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GEOPOLYMER CONCRETE AN ECO-FRIENDLY ALTERNATIVE TO CONCRETE

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ABSTRACT

Geo-polymer concrete deviates from conventional concrete by eliminating Portland cement from its composition. Instead, its binder is created through a reaction between an alkaline liquid and a source material abundant in silica and alumina. This innovative material stems from research into fire-resistant materials prompted by fire incidents. Research endeavors have yielded non-flammable and non-combustible Geo-polymer resins and adhesives, positioning Geo-polymers as a promising eco-friendly substitute for Portland cement. Extensive research efforts have been dedicated to Geo-polymers, spanning from fundamental chemistry to practical engineering applications and commercial production. Geo-polymer concrete has been found to possess favorable engineering properties, making it a viable option for construction projects.

Polypropylene, a thermoplastic polymer, finds application in various fields such as ropes, thermal garments, and blankets. Polymer cement, on the other hand, employs a polymer as a binding agent instead of traditional cement. Variants include polymer-filled solids, polymer cement, and Portland polymer-bonded concrete. The aim of the study was to optimize the strength of concrete by determining the ideal weight of polypropylene fibers. Fiber-reinforced concrete, which utilizes polypropylene fibers, is favored in engineering applications for its superior properties in both industry and construction sectors.

Keyword: GGBS, Polypropylene fiber, Conventional Concrete, Fiber Reinforced Concrete, etc.

INTRODUCTION

Concrete, second only to water in global usage, historically relies on Portland cement as its primary binding agent. The surge in infrastructure development, particularly in nations like China and India, fuels the demand for concrete. However, conventional Portland cement production raises significant environmental concerns. Each tonne of Portland cement manufactured emits an equivalent amount of carbon dioxide into the atmosphere, contributing to approximately 7% of global carbon dioxide emissions. Hence, there is a pressing need to explore alternative binding agents with lower carbon footprints, One promising solution is geo-polymers, which involve converting industrial waste materials like ground granulated blast furnace slag (GGBS) and fly ash into a binding substance for concrete. The term "geo-polymer" was coined by Davidovi to describe three-dimensional silico-aluminate structures that are either amorphous or semi-crystalline. These structures can manifest as Poly(sialate) (-Si-OAl-O-) or Poly(sialate-siloxo) (-Si-O-AI-O-Si-O-). The production process of geo-polymers entails stages such as dissolution, gelation, setting, and hardening of aluminium-silicon source materials;

Geo-polymer cement signifies a significant advancement in cement technology, succeeding gypsum cement and traditional Portland cement (OPC). It has garnered prominence as a construction material globally. Specific materials known as amorphous alkali aluminosilicate or alkali-activated cements fall under the geo-polymer category. Geo-polymer concrete can be produced by activating aluminosilicates like fly ash, metakaolin, slag, rice husk ash, and high calcium wood ash using an alkaline solution. The success of geo-polymer concrete manufacturing hinges largely on the choice of activators and the availability of various types of aluminosilicates.

Geo-polymer cement diverges from OPC or pozzolanic cements in its mechanism of attaining compressive strength. Instead of relying on the hydration of calcium silicates, as in OPC, geo-polymer cement achieves compressive strength through the process of polycondensation of silica and alumina, facilitated by a high alkali content. In the case of a geo-polymer blend containing OPC, the formation of calcium silicate hydrates (C-S-H) occurs alongside polycondensation of silica and alumina and a high concentration of alkali.

The utilization of geo-polymers offers several advantages over conventional Portland cement-based concrete. Firstly, it provides an environmentally friendly alternative by utilizing industrial waste materials, thus reducing reliance on virgin resources, and mitigating environmental impacts. Additionally, geo-polymer concrete exhibits comparable or even superior mechanical properties to OPC-based concrete, including higher compressive strength, durability, and resistance to environmental factors such as corrosion and fire.

Moreover, geo-polymer concrete production consumes less energy compared to Portland cement production, further contributing to its sustainability. By reducing the carbon footprint associated with construction materials, geo-polymer concrete aligns with global efforts to mitigate climate change and promote sustainable development.

