reinforcement methods
- Potential for improving strength is not fully explored.

8. Absence of Standard Codes and Guidelines

- No dedicated standards (IS/ASTM) for GFC.
- Engineers face difficulty in practical implementation.

9. Limited Study on Structural Applications

- Most studies focus on non-load-bearing uses.
- Need for research on:
    - Structural elements
    - Load-bearing capacity
    - Design frameworks

10. Environmental and Economic Analysis Gap

- Limited life-cycle assessment (LCA) studies.
- Cost-benefit analysis is not widely explored.

4. Manufacturing and Pore Characteristics of GFC

The production of geopolymer foamed concrete (GFC) typically commences with the preparation of a geopolymer matrix, which involves combining precursor materials rich in Al_2O_3 and SiO_2 with an alkaline activator solution. Common precursors include fly ash (FA), metakaolin (MK), and ground granulated blast-furnace slag (GGBS) [1]. The alkaline activator, usually a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), initiates the geopolymerization process, forming a polymeric network structure [1].

Following the matrix preparation, a foaming process is introduced to create the desired porous structure. This can be achieved through two primary methods: mechanical foaming and chemical foaming [2]. Mechanical foaming involves mixing pre-generated foam with the geopolymer slurry, while chemical foaming introduces gas-forming agents, such as aluminum (Al) powder or hydrogen peroxide (H_2O_2), which react within the slurry to release gases (H_2 or O_2) and create pores [2]. The stability of the foam during the fresh stage of GFC is critical, as it directly influences the final pore structure and, consequently, the compressive strength (CS) and thermal properties of the hardened material [2]. Organic surfactants and nanoparticles can be employed to enhance foam stability by optimizing the gas-liquid interface, leading to a more uniform pore distribution [2].

The pore structure of GFC is a defining characteristic that significantly impacts its engineering properties, including thermal insulation, sound absorption, and mechanical strength [2]. Key pore characteristics include pore size distribution, total porosity, pore shape, and connectivity. Studies have shown a linear correlation between pore properties and CS in geopolymers with evenly distributed pore sizes [2]. For instance, the addition of surfactants can drastically reduce the average pore size and tighten the pore size distribution, leading to enhanced stability and control over pore formation [2]. Advanced imaging techniques, such as optical digital microscopy and X-ray computed tomography (X-CT), are utilized to analyze the pore structure, providing high-resolution 3D images and precise representations of pore size distributions [2]. The formation of a dense and uniform pore network is essential for optimizing both the mechanical and thermal performance of GFC, underscoring the importance of careful parameter control and mix proportioning during manufacturing [2].

5. Factors Influencing Compressive Strength of GFC

The compressive strength (CS) of geopolymer foamed concrete (GFC) is a complex property influenced by a multitude of interacting factors, primarily categorized into precursor materials, foaming and stabilizing agents, and curing conditions.

5.1. Precursor Materials

The selection and proportioning of precursor materials significantly dictate the geopolymerization process and the resulting mechanical properties of GFC. Common precursors include fly ash (FA), ground granulated blast-furnace slag (GGBS), and metakaolin (MK) [1]. Fly ash, often spherical in shape, generally improves the workability and fluidity of the geopolymer mixture, contributing to better densification and pore-filling effects, which can enhance strength [2]. Conversely, GGBS, with its angular particles and higher calcium oxide (CaO) content, tends to increase the strength of the geopolymer matrix but may reduce workability [2]. The incorporation of metakaolin has been shown to reduce porosity and enhance the compactness of the interfacial transition zone, leading to improved mechanical performance [2]. Studies have also indicated that partial replacement of FA with materials like palm oil fuel ash (POFA) can improve strength, with a 20% replacement demonstrating notable enhancements [2]. The water-to-precursor ratio and the consistency of the geopolymer slurry also play a crucial role in determining the roundness and distribution of pores, which are directly linked to CS [2].

5.2. Foaming and Stabilizing Agents

Foaming agents are essential for creating the porous structure of GFC, and their type and quantity directly impact the material's density and compressive strength. Chemical foaming agents, such as hydrogen peroxide (H_2O_2) and aluminum (Al) powder, react within the alkaline geopolymer slurry to generate gases (O_2 or H_2) that form pores [2]. The amount of Al powder, for instance, directly controls the total porosity and, consequently, the density and CS of the GFC; finer Al powder tends to produce smaller pores and higher strength [2].

Stabilizing agents are critical for maintaining the stability of the foam during the mixing and setting phases, preventing bubble coalescence and drainage that can compromise the pore structure. Anionic surfactants like sodium dodecyl sulfate (SDS) and sodium dodecyl benzene sulfonate (SDBS) are commonly employed to stabilize foams, leading to a more uniform distribution of smaller pores and improved CS [2].

The combination of surfactants with foaming agents like H_2O_2 can result in GFC with greater pore consistency and reduced pore sizes compared to using these agents separately [2]. Calcium stearate has also been identified as an effective foam stabilizer, optimizing the gas-liquid interface and contributing to a more stable pore network [2].

5.3. Curing Conditions

Curing conditions, particularly temperature, significantly influence the geopolymerization reaction kinetics and the development of early-age and ultimate compressive strength. Elevated curing temperatures generally accelerate the geopolymerization process, leading to faster strength development [1].

