ADVANCEMENTS IN GEOPOLYMER CONCRETE: A COMPREHENSIVE REVIEW OF MATERIALS

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Abstract

The dynamic landscape of geopolymer concrete, shedding light on remarkable material advancements that have reshaped sustainability within the construction industry. It meticulously analyzes a spectrum of materials, including copper slag, ground granulated blast furnace slag (GGBS), sodium hydroxide, sodium silicate, metakaolin, and manufactured sand (M-sand). The comprehensive exploration of research findings unveils the pivotal roles each material plays in augmenting the mechanical properties, workability, and durability of geopolymer concrete. The synthesis of knowledge on optimal mix designs and sustainable applications not only provides valuable insights but also lays the groundwork for future innovations. This amalgamation of materials acts as a driving force propelling geopolymer concrete technology forward. Beyond technological advancements, this convergence contributes significantly to the ongoing evolution of environmentally conscious and resilient construction practices. As the construction industry increasingly prioritizes sustainability, the insights derived from this review are poised to shape the trajectory of geopolymer concrete, offering a robust foundation for a greener and more resilient future in construction.

Key words: Goepolymer, GGBS, metakaolin and copper slag.

1. Introduction

In recent years, the field of construction materials has witnessed a transformative shift towards sustainable and innovative alternatives to traditional concrete. Geopolymer concrete, a cutting-edge material born out of advancements in materials science and chemistry, has emerged as a promising solution to address both environmental concerns and the need for improved performance in construction. This comprehensive review delves into the latest advancements in geopolymer concrete, providing a thorough exploration of the materials involved and their applications. Geopolymer concrete represents a paradigm shift from conventional Portland cement-based concrete, offering enhanced durability, reduced carbon footprint, and increased resistance to harsh environmental conditions. This review will scrutinize the diverse range of raw materials, binders, and activators that contribute to the formulation of geopolymer concrete, shedding light on the chemical processes that govern its unique properties. The study will also delve into the mechanical, thermal, and structural characteristics of geopolymer concrete, evaluating its performance in comparison to traditional alternatives.

As the global construction industry faces escalating challenges related to sustainability and resource depletion, geopolymer concrete stands out as a sustainable and eco-friendly alternative. This review aims to consolidate the current state of knowledge on geopolymer concrete, offering a comprehensive understanding of its composition, manufacturing processes, and practical applications. By examining recent research findings and technological breakthroughs, this review seeks to contribute to the ongoing discourse on advancing sustainable construction practices through the adoption of geopolymer concrete.

2. Materials

The effects of curing temperature, fly ash to slag ratios, and NaOH molar concentration on the hydration products and strength. After being activated with 10 M NaOH, 50% fly ash and 50% slag were mixed, cured at 25°C for 28 days, and the combination had a compressive strength of around 50 MPa. When the slag reacts completely, the major product is a C-S-H gel that has significant concentrations of Na ions in the interlayer gaps and tetra coordinated Al in its structure. No hydrated alkaline alumino-silicates with three-dimensional structural properties of alkaline activation of fly ash are known, despite the fact that fly ash is partially dissolved. [1, 2]

The composition, crystallographic and microstructure by considering four types of cementitious material samples such as ordinary Portland cement, an alkali activated Slag, a geopolymer and a sample containing both alkali-activated slag phase and geopolymer phase. [3] In X-ray diffraction, PC sample contains C-S-H gel phase, ettringite, Portlandite and quartz, but no crystalline or semi- crystalline phase is formed in geopolymer, geopolymer -alkali activated Slag and alkali activated slag samples. [4] Compared to other samples, geopolymer appears to be a composite composed of GGBFS particles surrounded by a binding matrix. They also conclude that except geopolymer sample, all other samples contain carbonate species. Thus, except geopolymer sample, all the other samples contain carbonate species, and geopolymer has greater resistance to carbonation. [5]

Synchrotron X-ray SEM imaging and compressive strength tests are conducted after diffraction on fly ash-based geopolymers and alkali-activated ground blast furnace slag to investigate phase development. They came to the conclusion that calcium in slag dissolves more quickly in the activator solution than calcium class-C fly ash. Because C-S-H can easily obtain calcium from this, the final mechanical strength appears to be increased. According to reports, adding water glass to the NaOH activator did not cause the class-C fly ash geopolymer to enter a new phase, but it did significantly increase the compressive strength and the pace at which strength developed. [6, 7]