In summary, geo-polymer concrete represents a promising alternative to traditional Portland cement-based concrete, offering environmental, economic, and performance benefits. As research and development in this field continue, geo-polymers have the potential to revolutionize the construction industry and contribute to a more sustainable built environment.

Despite considerable research efforts, geo-polymer concrete has faced challenges in achieving widespread acceptance as a construction material on the international stage. Several factors contribute to these hurdles:

1. **Limited Awareness and Understanding:** One of the primary reasons for the slow adoption of geo-polymer concrete is the lack of awareness and understanding among engineers, architects, contractors, and other stakeholders in the construction industry. Compared to traditional Portland cement-based concrete, which has been extensively studied and widely used for decades, geo-polymer concrete is a relatively newer material. As a result, there may be skepticism and reluctance to embrace it without a comprehensive understanding of its properties, performance, and long-term durability.

2. **Standardization and Certification:** The absence of standardized testing methods, specifications, and certification protocols specific to geo-polymer concrete presents a significant challenge. Standardization is essential to ensure uniformity in quality, performance, and compatibility with existing construction practices and regulations. Without established standards and certifications, engineers and contractors may be hesitant to use geo-polymer concrete in projects due to uncertainties regarding its suitability and compliance with building codes and regulations.

3. **Cost and Economics:** The initial cost of implementing geo-polymer concrete may be higher than that of traditional concrete due to factors such as the procurement of specialized raw materials, equipment, and expertise required for its production and installation. Additionally, the lack of economies of scale associated with geo-polymer concrete production, coupled with limited market demand and competition, may further inflate costs. In regions where construction budgets are tight or where there is a preference for low-cost materials, the perceived cost barrier may deter the widespread adoption of geo-polymer concrete.

4. **Technical Challenges and Performance Concerns:** Despite its promising properties, geo-

polymer concrete still faces technical challenges and performance concerns that need to be addressed. These challenges may include issues related to workability, setting time, curing requirements, long-term durability, and resistance to harsh environmental conditions such as freeze-thaw cycles and chemical exposure. Addressing these technical challenges and demonstrating the reliability and performance of geo-polymer concrete through rigorous testing and field trials is crucial to instilling confidence among stakeholders and facilitating its broader acceptance.

5. **Resistance to Change and Traditional Practices:** The construction industry is often resistant to change, particularly when it comes to adopting new materials, technologies, and construction methods. Established practices and preferences for conventional materials like Portland cement-based concrete may hinder the adoption of geo-polymer concrete, despite its potential benefits. Overcoming resistance to change requires education, demonstration of benefits, and gradual integration into existing construction practices through pilot projects, research initiatives, and industry collaboration.

1.1 Geo-Polymer Concrete Advantages

- **Reduced Maintenance:** Geo-polymer concrete requires less maintenance compared to conventional concrete, leading to cost savings over its lifespan. Its durability and resistance to degradation contribute to longer service life without the need for frequent repairs or replacements.
- **Proven Durability:** Geo-polymer concrete has a history dating back to the Roman Empire, demonstrating its longevity and durability. Structures built with geo-polymer concrete have been known to last for hundreds of years, surpassing the lifespan of conventional concrete structures, which typically last for tens of years.
- **Fire Resistance:** Geo-polymer concrete exhibits superior fire resistance compared to conventional concrete. Its composition and properties make it highly resistant to high temperatures and fire damage, making it suitable for applications where fire safety is a concern, such as in industrial settings or high-rise buildings.
- **Corrosion Resistance:** Geo-polymer concrete offers excellent resistance to corrosion, particularly in harsh environments where exposure to moisture, chemicals, or salt can lead to corrosion of conventional concrete structures. This corrosion resistance enhances the

durability and longevity of geo-polymer concrete in marine, coastal, or chemical processing facilities.

