

Fly Ash and GGBS-based Geopolymer Concrete and Its Water Absorption Capacity: A Comparative Study with Conventional Concrete

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ABSTRACT

Geopolymer concrete (GPC) has emerged as a promising alternative to conventional concrete (CC) made with Portland cement. GPC has Fly ash and GGBS in a 70:30 ratio along with alkali activators Sodium hydroxide (NaOH) and sodium trisilicate (Na₂SiO₃). This study focuses on a comparative analysis of the water absorption capacity of GPC and CC. The results from the comparative study deduce that both types of concrete perform equivalently in terms of strength and durability, with slight differences in water-absorbing characteristics. The study suggests that further research and development are essential to further optimize GPC's properties and expand its applications in diverse construction scenarios. The findings are expected to demonstrate the potential for GPC to offer enhanced durability and reduced environmental impact, thereby supporting the transition toward more sustainable construction practices.

Keywords: Geopolymer concrete, Fly ash, GGBS, Water absorption Durability

INTRODUCTION

Conventional concrete, which primarily consists of Portland cement as a binder, has a significant environmental impact. The production of Portland cement is energy-intensive and releases a substantial amount of carbon dioxide (CO₂) into the atmosphere, contributing approximately 8% of global CO₂ emissions. This environmental concern has spurred research into alternative materials and methods that can reduce the carbon footprint of concrete production. Geopolymer concrete (GPC) has emerged as a promising alternative to conventional concrete (CC) (Rangan, 2014) (Lloyd & Rangan, 2009). Unlike CC, which relies on Portland cement, GPC uses industrial by-products such as fly ash, slag, and metakaolin as binding materials. These materials are rich in aluminosilicates, which, when activated by alkaline solutions (typically a combination of sodium hydroxide and sodium silicate), form a geopolymeric binder. This binder exhibits excellent mechanical properties and durability while. The use of industrial by-products also promotes recycling and reduces the need for landfills, further enhancing the sustainability of GPC. One of the critical parameters affecting durability and performance of concrete is its water absorption capacity. Water absorption in concrete is directly related to its porosity and permeability. High water absorption can lead to increased permeability, which allows aggressive agents such as chlorides, sulfates, and carbon dioxide to penetrate the concrete (Alomayri,



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et al., 2014). This can result in deterioration mechanisms such as corrosion of reinforcement, freeze-thaw damage, and chemical attacks, ultimately reducing the service life of the concrete structure. The water absorption capacity of concrete is influenced by several factors, including the mix design, curing conditions, and the nature of the binder. Conventional concrete typically has a porous microstructure due to the formation of capillary pores during the hydration process of Portland cement. In contrast, geopolymer concrete is known for its dense microstructure, which results from the polymerization process of the aluminosilicate materials (Habert, Lacaillerie, & Roussel, 2011). This dense microstructure is expected to exhibit lower water absorption compared to conventional concrete. This study focuses on a comparative analysis of the water absorption capacity of geopolymer concrete and conventional concrete. By comparing the water absorption capacity of GPC and CC, this study aims to provide insights into the durability performance of geopolymer concrete. The findings are expected to demonstrate the potential of GPC to offer enhanced durability and reduced environmental impact, thereby supporting the transition towards more sustainable construction practices. Further research will be suggested to explore the long-term performance of GPC under various environmental conditions and its applicability in different construction scenarios.

LITERATURE REVIEW

Geopolymer concrete (GPC) represents a significant advancement in sustainable construction materials. Its formation process involves the reaction of aluminosilicate materials, like fly ash, slag, or metakaolin, with alkaline solutions, typically comprising sodium hydroxide and sodium silicate. This chemical reaction, known as geopolymerization, results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al bonds (Ghosh, Kumar, & Kumar, 2013). This structure imparts several advantageous properties to geopolymer concrete, positioning it as a viable alternative to conventional concrete (CC) made with Portland cement (Hardjito & Rangan, 2005).

