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A REVIEW ON ULTRAFINE FLY ASH-BASED GEOPOLYMER CONCRETE

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ABSTRACT

Research is ongoing to improve the workability, strength, and durability of geopolymer concrete at ambient curing conditions. Investigations into hybrid binders, combining ultrafine fly ash with other pozzolanic materials such as slag or silica fume, may further enhance the performance of geopolymer concrete. Additionally, efforts to reduce the cost of alkaline activators will be critical to the broader adoption of this material. The cost of the alkaline activators used in geopolymer production (sodium hydroxide and sodium silicate) can be higher than traditional cement. The lack of standardized mix designs and guidelines for geopolymer concrete creates challenges in widespread adoption. Heat curing requirements may limit its use in some construction applications, though ongoing research into ambient curing is promising.

Keywords: Workability, Strength, Durability, Geopolymer Concrete, alkaline activators

1. INTRODUCTION

Ultrafine fly ash-based geopolymer concrete is an emerging alternative to traditional Ordinary Portland Cement (OPC) concrete, addressing the need for sustainable construction materials. The growing environmental concerns surrounding cement production, which is responsible for significant CO_2 emissions, have driven the interest in geopolymer binders. Fly ash, a byproduct of coal combustion, is particularly advantageous in this context due to its availability and pozzolanic properties. Ultrafine fly ash, characterized by smaller particle sizes, further enhances the performance of geopolymer concrete by improving workability, strength, and durability.

Geopolymer Concrete: A Sustainable Alternative

Geopolymers are aluminosilicate materials formed by the polymerization of alumina and silica in alkaline environments. When fly ash is activated with an alkaline solution (usually a combination of sodium hydroxide and sodium silicate), it reacts to form a three-dimensional network of aluminosilicate, which acts as a binder in geopolymer concrete. This process, unlike OPC production, does not require high-temperature calcination, thus significantly reducing greenhouse gas emissions. The use of ultrafine fly ash as the main binder in geopolymer concrete offers several benefits over standard fly ash, including faster chemical reactions during the geopolymerization process, higher compressive strengths, and improved microstructure.

Mechanical Properties

Compressive Strength: Ultrafine fly ash enhances the compressive strength of geopolymer concrete. The smaller particle size allows for better packing and a denser microstructure, which leads to higher strength. Studies have shown that compressive strength can reach up to 60 MPa and beyond, depending on the mix design and curing conditions.

Flexural Strength: The flexural strength of ultrafine fly ash-based geopolymer concrete is superior to that of conventional fly ash geopolymer concrete, owing to the improved bond between particles.

Tensile Strength: Like flexural strength, tensile strength is also enhanced due to the increased reactivity of ultrafine particles and the resulting denser matrix.

Durability

Resistance to Sulfate and Chloride Attack: Ultrafine fly ash-based geopolymer concrete shows excellent resistance to chemical attacks, such as sulfate and chloride exposure. This makes it suitable for structures in aggressive environments, such as marine or industrial settings.

Permeability: The dense matrix resulting from the use of ultrafine fly ash reduces the permeability of the concrete, making it more durable and less prone to water ingress and related issues like corrosion of reinforcement.

High-Temperature Resistance: Geopolymer concrete has shown superior fire resistance compared to OPC-based concrete. The ultrafine fly ash-based geopolymer further enhances this property, withstanding temperatures of up to 800°C to 1200°C.

Workability

Ultrafine fly ash improves the workability of the mix due to its small particle size and spherical shape. This allows for better flow and compaction without requiring excessive water, which would otherwise reduce strength.

2. CURING METHODS

Curing plays a crucial role in the development of strength in geopolymer concrete. Heat curing is often employed for fly ash-based geopolymers, typically at temperatures between 60°C and 90°C for periods ranging from 24 to 48 hours. This accelerates the polymerization process, yielding higher early-age strength. However, ambient curing methods are also being researched, especially for applications where heat curing is impractical.