- **High Strength:** Geo-polymer concrete demonstrates higher compressive and tensile strength compared to conventional concrete. This superior strength makes it suitable for use in structural applications where load-bearing capacity and structural integrity are critical, such as bridges, highways, and buildings.
- **Faster Curing:** Geo-polymer concrete typically cures faster than conventional concrete, allowing for shorter construction timelines and faster project completion. This accelerated curing process can result in increased construction efficiency and reduced overall project costs.
- **Lower Shrinkage:** Geo-polymer concrete exhibits lower shrinkage rates than traditional concrete, reducing the risk of cracking and deformation over time. This property helps maintain the structural integrity and aesthetics of geo-polymer concrete structures, particularly in applications where dimensional stability is essential, such as pavement and flooring.

1.2 Uses of Geo-Polymer Concrete

- **Infrastructure Construction:** Geo-polymer concrete is commonly used in the construction of various infrastructure projects, including bridges, highways, tunnels, and dams. Its high strength, durability, and resistance to environmental factors make it well-suited for applications where robust construction materials are required to withstand heavy loads and harsh conditions.
- **Building Construction:** Geo-polymer concrete finds application in the construction of commercial and residential buildings, including high-rise structures, apartments, and houses. Its fire resistance, corrosion resistance, and superior strength make it an ideal choice for building foundations, walls, floors, and other structural elements where safety and longevity are paramount.
- **Marine and Coastal Structures:** Due to its excellent resistance to corrosion and erosion, geo-polymer concrete is extensively used in the construction of marine and coastal structures, such as seawalls, piers, jetties, and harbor facilities. These structures are exposed to saltwater, moisture, and wave action, making geo-polymer concrete an ideal material choice for ensuring long-term durability and structural integrity.

- **Industrial Facilities:** Geo-polymer concrete is employed in the construction of industrial facilities, including chemical plants, refineries, power plants, and manufacturing plants. Its resistance to chemical corrosion, high temperatures, and mechanical stresses makes it suitable for use in environments where conventional concrete may deteriorate rapidly.
- **Infrastructure Rehabilitation:** Geo-polymer concrete is also used for the rehabilitation and repair of existing infrastructure, such as bridges, roads, and underground utilities. Its fast-curing properties and compatibility with existing concrete structures make it a cost-effective solution for extending the service life of aging infrastructure and addressing structural deficiencies.
- **Specialized Applications:** In addition to traditional construction applications, geo-polymer concrete is utilized in specialized applications that require specific performance characteristics. These include radiation shielding in nuclear facilities, ballistic protection in military installations, and thermal insulation in cold storage facilities. The versatility and customizable properties of geo-polymer concrete make it suitable for a wide range of specialized applications across various industries.

1.3 GGBS

GGBS, or Ground Granulated Blast-furnace Slag, is a cementitious material widely used in concrete production and is derived as a by-product from iron blast furnaces. In the process of iron production, blast furnaces operate at extremely high temperatures exceeding 1,500°C and are charged with a carefully balanced mixture of iron ore, coke, and limestone. As the iron ore undergoes reduction to form iron, the remaining components combine to form a molten slag that floats atop the molten iron. This slag is periodically drained off from the furnace as a liquid and rapidly cooled by immersion in large volumes of water to produce GGBS.

The rapid cooling process, known as quenching, enhances the cementitious properties of the slag and transforms it into coarse sand-like granules. After quenching, the granulated slag is dried and ground into a fine powder, resulting in GGBS. The composition of GGBS primarily comprises calcium oxide (CaO), silicon dioxide (SiO2), aluminum oxide (Al2O3), and magnesium oxide (MgO).

1.4 Metakaolin

Metakaolin is a clay material that undergoes a process called de-hydroxylation, resulting in the transformation of kaolinite, another type of clay. Kaolinite is commonly used as a cement substitute in concrete applications. Metakaolin particles are characterized by their small size, typically ranging from 1 to 2 micrometers, and they possess a high surface area relative to their volume.

The production of metakaolin involves subjecting purified kaolinite to high temperatures in an externally fired rotary kiln, typically ranging from 670 to 750 degrees Celsius. This process alters the chemical composition and structure of the kaolinite, converting it into metakaolin.

1.1 Propylene Fiber

Polypropylene fiber is a type of synthetic polymer fiber derived from the polymerization process of propylene material. This fiber possesses several beneficial properties, including high strength, toughness, increased corrosion resistance, and lightweight characteristics. These qualities make polypropylene fiber suitable for various applications across different industries.