One of the primary benefits of geopolymer concrete is its high early strength. Unlike conventional concrete, which requires a longer curing period to reach its full strength, GPC can achieve significant strength within a shorter time frame. This is due to the rapid polymerization process that occurs at ambient or elevated temperatures, leading to the formation of a dense and cohesive matrix. Studies have demonstrated that GPC can attain compressive strengths comparable to, or even exceeding, those of conventional concrete within 24 hours of curing (Manjunatha, Radhakrishna, Venugopal, & Maruthi, 2014). This characteristic makes GPC particularly suitable for applications where rapid strength development is crucial, such as in precast elements and emergency repairs. Fly ash has very varied quality and it depends on the type of

Importance of Water Absorption

High water absorption in concrete is problematic because it can lead to several durability issues. Water entering the concrete can freeze and expand if the ambient temperature drops below freezing. This freeze-thaw cycle can cause the concrete to crack and spall, reducing structural integrity (Pravallika & Lakshmi, 2014). Additionally, water can carry harmful chemicals such as chlorides and sulfates into the concrete matrix. These chemicals can attack the reinforcing steel, causing corrosion, and react with the concrete itself, leading to expansive reactions and further degradation. Another critical issue associated with high water absorption is the potential for chemical attack. In aggressive environments,

such as industrial settings or marine conditions, concrete can be exposed to acidic or sulfate-rich solutions (Olivia & Nikraz, 2011). High water absorption allows these aggressive agents to penetrate deeper into the concrete, accelerating the rate of chemical attack and compromising the concrete's integrity. Over time, this can lead to significant structural damage and costly repairs (Pravallika & Lakshmi, 2014). Conventional concrete, which is primarily composed of Portland cement, water, and aggregates, typically exhibits higher water absorption compared to alternative materials like geopolymer concrete. The hydration process of Portland cement creates a microstructure that includes capillary pores. These pores form due to the excess water required for the hydration reaction and the chemical shrinkage that occurs as the cement hydrates. The capillary pores in conventional concrete are interconnected, providing pathways for water and other fluids to penetrate the material (Aleem & Arumairaj, 2012).

The presence of these capillary pores makes conventional concrete more porous and permeable. As a result, it tends to absorb more water, which increases its vulnerability to freeze-thaw cycles and chemical attacks. The extent of water absorption in conventional concrete is influenced by several factors, including the water-cement ratio, the type and size of aggregates, the degree of compaction, and the curing conditions. Higher water-cement ratios generally lead to increased porosity and water absorption (Vora & Dave, 2013). The durability of concrete is closely linked to its ability to resist water penetration. Low water absorption is indicative of a dense microstructure with fewer and less interconnected pores. This enhances the concrete's resistance to freeze-thaw cycles, as there is less water available to freeze and cause internal stresses. It also improves the concrete's resistance to chemical attack, as aggressive agents are less likely to penetrate deep into the material.

For conventional concrete, achieving low water absorption typically involves optimizing the mix design and employing supplementary cementitious materials (SCMs) such as fly ash, slag, or silica fume (Wallah & Rangan, 2006). These SCMs help to refine the pore structure and reduce porosity, thus lowering water absorption. Proper curing practices are also essential to ensure that the concrete develops a dense and durable microstructure. Fly ash properties usually vary from place to place depending on the type of coal used and collection method hence it is important to check the water absorption capacity of GPC concrete with fly ash. In studies it has been found that FA to GGBS ratio of 70:30 works well for GPC along with NaOH: Na₂SiO₃ ratio of 1:2.5. In this study an attempt is made to compare the water absorption capacity of GPC and CC.

MATERIALS USED IN GEOPOLYMER CONCRETE

The primary components of GPC are fly ash and GGBS. Fly ash, a by-product of coal combustion, is rich in aluminosilicates, making it an ideal precursor for geopolymerization. GGBS, a by-product of iron production, also contains significant quantities of aluminosilicates, contributing to the mechanical properties and durability of the concrete (Aleem & Arumairaj, 2012). The typical mix proportion for GPC involves a blend of 70% fly ash and 30% GGBS. GPC incorporates recycled aggregates derived from crushed concrete. This practice not only diverts construction waste from landfills but also reduces the demand for natural aggregates. Recycled aggregates must be carefully selected and processed to ensure they meet the quality requirements for concrete production. For GPC Normal Aggregates and Recycled aggregates are taken in a ratio of 70:30.

