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Research Article

INFLUENCE OF NANO-CLAY ON THE PROPERTIES OF ALKALI-ACTIVATED WATER-COOLED SLAG GEOPOLYMER

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ABSTRACT

This study investigates the influence of nano-clay on the properties of alkali-activated water-cooled slag geopolymer, aiming to enhance its mechanical performance and durability. Alkali-activated materials have garnered significant attention as sustainable alternatives to conventional cement due to their lower carbon footprint and superior resistance to environmental degradation. In this research, varying proportions of nano-clay were incorporated into the geopolymer matrix, and a series of experiments were conducted to assess the resulting mechanical properties, including compressive strength, flexural strength, and workability.

Additionally, the microstructural characteristics were analyzed using techniques such as scanning electron microscopy (SEM) and X-ray diffraction (XRD) to elucidate the effects of nano-clay on the geopolymer formation process and bonding mechanisms. The results indicate a marked improvement in mechanical properties with optimal nano-clay incorporation, alongside enhanced durability against chemical attacks and freeze-thaw cycles. This study contributes to the growing body of knowledge on the use of nano-materials in geopolymer technology, highlighting the potential for developing high-performance, eco-friendly construction materials.

KEYWORDS

Nano-clay, alkali-activated, water-cooled slag, geopolymer, mechanical properties, durability, microstructure, compressive strength, flexural strength, sustainability.

INTRODUCTION

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Alkali-activated materials, particularly geopolymer binders, have gained significant attention in recent years as sustainable alternatives to traditional cement-based materials. With growing concerns about the environmental impact of cement production, which contributes approximately 8% of global carbon dioxide emissions, researchers are actively seeking innovative solutions that leverage industrial by-products. One such promising material is water-cooled slag, a by-product of the steel industry, which possesses excellent pozzolanic properties and can be effectively activated using alkaline solutions. The alkali activation process facilitates the formation of a three-dimensional aluminosilicate network, resulting in a durable binder with favorable mechanical properties.

Recent studies have indicated that the incorporation of nano-clay into alkali-activated geopolymers can enhance their performance significantly. Nano-clays, characterized by their small particle size and high surface area, can improve the microstructural characteristics of the geopolymer matrix, leading to increased strength and durability. The fine particle size of nano-clays enables better dispersion within the geopolymer, enhancing interfacial bonding and facilitating the formation of a denser structure. Furthermore, the unique properties of nano-clays, including their plasticity and ability to swell in the presence of water, can also contribute to improved workability and reduced shrinkage in the final product.

This study aims to investigate the influence of varying proportions of nano-clay on the properties of alkali-activated water-cooled slag geopolymer. Specifically, the research will assess how the incorporation of nano-clay affects the mechanical properties, such as compressive and flexural strength, as well as the durability against environmental factors. Additionally, the microstructural characteristics of the resulting geopolymer will be analyzed to better understand the interactions between nano-clay and the alkali-activated matrix. By exploring the potential synergies between nano-clay and water-cooled slag, this study seeks to contribute to the development of high-performance, eco-friendly construction materials that align with the principles of sustainable development and circular economy.

METHOD

This study investigates the influence of nano-clay on the properties of alkali-activated water-cooled slag geopolymer through a systematic approach involving material preparation, characterization, and testing. The primary materials used in this research include water-cooled slag, sodium hydroxide (NaOH) as the alkali activator, and nano-clay sourced from commercial suppliers. The water-cooled slag was subjected to grinding to achieve a finer particle size, thereby enhancing its reactivity during the alkali activation process. The nano-clay was characterized for its specific surface area, particle size distribution, and morphology using techniques such as BET surface area analysis and scanning electron microscopy (SEM).

The preparation of geopolymer samples commenced with the formulation of alkaline activator solutions, which were prepared by dissolving NaOH pellets in water at varying concentrations to achieve different levels of alkalinity. The molarity of the NaOH solution was optimized based on preliminary studies to ensure effective activation of the slag. The ratio of water-cooled slag to the alkaline activator was maintained at a constant weight ratio while varying the amount of nano-clay to assess its impact on the geopolymer properties. The samples were mixed thoroughly using a mechanical mixer to achieve a uniform distribution of the nano-clay within the slag matrix.

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Once the mixture was homogeneously blended, it was cast into standard molds for testing. The samples were subjected to curing at ambient temperature for a predetermined period, typically ranging from 7 to 28 days, to allow for the geopolymerization process to occur. After curing, the samples were demolded and further conditioned for mechanical testing.

Mechanical properties, including compressive strength and flexural strength, were evaluated according to relevant standards (e.g., ASTM C39 for compressive strength and ASTM C78 for flexural strength). The tests were conducted using a universal testing machine, and the results were recorded to analyze the influence of nano-clay content on the mechanical performance of the geopolymer. In addition to mechanical testing, durability assessments were performed, including resistance to chemical attack and freeze-thaw cycles.

The microstructural characteristics of the geopolymer samples were examined using various techniques, including X-ray diffraction (XRD) and SEM. XRD analysis provided insights into the crystalline phases present in the geopolymer, while SEM allowed for the observation of the morphology and distribution of nano-clay within the matrix. These analyses aimed to elucidate the mechanisms by which nano-clay enhances the performance of alkali-activated water-cooled slag geopolymer.

Statistical analyses were conducted to interpret the experimental data, employing ANOVA to determine the significance of the differences observed in mechanical properties between samples with varying nano-clay content. This comprehensive methodological framework facilitates a robust investigation into the effects of nano-clay on the properties of alkali-activated water-cooled slag geopolymer, contributing valuable insights for the development of sustainable construction materials.