Arnab Kumar Sinha et al (2023) study on the development of Geopolymer Concrete (GPC) using ultrafine ground granulated blast furnace slag (UBFS) blended with fly ash (FA) and sodium hydroxide (SH) activator is quite comprehensive. It addresses several key factors influencing both fresh and hardened properties of GPC, including bond strength with Portland cement concrete (PCC). The sodium hydroxide concentration (molarity) plays a significant role in the strength and bonding properties of GPC. Higher molarity increases the degree of polymerization but might affect adhesion with PCC. The s/a ratio of 0.41 was found to be ideal, balancing workability, minimizing segregation and bleeding, and improving the overall packing of the GPC, leading to enhanced mechanical properties. High volume UBFS in GPC enhances the reaction products, yielding better mechanical performance even at lower alkali concentrations. GPC exhibited strong adhesion to PCC substrates. However, the molarity of the SH activator influences the bond strength, with lower molarity providing better adhesion. The use of UBFS results in denser microstructures, as observed through Field Emission Scanning Electron Microscopy (FESEM). This contributes to the improved strength of GPC. X-ray diffraction (XRD) analysis reveals the formation of better reaction products, confirming the beneficial impact of UBFS on the GPC matrix. The study identified the importance of fine aggregate to total aggregate ratio in managing workability and controlling bleeding, with the optimal ratio enhancing fresh properties and contributing to better compaction. This research underlines the viability of GPC with high-volume UBFS as a sustainable and high-performance alternative to ordinary Portland cement, with potential applications in construction where strong adhesion with existing PCC substrates is required.

A. Chithambar Ganesh et al (2023) this study focuses on the development of sustainable geopolymer concrete (GPC) by incorporating industrial waste materials such as Ground Granulated Blast Furnace Slag (GGBS) and ultra-fine Rice Husk Ash (URA). By partially substituting GGBS with URA in varying proportions (0%, 5%, 10%, 15%, and 20%), the study evaluates key performance metrics including workability, drying shrinkage, compressive strength, and tensile strength across a range of concrete ages (from 7 to 90 days). Additionally, the study incorporates microstructural analysis using Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) to investigate the internal structure of the geopolymer matrix. The findings highlight significant improvements in both workability and mechanical properties—particularly compressive and tensile strength—with the 15% URA substitution. The drying shrinkage also showed a decrease at this substitution level. From a microstructural perspective, the results demonstrate a dense and compact matrix, indicating the formation of a strong bond between the calcium-based and sodium-based products within the geopolymer matrix. This suggests enhanced structural integrity due to the interaction between the alkali activator and the fine URA particles. The sustainability analysis, which looked at factors such as cost efficiency, energy efficiency, and CO_2 emissions, revealed that utilizing 15% URA in GPC offers increased economic and environmental benefits. The reduction in energy consumption and carbon footprint points to the viability of GPC as a more sustainable alternative to conventional Portland cement concrete. The study concludes that the inclusion of URA in geopolymer concrete offers significant potential for reducing environmental impact and advancing eco-friendly construction practices.

Kumar Vishal et al (2022) sustainable construction materials research—geopolymer concrete (GPC), particularly the role of fly ash and ground granulated blast furnace slag (GGBS). As the world faces challenges in reducing greenhouse gas emissions and conserving natural resources, GPC has emerged as a potential solution. The blend of GGBS with fly ash in geopolymer mixtures significantly influences the material's properties, particularly its compressive strength. The inclusion of varying amounts of GGBS (ranging from 0% to 100%) in fly ash-based GPC significantly improves compressive strength. This is due to the enhanced reactivity of GGBS compared to fly ash alone, which accelerates the geopolymerization process. The study explores how increasing the volume of AAS (comprising sodium silicate and sodium hydroxide solutions) affects the compressive strength of the concrete. A key observation was that more AAS, particularly sodium silicate, resulted in higher strength. The experiments fixed the sodium hydroxide concentration at 10M (molar), and the results indicated that with a constant sodium hydroxide concentration, the increase in sodium silicate volume in the AAS contributed to strength gains. The study is particularly relevant since the geopolymer concrete was cured at ambient temperatures, making it more practical for construction in various climates, compared to the traditional heat-curing methods often used for GPC. this research suggests that fly ash-based geopolymer concrete can achieve higher compressive strength when GGBS is added and the sodium silicate content is increased in the AAS mix, even at ambient temperatures. These findings have significant implications for developing environmentally friendly construction materials with enhanced performance.

S. Nagajothi et al (2022) study delves into the durability of G30 grade geopolymer concrete (GPC) produced from fly ash and Ground Granulated Blast Furnace Slag (GGBS) activated by alkaline solutions, with manufactured sand as a river sand substitute. The durability of GPC is compared to conventional concrete through various tests, including. This evaluates the concrete's performance in acidic environments, crucial for its longevity in harsh conditions. Conducted at 28, 56, and 90 days, this test determines how much water the concrete absorbs, reflecting its porosity and long-term durability. Using sodium sulphate, this test assesses concrete's resistance to sulphate attack, which can cause expansion and cracking. This measures the concrete's ability to resist chloride ions, vital for assessing its corrosion resistance in chloride-rich environments. This test determines the rate at which concrete absorbs water, which is important for evaluating its vulnerability to moisture ingress. Geopolymer concrete demonstrated superior resistance to acid and sulphate attacks compared to conventional concrete. The water absorption and compressive strength loss were lower in GPC, indicating better long-term durability. Chloride penetrability and the rate of absorption in GPC were comparable to conventional concrete. The regression analysis of the rate of absorption test for both concrete types showed a strong relationship between absorption and the square root of time.