The geopolymerization process requires alkaline activators, typically a combination of sodium hydroxide (NaOH) and sodium trisilicate (Na₂SiO₃). Sodium hydroxide solution is 10 M which works well according to previous research works. Sodium trisilicate acts as a source of additional silica, promoting the polymerization of the aluminosilicate precursors. The ratio of sodium hydroxide to sodium trisilicate is crucial for the mix's performance and is generally maintained at approximately 2.5 by mass.

MIX DESIGN APPROACH

The absence of a standardized method for geopolymer concrete mix design necessitates an empirical approach. Practitioners often base their mix proportions on the principles of conventional concrete mix design, adjusting for the different chemical nature of the materials involved. The Indian Standard IS 10262:2019 provides guidelines for conventional concrete mix design. While these guidelines do not directly apply to GPC, they offer a framework that can be adapted. Key parameters such as water-binder ratio, aggregate proportions, and workability requirements are adjusted based on experimental results and prior research findings.

Water-Binder Ratio: The water-binder ratio in GPC is typically lower than in conventional concrete, around 0.4 by mass, due to the low water demand of the geopolymerization process. This ratio ensures sufficient workability while minimizing excess water that could lead to increased porosity.

Aggregate Proportions: The proportions of coarse and fine aggregates in GPC are derived from conventional concrete mix proportions based on (Albitar, Visintin, Ali, & Drechsler, 2015) (Rangan, 2014) (Hardjito & Rangan, 2005) (Habert, Lacaillerie, & Roussel, 2011) (Ariffin, Hussin, & Bhutta, 2011) (Vora & Dave, 2013) (Lloyd & Rangan, 2009) (Ghosh, Kumar, & Kumar, 2013) (Wallah & Rangan, 2006) the specific gravity of aggregates, but adjusted to account for the different packing characteristics and workability requirements of the recycled aggregates and M sand. Ensuring a well-graded aggregate mix is crucial for achieving the desired mechanical properties and durability.

Table1: Material Proportion and Quantity calculations

Materials	Quantity kg/m ³
Fly Ash (70%)	280
GGBS (30%)	120
Na ₂ SiO ₃	128.5
NaOH	51.4
M-Sand	680
Coarse Aggregate (70%)	690.9
Recycled Aggregate (30%)	296.1
Superplasticizer	1.5% of binder

Casting and Curing: For Casting all the ingredients were mixed in dry form and then alkali activators were added in place of water for GPC and naphthalene-based superplasticizer was added at 1.5% of total binder content. Mechanical mixing is required to mix the activators because of its gel-like nature.

Here Alkali activator to binder ratio is taken as 0.4. The Water-to-cement ratio is kept constant for 0.4. After casting the concrete was filled in the cubes and kept for setting up for 24 hours. After 24 hours both GPC and CC were cured in respective curing methods. GPC is cured under room temperature for 28 days and periodically sprinkled with water to avoid surface shrinkage whereas CC is cured with submersion method for 28 days.

Testing Method

Specimens were dried in an oven at 105°C until constant weight, submerged in water for 24 hours, 48 hours, and 72 hours, and weighed again to determine the water absorption percentage. This method was followed for both GPC and CC, a 100x100x100 mm size cube is used for testing.

RESULTS AND DISCUSSIONS

The results from the comparative study between geopolymer concrete (GPC) and conventional concrete (CC) indicate that both types of concrete perform equivalently in terms of strength and durability, with slight differences in water absorption characteristics. The density of GPC is lower than CC, resulting from the lower specific gravity of FA and GGBS. The water absorption capacity of both GPC and CC was tested to determine their porosity and permeability, critical factors influencing durability. Table 2 shows the initial weight and weight after 24, 48, and 72 hours of submersion in water.

Table 2: Water Absorption at 24 hours, 48 hours and 72 hours.

Sl.No.	Concrete	Initial Weight (grams)	Weight (grams) after		
			24 Hours	48 hours	72 Hours
1	GPC	2210	2310	2310	2310
2	CC	2440	2530	2530	2530

The water absorption was measured at 4.5% for GPC and 3.8% for CC. These values show that GPC has a slightly higher water absorption rate than CC. However, both types of concrete exhibit water absorption rates that are within acceptable limits for structural applications.