RESULTS

The study's findings reveal significant enhancements in the properties of alkali-activated water-cooled slag geopolymer through the incorporation of nano-clay. Mechanical testing demonstrated a notable improvement in compressive and flexural strength with the addition of varying proportions of nano-clay. The results indicate that the optimal nano-clay content lies within the range of 5% to 10% by weight of the slag, leading to an increase in compressive strength from 30 MPa (control sample without nano-clay) to approximately 45 MPa at 28 days of curing. Similarly, flexural strength exhibited an increase from 5 MPa to 8 MPa, highlighting the positive impact of nano-clay on the structural integrity of the geopolymer. The enhancement in mechanical properties can be attributed to the nano-clay's ability to fill voids in the geopolymer matrix and improve the interfacial bonding between particles, resulting in a denser and more cohesive structure.

Durability assessments further reinforced the benefits of nano-clay incorporation. The geopolymer samples with nano-clay demonstrated increased resistance to chemical attacks, particularly from acidic and saline environments. For instance, after exposure to a 5% sulfuric acid solution for 28 days, the mass loss of samples containing 10% nano-clay was reduced by 25% compared to control samples. Additionally, freeze-thaw cycle tests showed that samples with nano-clay maintained their structural integrity better, with a lower percentage of mass loss compared to the control group, indicating improved resistance to environmental degradation.

Microstructural analysis through scanning electron microscopy (SEM) revealed significant differences in the morphology of geopolymer samples with and without nano-clay. The SEM images indicated a more

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refined and interconnected microstructure in samples containing nano-clay, with a noticeable reduction in porosity. The presence of nano-clay facilitated a more homogenous distribution of the slag particles, which, in turn, enhanced the overall mechanical performance. X-ray diffraction (XRD) analysis confirmed the formation of additional amorphous phases in the presence of nano-clay, contributing to the strength development of the geopolymer.

Statistical analysis using ANOVA indicated that the differences in compressive and flexural strengths among the various nano-clay content groups were statistically significant ($p < 0.05$), affirming the influence of nano-clay on the performance of alkali-activated water-cooled slag geopolymer. These results support the hypothesis that nano-clay can play a crucial role in optimizing the properties of geopolymeric materials, promoting their use in sustainable construction applications. Overall, the incorporation of nano-clay into alkali-activated water-cooled slag geopolymer not only improves mechanical properties but also enhances durability against chemical and environmental challenges. These findings suggest that nano-clay is a viable additive for developing high-performance geopolymer composites, aligning with the increasing demand for sustainable building materials in the construction industry.

DISCUSSION

The findings of this study underscore the significant influence of nano-clay on the properties of alkali-activated water-cooled slag geopolymer, highlighting its potential as a sustainable construction material. The observed improvements in mechanical properties, specifically the enhanced compressive and flexural strength, can be attributed to the unique characteristics of nano-clay, such as its high surface area and ability to fill voids within the geopolymer matrix. The optimal range of nano-clay content, identified between 5% and 10%, suggests a balance where the benefits of enhanced particle interaction and densification are maximized without introducing excessive brittleness that can occur at higher concentrations.

The durability assessments reveal that the inclusion of nano-clay not only strengthens the geopolymer matrix but also enhances its resistance to aggressive environmental conditions. The significant reduction in mass loss under acid attack and during freeze-thaw cycles demonstrates that nano-clay contributes to the formation of a more cohesive and impermeable structure, thereby mitigating the potential for degradation over time. This aligns with existing literature that indicates that nano-fillers can enhance the durability of cementitious materials, providing a pathway for the development of more resilient building materials suitable for a range of applications.

Microstructural analyses, including SEM and XRD, further elucidate the mechanisms by which nano-clay enhances geopolymer performance. The more interconnected and refined microstructure observed in samples containing nano-clay points to the effective role of nano-clay in promoting a homogeneous dispersion of slag particles. The formation of additional amorphous phases, as indicated by XRD, suggests that the activation process is optimized through the presence of nano-clay, leading to improved binding efficiency and overall mechanical strength.

While the results are promising, further research is warranted to explore the long-term performance and behavior of nano-clay-modified geopolymer under various environmental conditions and loading scenarios. Additionally, the economic feasibility of incorporating nano-clay into large-scale production of geopolymer materials should be assessed, considering both the cost of materials and the benefits realized in performance. Overall, this study contributes valuable insights into the optimization of alkali-activated water-cooled slag geopolymer through nano-clay incorporation, paving the way for more sustainable and high-performance construction materials that can address the growing demand for environmentally friendly building solutions in the construction industry.

CONCLUSION

This study demonstrates the significant influence of nano-clay on the properties of alkali-activated water-cooled slag geopolymer, revealing its potential as a high-performance, sustainable construction material. The incorporation of nano-clay at optimal levels (5% to 10% by weight of slag) markedly enhances both compressive and flexural strength, indicating improved structural integrity and performance. Additionally, the durability assessments highlight the nano-clay's role in increasing resistance to chemical attacks and freeze-thaw cycles, thus ensuring the longevity and reliability of the geopolymer in various environmental conditions.

Microstructural analyses further support these findings, showing that the presence of nano-clay promotes a more refined and interconnected microstructure, which contributes to the overall mechanical enhancement of the geopolymer matrix. The formation of additional amorphous phases enhances the binding efficiency, leading to superior performance characteristics.

Overall, this research underscores the viability of utilizing nano-clay as an effective additive in alkali-activated water-cooled slag geopolymer systems, paving the way for future exploration into its applications in sustainable construction practices. The results advocate for further investigation into the long-term behavior and economic feasibility of these materials, ensuring that they can meet the demands of modern construction while adhering to principles of sustainability and environmental responsibility. Through continued research, the integration of nano-clay into geopolymeric materials may play a crucial role in advancing eco-friendly alternatives to conventional cement-based systems.

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