Priyanka Pradhan et al (2022) Geopolymer concrete (GPC) offers a sustainable alternative to Ordinary Portland Cement (OPC) based concrete due to its lower carbon footprint, as the production of OPC releases large amounts of CO_2, contributing to environmental damage. GPC, made from industrial waste materials like fly ash and slag, has been gaining attention for its superior performance in both fresh and hardened states. However, despite its promising properties, GPC has not yet achieved widespread global acceptance, largely due to concerns about its long-term durability and lack of standardized information. Over the past three decades, extensive research has been conducted on the durability of GPC, revealing insights into twelve critical durability characteristics. The capacity of GPC to withstand loads tends to increase with time, often exceeding OPC-based concrete. While generally lower than compressive strength, GPC shows a similar behavior to OPC concrete in its ability to resist tension. GPC displays favorable flexural strength, making it suitable for structural applications requiring resistance to bending. GPC generally exhibits lower permeability, enhancing its durability against water and chemical ingress. Studies have demonstrated that GPC resists chloride ion penetration, which helps in reducing the risk of corrosion of reinforcement in concrete structures. GPC is found to be highly resistant to sulphate attacks, making it more durable in aggressive environmental conditions. Carbonation, which affects the long-term durability of concrete, is generally low in GPC, contributing to its extended lifespan.

Gholamreza Pazouki et al (2022) study highlights the growing interest in using geopolymer concrete (GPC) as a sustainable alternative to traditional concrete, with a particular focus on fly ash-based geopolymer concrete (FAGC)**.** By replacing cement with **fly ash** and other industrial by-products, FAGC offers multiple environmental benefits. Data from 360 samples of FAGC were analyzed, and the statistical performance of these models was compared to experimental test results. Although all three models exhibited reliable prediction accuracy, the RBFNN with ACO outperformed the others in terms of precision and overall performance. underscores the potential of machine learning models to improve the efficiency and effectiveness of designing sustainable construction materials like geopolymer concrete**.** This approach offers a promising avenue for optimizing concrete properties and promoting eco-friendly construction practices.

Enzo Martinelli et al (2022) provides a comprehensive summary of the benefits and potential of geopolymer concrete, focusing on its durability and environmental advantages compared to Ordinary Portland Cement (OPC) concrete. By highlighting the geopolymerization process, you emphasize the integration of aluminosilicate sources, like metakaolin and fly ash, with an alkaline activator to produce a geopolymer binder. Geopolymer concrete has a smaller environmental impact due to its reduced thermal energy requirements during production. The article effectively demonstrates the resilience of geopolymer concrete, especially in resisting heat and chemical aggression, with enhancements from additives such as micro-silica and fibers like polypropylene. Geopolymer concrete's medium to low chloride ion penetrability and resistance to acid attack indicate its potential for long-term durability in harsh environments. Elevated temperatures enhance its compressive strength, making it an ideal material for structures exposed to high thermal loads. this article aligns with the current research interest in the durability and eco-friendliness of geopolymer concrete, supporting its adoption as a sustainable alternative to OPC concrete in the construction industry.

Vijayasarathy Rathanasalam et al (2020) The incorporation of ultrafine ground granulated blast-furnace slag (UFGGBFS) along with fly ash and crushed-stone sand in geopolymer concrete (GPC) shows promising results for industrial by-products, aligning with sustainable construction practices. Your study highlights the performance of GPC under different molarities (10M, 12M, 14M) of the alkaline solution. The addition of UFGGBFS significantly enhances the compressive strength of GPC due to improved binding and the densification of the material. GPC specimens exhibited increased flexural strength, indicating that UFGGBFS contributes to better crack resistance and load-bearing capacity. Similar to compressive and flexural strength, an increase in molarity improves tensile properties, making GPC a viable alternative for tensile load applications. The addition of UFGGBFS reduced water absorption rates, pointing to better durability and reduced porosity. The presence of UFGGBFS improves the microstructure of GPC by refining the ITZ, which is crucial for enhancing mechanical properties. The study supports that GPC with UFGGBFS and fly ash can serve as a sustainable alternative to conventional cement-based concrete, especially when optimizing the molarity of the alkaline solution, which influences the strength gains. This aligns with current trends in reducing reliance on Ordinary Portland Cement (OPC) and promoting eco-friendly construction materials.