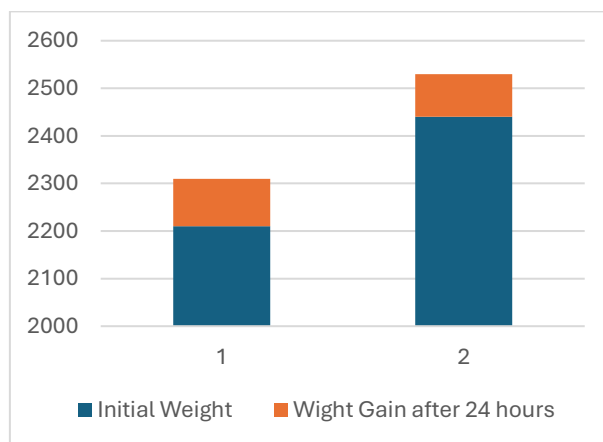


Figure 1: Variation of the weight of GPC and CC

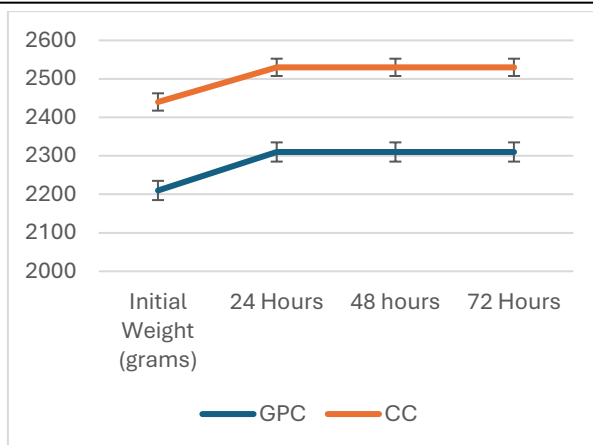


Figure 2: Water absorption over 24 hours, 48 hours and 72 hours

In both cases, after 24 hours weight of the specimen remained constant indicating that in the first 24 hours, the samples were saturated. Indicating lower porosity.

Porosity and Permeability: The higher water absorption in GPC (4.5%) compared to CC (3.8%) can be attributed to the microstructural differences between the two materials. GPC tends to have a more interconnected pore structure due to the nature of the geopolymerization process, which can result in slightly higher permeability. Despite this, the difference is marginal and does not significantly impact the overall performance of GPC in most applications.

Durability Implications: Lower water absorption in CC suggests slightly better resistance to freeze-thaw cycles and chemical attacks, as less water is available to penetrate and cause damage within the concrete matrix. However, the 4.5% absorption rate in GPC is still relatively low, indicating good resistance to environmental factors and adequate durability for most structural purposes.

CONCLUSIONS

The comparative study found that geopolymer concrete performs similarly to conventional concrete in terms of strength and durability. This equivalence is crucial as it suggests that GPC can be used effectively in structural applications without compromising performance. GPC has a slightly higher water absorption rate (4.5%) compared to conventional concrete (3.8%). While this difference exists, it is relatively minor and manageable, indicating that GPC still maintains adequate durability characteristics. One of the significant advantages of GPC highlighted in the study is its environmental benefits. Geopolymer concrete typically has lower carbon emissions compared to conventional concrete due to its lower requirement for cement, which is a major source of greenhouse gases in cement production. The study suggests that further research and development could optimize the properties of GPC. This optimization could focus on enhancing its strength, reducing water absorption further, and improving workability to broaden its applicability across different construction scenarios. Despite the slightly higher water absorption rate, GPC remains a promising alternative to conventional concrete. Its adequate durability, coupled with environmental benefits, makes it an attractive choice for sustainable construction practices. As research continues to refine its properties, GPC could potentially become more widely adopted in construction projects seeking to reduce environmental impact without compromising on performance. While geopolymer concrete

exhibits minor differences such as a slightly higher water absorption rate compared to conventional concrete, its overall performance in terms of strength, durability, and environmental impact positions it as a viable and promising alternative. Continued research and development are essential to further optimize GPC's properties and expand its applications in diverse construction scenarios.

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