The long-term characteristics of geopolymer concrete made with low calcium fly ash, such as its resistance to sulfuric acid, sulfate, and drying shrinkage. They found that there is minimal drying shrinkage and low creep in fly ash that has been heat-cured. Additionally, it resists sulfate assaults rather well. [8] They came to the conclusion that low-calcium fly ash heat-cured geopolymer concrete has outstanding acid resistance, minimal creep, and very little drying shrinkage in addition to superior sulfate attack resistance. [9] Additionally, a number of geopolymer concrete's financial advantages were mentioned. In-depth research on the long-term characteristics of low calcium fly ash-based geopolymer concrete, including creep, drying shrinkage, sulfate resistance, and sulfuric acid resistance. [10] They found that there is minimal drying shrinkage and low creep in fly ash that has been heat-cured. Additionally, it resists sulfate assaults rather well. [11]

An analytical and experimental research on the behavior and strength of geopolymer concrete beams and columns reinforced with fly ash. According to the investigations, silicate-containing components and a high concentration of alkaline solution are necessary for the activation of class F fly ash, together with heat curing. [12] Activation frequently requires a concentration of 8–10 molar hydroxide. Using the design guidelines and rules, it was discovered that the behavior and elastic characteristics of hardened geopolymer concrete were comparable to those of Portland cement concrete. Overall, they came to the conclusion that Portland cement might be substituted with low calcium fly ash-based geopolymer concrete. [13]

The function of calcium in geopolymerization, seven distinct calcium silicate materials were examined. Based on the findings, they deduced that the coexistence of C-S-H gel and geopolymeric gel gave the matrices produced at low alkalinities good mechanical characteristics. High alkalinity seems to favor geopolymeric gel, which means calcium has less of an impact on the final result. [14] The calcium dissolved in GGBS has a major impact on characteristics at both early and older ages. The breakdown of fly ash is delayed and the creation of geopolymer gel is enhanced because free calcium ions are available. [15]

The impact of meta-kaolin on M.K. cement blended binder properties. Metakaolin was used to partially replace cement in a range of 0 to 40%, and the amount of time that blended cement paste took to set was recorded. The outcome demonstrates how MK speeds up OPC and drastically cuts down on both the initial and final setup times. Up to 30% less cement was needed to set, according to observations. Nonetheless, a notable decrease was noted in the paste when 10% and 20% less cement was used. Even the paste that replaced 40% of the cement showed a little decrease in setting time. [16] It was observed that compared to a control matrix, a matrix containing 10% meta-kaolin showed the best bond-slip behavior of steel fiber. Additionally, the cement matrix that included both meta-kaolin and silica fume generated an excessive binding strength that caused the fiber to fracture and made the matrix brittle. [17]

The functionality of mortar that contains meta-kaolin as a filler ingredient and mineral additive. In this study, the effectiveness of mortar containing MK was assessed and contrasted with mortar composed of OPC mixed with silica fume. According to a report, the portlandite (CH) content of mortar containing 15% metakaolin by mass of OPC was reduced to 6%. [18] Remarkably, the control mortar's portlandite percentage is less than 24%. Additionally, it was noted that the properties of the meta-kaolin affected the variance in CH content. [19]

The effect of Ground Copper Slag (GCS) on the strength and fracture of cement-based materials. Upto 15% by mass of GCS is used as a Portland cement replacement. The strength and fracture toughness of concrete samples are studied using closed-loop controlled compression and three-point bending fracture tests. [20] The compression investigation utilizes a mixture of the axial and transverse strains as a control constraint to develop a stable post-peak response. A cyclic loading-unloading investigation is performed on three-point bending notched specimens under closed-loop crack mouth opening control. [21]

The possible utilization of flotation waste of copper slag (FWCS) as a source of iron for Portland cement clinker manufacture. The FWCS seems to be a good raw material for iron sources since it contains more than 59% Fe_2O_3, mostly in the form of magnetite (Fe_3O_4) and fayalite (Fe_2SiO_4). [22] The chemical composition conformance of the clinker products acquired over a four-month period from the industrial scale testing operations employing the FWCS is studied. The resulting cement products' physic-mechanical performance is assessed. Currently, the data gathered for the clinker products—which are made from iron ore—is utilized as a raw material for cement. It's offered for comparison as well. [23]