One of the primary advantages of polypropylene fiber is its high strength, which enables it to withstand significant loads and stresses without experiencing deformation or failure. This strength makes it suitable for use in applications where structural integrity is crucial, such as reinforcing concrete structures or providing support in composite materials.

Additionally, polypropylene fiber exhibits toughness, meaning it can absorb energy and deform without fracturing under impact or sudden loads. This property enhances the durability and resilience of materials containing polypropylene fiber, making them more resistant to damage from external forces.

Literature Review

The process by which Geo-polymer is formed through the reaction of silica and alumina-rich source materials with an alkaline liquid, resulting in a material that resembles concrete but does not contain traditional cement. This distinction positions Geo-polymer as a promising alternative to standard Portland cement concrete, offering potential environmental benefits.

The research indicates that Geo-polymer concrete is gaining attention as a greener alternative to traditional concrete, with intensive exploration in various applications. As the focus of Geo-polymer concrete research shifts from chemistry to engineering applications and commercial manufacturing, efforts are being made to improve its workability and strength through mix design enhancements.

The study discusses how factors such as curing temperature and regime, aggregate form, strengths, moisture content, preparations, and grades influence the workability and strength of Geo-polymer concrete. By understanding and optimizing these parameters, researchers can enhance the performance and usability of Geo-polymer concrete in construction applications.

Furthermore, the research provides a summary of current uses of Geo-polymer concrete, showcasing its versatility and potential in various construction projects. This highlights the growing interest and adoption of Geo-polymer concrete as a sustainable building material.

Overall, the study underscores the importance of ongoing research and development efforts to advance Geo-polymer concrete technology and its applications. By addressing key challenges and optimizing mix designs, Geo-polymer concrete has the potential to become a mainstream construction material, offering both environmental and performance advantages over traditional concrete.

However, challenges such as supply constraints for raw materials like sodium hydroxide and the need for further research to optimize mix designs and standardize engineering applications remain.

This literature review provides valuable insights into the ongoing research and development efforts aimed at advancing Geo-polymer concrete as a sustainable and viable alternative to traditional concrete in construction and infrastructure projects.

Methodology

Geo-polymer concrete (GPC) offers a sustainable alternative to traditional concrete, synthesized by mixing silicate-bearing and aluminate materials with a caustic activating agent, eliminating carbon dioxide emissions associated with its production. The materials typically include cement, aggregate, sand, GGBS, metakaoline, and polypropylene fiber, providing strength, durability, and eco-friendliness. Various tests assess its properties, including the slump test for workability, compressive strength test, split tensile test, and flexural strength test. Adjustments in water-cement ratio and admixture dosage optimize mix proportions, ensuring desired characteristics.

The mix design for M30 concrete specifies OPC 53 Grade cement, 20mm aggregate, 0.44 water-cement ratio, and a slump range of 25-50mm for moderate exposure conditions with pumping as the placement method. The target average compressive strength after 28 days is 38.25 N/mm². Materials meet relevant standards, with chemical admixture enhancing workability. Mix calculations yield proportions ensuring desired characteristics.

Further testing with varied water-cement ratios provides insights into concrete strength and durability, guiding mix optimization for field trials. Mix formulations with varying percentages of propylene fiber, GGBS, and metakaolin are tested to determine optimal combinations for desired properties.

In summary, GPC offers a sustainable solution with reduced environmental impact compared to traditional concrete. Through precise mix design, testing, and optimization, its properties can be tailored to meet specific requirements, ensuring durability, strength, and eco-friendliness in construction applications.

RESULT & DISCUSSION

The experiment conducted evaluates the effects of adding propylene fiber (PF) to geopolymer concrete, examining its impact on slump, compressive strength, split tensile strength, and flexural strength. The results are summarized to determine the optimum PF content in the concrete mix.

Slump Test: The addition of PF leads to an increase in slump, indicating enhanced workability of geopolymer concrete. The highest slump value of 43 mm is achieved with 1.8% PF.