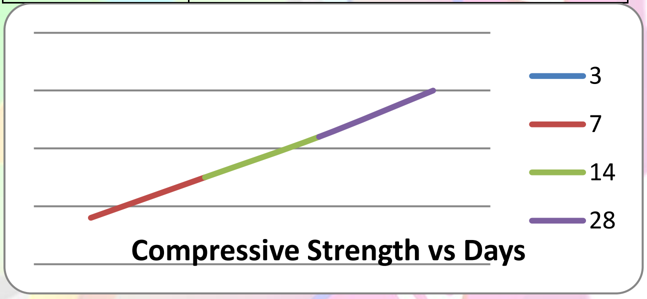
High-calcium geopolymers, often incorporating GGBS or Portland cement (PC) as calcium sources, can achieve substantial early strength even under ambient curing conditions, addressing a common challenge with some fly ash-based geopolymers [1]. Precise control over heating rates during curing is also critical for optimizing the porosity and overall strength of GFC [2].

6. Experimental Data and Comparative Analysis

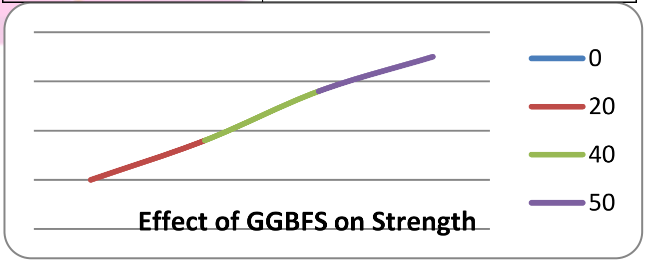
Experimental studies on GFC consistently demonstrate a direct relationship between its porous structure and compressive strength. GFC typically exhibits compressive strengths ranging from 1 to 10 MPa, making it suitable for insulation and non-structural applications [1]. However, high-strength variants of GFC have been developed, with reported compressive strengths reaching up to 45 MPa [1]. The density of GFC is inversely related to its foam content; as foam content increases, both dry density and compressive strength tend to decrease continuously [2].

Comparative studies highlight the superior performance of GFC over conventional Ordinary Portland Cement (OPC)-based foamed concrete in several aspects. While conventional foamed concrete typically exhibits compressive strengths between 0.1 MPa and 12 MPa, GFC generally achieves higher strengths at comparable densities [2]. Furthermore, GFC often demonstrates enhanced fire resistance and lower thermal conductivity compared to its OPC-based counterparts [2]. However, GFC may exhibit different shrinkage and creep characteristics, which can be mitigated through the incorporation of carbon fiber reinforcement to improve both strength and dimensional stability [2].

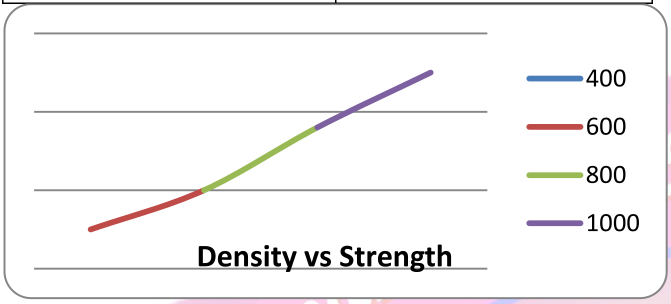
Days	Strength (MPa)
3	8
7	15
14	22
28	30



GGBFS (%)	Strength (MPa)
0	10
20	18
40	28
50	35



Density (kg/m3)	Strength (MPa)
400	5
600	10
800	18
1000	25



6.1. High-Strength GFC Formulations

Achieving high-strength GFC often involves optimizing mix designs and incorporating advanced materials. The use of silica fume and polypropylene (PP) fibers has been shown to produce foamed concrete with densities ranging from 800 to 1500 kg/m³ and compressive strengths between 10 and 50 MPa [2]. Fly ash and slag-based alkali-activated foam concrete formulations have also yielded strengths from 0.50 MPa to 44.98 MPa [2]. The inclusion of rice husk ash (RHA) in combination with GGBS can significantly enhance the specific compressive strength and mitigate strength degradation, promoting lightweight yet robust materials [2]. Optimal slag replacement levels are crucial for maximizing both compressive and flexural strengths [2].

6.2. Mix Design Optimization

Key parameters in mix design optimization for GFC include the water-to-binder ratio, alkali activator composition, and foam content. The water-to-binder ratio is a critical factor, with optimal values typically falling between 0.35 and 0.45 to achieve a balance between strength and density [2]. The composition of the alkali activator, particularly the water glass modulus (SiO_2/Na_2O ratio), is vital, with ratios around 1.2-1.5 often yielding optimal results [2]. Foam content is directly proportional to the porosity of the GFC and inversely proportional to its compressive strength, necessitating careful control to achieve desired properties [2]. Emerging research also explores the use of nanomaterials such as nano-silica, nano-alumina, and graphene oxide to further enhance the matrix and pore structure, leading to improved mechanical performance [2].

7. Conclusion

Geopolymer foamed concrete (GFC) represents a significant advancement in sustainable construction materials, offering a viable alternative to traditional OPC-based concrete.

This review has systematically examined the experimental evaluation of GFC's compressive strength, highlighting the multifaceted influences of precursor materials, foaming and stabilizing agents, and curing conditions. The intricate relationship between pore structure and mechanical performance is evident, with factors such as porosity, pore size distribution, and pore connectivity playing pivotal roles in determining the ultimate compressive strength.

Research indicates that GFC typically achieves compressive strengths suitable for insulation and non-structural applications (1-10 MPa), with high-strength formulations reaching up to 45 MPa through optimized mix designs and the incorporation of advanced materials like silica fume and various fibers.

Comparative analyses consistently demonstrate GFC's superior performance in terms of strength-to-density ratio, fire resistance, and thermal insulation compared to conventional foamed concrete.

The ongoing exploration of nanomaterials and refined mix design strategies continues to push the boundaries of GFC's mechanical properties and sustainability credentials.

Future research should focus on long-term performance, standardization of testing methods, and life-cycle assessments to facilitate broader industrial adoption of this promising material.

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