2. Mechanical Properties and Micro Structural Properties

The fracture characteristics of GGBS, or geopolymer concrete combined with fly ash and cured at room temperature. It has been discovered that the water content and mixture compositions affect the fracture qualities. More ductility was shown by GC with slag and fly ash mix than by low calcium fly ash-based geopolymer concrete that underwent heat curing. [24] For the ambient temperature cured samples, mechanical characteristics are reported to increase with the addition of calcium compounds, such as a fly ash replacement; however, for the 70 °C cured samples, mechanical values have been noted to decrease. [25] Only at low alkalinity does the geopolymeric gel and C-S-H gel form together. The geopolymeric gel predominates in the presence of high NaOH concentrations, and calcium precipitate traces have been seen. [26]

The inorganic polymer cements' microstructure. According to his research, the binder consists mostly of an aluminosilicate gel that is charged-balanced by alkali metal cations. Slag particles supply the calcium, which is comparatively well spread throughout the gel. [27] In comparison to a corresponding silicate-activated system, the microstructure of the binder formed by hydroxide activation of fly ash was found to be less uniform; this finding can be explained by a recently developed theory explaining the differences in reaction mechanisms between these two systems. [28, 29] The newly generated gel phase nucleates and expands outward from the surfaces of the ash particles during hydroxide activation. The high concentration of silica in a silicate-activated solution allows a more uniform gelation process to take place over the interparticle volume. Therefore, it is somewhat understandable how adding calcium-rich substances to fly ash during alkali activation affects things. [30]

Compared to Portland cement and mixed concretes, alkali-activated slag outperforms them in durability attributes such water sorptivity, chloride resistance, and carbonation resistance. [31] When it comes to weight loss, compressive strength, volume fluctuations, the presence of degradation products and microstructural changes, and the involvement of water in geopolymeric processes, alkali-activated fly ash performs better than Portland cement concrete. [32, 33]

3. Structural Behavior

Similar to those described in the literature for reinforced Portland cement concrete beams, the crack patterns seen in reinforced geopolymer concrete beams were also seen. [34] As the tensile reinforcement ratio dropped, reinforced geopolymer concrete beams' ductility rose. Test beam service load deflections were compared to values determined by using the Australian draft code AS 3600's serviceability requirements. [35, 36] Beams of geopolymer concrete reinforced by ambient temperature curing. Six geopolymer concrete mixtures were prepared with different fly ash to GGBS ratios, and eighteen beams were put through testing. [37] The strengths of the geopolymer concrete mixtures ranged from 17 to 63 MPa. In order to achieve the anticipated characteristic strength, the beams section was designed as a balanced section. It was found that the deflections of geopolymer concrete beams were greater at the cracking load, service load, and peak load phases. The ductility factor was similar to that of beams made of OPCC. [38] The research demonstrated that, within tolerable bounds, the moment capacity, deflection, and crack width of reinforced geopolymer concrete flexural beams could be computed using the standard theory of reinforced concrete. [39]

Using composite beams made of geopolymer concrete reinforced with fibers. Steel rebars were used, and they had varying volume percentages of steel, polypropylene, and glass fibers. Nonlinear finite element analysis was used to compare the experimental results. [40] The reinforced geopolymer concrete beams' flexural strength. To compare the findings with excellent finite element simulations, the commercially available finite element software is integrated. [41]

4. Conclusion

The comprehensive review of advancements in geopolymer concrete underscores the significant strides made in the field of construction materials. The exploration of alternative and sustainable options is crucial in addressing the environmental impact of traditional Portland cement-based concrete. Geopolymer concrete, with its innovative use of industrial by-products and lower carbon footprint, presents itself as a promising solution. Throughout this review, we have delved into the diverse range of materials utilized in geopolymer concrete formulations, from GGBS, metakaolin and copper slag. The understanding of these materials, their properties, and their effects on the overall performance of geopolymer concrete is essential for the successful implementation of this technology. The improved mechanical properties, durability, and resistance to various environmental factors exhibited by geopolymer concrete further highlight its potential to revolutionize the construction industry. As research continues to refine mix designs, optimize curing processes, and address any remaining challenges, the widespread adoption of geopolymer concrete could contribute significantly to sustainable infrastructure development. In the face of growing environmental concerns and the need for resilient and eco-friendly construction materials, geopolymer concrete stands as a beacon of innovation.

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