Compressive Strength Test: At 7 days, compressive strength increases with PF content, peaking at 23.42 N/mm² for 1.5% PF. At 28 days, a similar trend is observed, with the highest strength of 34.83 N/mm² for 1.5% PF. However, beyond 1.5% PF, compressive strength decreases.

Split Tensile Test: Split tensile strength increases with PF content up to 2.220 N/mm² at 7 days and 3.302 N/mm² at 28 days for 1.5% PF. Beyond this, strength decreases, indicating an optimal PF content.

Flexural Strength Test: Flexural strength also follows a similar pattern, peaking at 3.970 N/mm² at 7 days and 4.841 N/mm² at 28 days for 1.5% PF.

Optimum PF Content: The optimal PF content for enhancing properties like compressive strength, split tensile strength, and flexural strength is determined to be 1.5% in the concrete mix. Beyond this, the effectiveness of PF diminishes.

Further Testing: The experiment is extended to explore the combined effects of PF with varying percentages of ground granulated blast furnace slag (GGBS) and metakaolin. Results show improvements in slump, compressive strength, split tensile strength, and flexural strength compared to conventional concrete

Conclusion: Adding PF to geopolymer concrete enhances its workability, compressive strength, split tensile strength, and flexural strength up to an optimal content of 1.5%. Beyond this, the benefits diminish. The combination of PF with GGBS and metakaolin further improves concrete properties, suggesting potential applications in construction for enhanced performance and durability.

In conclusion, the findings emphasize the significance of optimizing PF content and exploring supplementary materials like GGBS and metakaolin to tailor geopolymer concrete for specific structural requirements.

CONCLUSION

The comprehensive analysis conducted on the structural characteristics of geo-polymer concrete with the addition of propylene fiber, GGBS, and Metakaolin has yielded valuable insights. Here's a summary of the key findings and future scope:

1. Slump Test: The workability of geo-polymer concrete decreases with an increase in the percentage of propylene fiber. The lowest workability, observed at 1.8% propylene fiber with a slump degree of 43, suggests its suitability for applications requiring light reinforcements, such as foundations.

2. Compressive Strength: The addition of propylene fiber enhances the compressive strength of geo-polymer concrete up to 1.5%. Beyond this threshold, there is a decline in strength. The maximum compressive strength of 23.426 N/mm2 is achieved at 1.5% propylene fiber, indicating an optimal range for enhancing structural integrity.

3. Split Tensile Test: Tensile strength increases with the incorporation of propylene fiber, reaching a peak of 2.22 N/mm2 at 1.5% propylene fiber. This demonstrates the effectiveness of propylene fiber in improving the tensile properties of geo-polymer concrete.

4. Flexural Strength: The flexural strength, indicative of the ability of concrete beams to withstand bending failure, exhibits maximum strength at 1.5% propylene fiber, with a magnitude of 3.97 N/mm2. This highlights the importance of propylene fiber in enhancing the flexural performance of geo-polymer concrete.

5. Conclusion: The findings suggest that the addition of propylene fiber enhances the mechanical properties of geo-polymer concrete up to a certain percentage (1.5%), beyond which there is a diminishing return in strength. This information is crucial for optimizing the composition of geo-polymer concrete for specific structural applications, ensuring adequate performance and durability.

Future Scope: Moving forward, further tests on geo-polymer concrete can leverage advanced techniques such as the Finite Element Method (FEM) for structural analysis. By applying specimen properties, FEM tests can evaluate the behavior of various building structures, including residential and commercial buildings. Specifically, investigating the impact of seismic loads on the lateral load resistance of buildings constructed from geo-polymer concrete is vital, particularly in seismic-prone regions. This research could provide valuable insights into the seismic performance and structural integrity of such buildings, informing construction practices and standards.

In summary, the detailed analysis of geo-polymer concrete with the addition of propylene fiber, GGBS, and Metakaolin offers valuable insights into optimizing its composition for enhanced mechanical properties. The future scope involves leveraging advanced analytical techniques to further explore the structural performance of geo-polymer concrete and its applicability in diverse construction scenarios, including seismic-prone regions.

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