Herwani et al (2018) the study you described investigates the effects of sodium hydroxide (NaOH) molarity on the compressive strength of fly ash-based geopolymer concrete. The experimental procedure involved varying the molarity of the alkaline activator solution (AAS), specifically sodium hydroxide, to determine its influence on compressive strength. To assess the effect of different NaOH concentrations (10 M, 12 M, 14 M) on the compressive strength of geopolymer concrete. Increasing the molarity of the sodium hydroxide solution led to higher compressive strength in geopolymer concrete. A 12 M NaOH solution yielded the highest compressive strength, suggesting it is the optimal concentration under these experimental conditions. Despite the molarity increase improving strength, the geopolymer concrete reached only 50-60% of the planned strength. This highlights the need for further refinement in mix design or curing methods to achieve target performance levels. The experiment demonstrated that alkaline activator **c**oncentration significantly influences the compressive strength of geopolymer concrete. However, while the 12 M NaOH solution provided the optimal results in this context, the material's overall strength still fell short of expectations, possibly due to factors such as the mix proportions, curing conditions, or the type of fly ash used. Investigating other factors like curing temperature**,** activator ratios**, or** different alumino-silicate sources**.** Optimizing the mix design to improve the overall performance, especially to meet or exceed conventional concrete's strength.

Manvendra Verma et al (2017) The rise in global infrastructure demands has led to an increased reliance on Portland cement concrete, yet this has also escalated concerns over its environmental impact, particularly in terms of durability issues and carbon dioxide emissions. The production of Portland cement is a major contributor to CO_2 emissions, making it essential to find more sustainable alternatives. One such promising alternative is Geopolymer Concrete, which replaces cement with pozzolanic materials rich in silicon and aluminum, such as fly ash. Fly ash is a byproduct from coal combustion at thermal power plants, and around 120 million tons are generated annually in India alone. The disposal of this fly ash is a significant environmental challenge, and its recycling in geopolymer concrete offers a solution. By incorporating fly ash and other industrial by-products, geopolymer concrete not only helps in waste management but also reduces the reliance on Portland cement, thereby cutting down carbon emissions. The key to geopolymer concrete lies in alkali activation of aluminosilicates, which leads to the formation of a strong, durable binder that can replace traditional cement. This method makes geopolymer concrete not only environmentally friendly but also technically superior in certain aspects, such as higher resistance to chemical attack and better durability. This brief review highlights the benefits of geopolymer technology, its potential to revolutionize the construction industry, and the wide range of materials that can be synthesized through this process, offering a sustainable pathway for future construction practices.

Pruthvi Sagar et al (2016) was study an important shift towards sustainable construction materials, addressing both environmental concerns from cement production and the depletion of natural resources. By focusing on geopolymer concrete, which utilizes industrial byproducts such as ultrafine fly ash (UFFA) and ground granulated blast furnace slag (GGBFS), you're aligning with the goal of reducing reliance on ordinary Portland cement while improving concrete's strength and durability. Geopolymers, formed by reacting aluminosilicate materials with alkaline solutions (like sodium hydroxide and sodium silicate), show great potential for producing eco-friendly and high-performance concrete. Your investigation into varying proportions of GGBFS and UFFA offers valuable insights into optimizing geopolymer concrete mixtures. Silica fume demonstrates higher pozzolanic reactivity due to finer particle size, but UFFA's enhanced reactivity (via air classification) also contributes positively. The 92.5:7.5 ratio of GGBFS to UFFA produced the best results, achieving the highest compressive strength, showing that higher GGBFS content may contribute significantly to the overall strength development. Achieved strengths range from 36.5 MPa (1st day) to 91.6 MPa (28th day of hot curing), indicating that with hot curing, geopolymer concrete can develop strength rapidly, making it suitable for various structural applications. Conducting permeability, abrasion, sorptivity, acid and sulfate attack, and drying shrinkage tests is essential for assessing long-term performance. Geopolymer concrete is generally expected to perform better in these areas compared to conventional concrete due to its dense microstructure and reduced permeability. This work paves the way for more eco-friendly, durable concrete solutions and contributes to the broader conversation on reducing cement usage in the construction industry. Would you like assistance interpreting any specific test results or exploring further applications of these materials.

3. CONCLUSION

Ultrafine fly ash-based geopolymer concrete represents a promising advancement in sustainable construction materials. Its superior mechanical properties, durability, and environmental benefits position it as a viable alternative to traditional OPC concrete. While challenges remain, particularly in terms of cost and curing methods, continued research and development are likely to make geopolymer concrete a more prevalent choice in the construction industry.

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