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Use of Geopolymer Concrete with Nano Materials Like Silica Fume in Construction

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Abstract
This study investigates the performance of Geopolymer Concrete (GPC) synthesized from fly ash and GGBS, modified with silica fume and nano-silica. Experimental results indicate that the integration of nanomaterials refines the microstructure and accelerates the formation of N-A-S-H and C-A-S-H gels. The optimized mixes demonstrated a 15–35% increase in compressive strength and a 20–40% improvement in durability indicators, including acid and sulfate resistance. These findings position nano-modified GPC as a high-performance, low-carbon alternative to traditional cement.

Keywords: Geopolymer Concrete, Nano-Silica, Silica Fume, Fly Ash, GGBS, Sustainability

1. Introduction

The production of Ordinary Portland Cement (OPC) is responsible for approximately 7–8% of global $CO2$ emissions. Geopolymer concrete offers a sustainable alternative, utilizing industrial by-products like fly ash and GGBS to reduce the carbon footprint by up to 60–80%. While GPC exhibits excellent thermal and chemical resistance, its mechanical properties can be further enhanced through nano-engineering. Nanomaterials such as silica fume and nano-silica possess high surface area and reactivity, which accelerate geopolymerization and refine the internal pore structure.

2. Methodology

- **Materials:** Class F Fly Ash and GGBS served as primary aluminosilicate sources. Silica fume (100–500 nm) and nano-silica (1–100 nm) were used as partial binder replacement
- **Activation:** An alkaline solution of $NaOH$ (8M to 12M) and $Na2SiO3$ was prepared 24 hours prior to casting. The optimized $Na2SiO3$:$NaOH$ ratio was maintained at 2.5.
- **Mix Design:** Binder composition consisted of 50–60% Fly Ash and 30–40% GGBS. Silica fume was added at 5–15% and nano-silica at 0.5–3% by weight of the binder
- **Testing:** Specimens were tested for compressive, split tensile, and flexural strength at 7, 14, and 28 days. Durability was assessed via water absorption and immersion in 5% $H2SO4$ and $Na2SO4$ solutions

3. Results and Discussion

3.1 Mechanical Performance

- **Compressive Strength:** Mixes containing nano-silica exhibited a significant rise in strength (15–35% improvement over control). This is attributed to the ultrafine particles filling microvoids and creating a denser matrix.
- **Tensile & Flexural Strength:** Improved particle packing and crack-bridging capacity resulted in enhanced internal cohesion and ductility.

3.2 Durability and Microstructure

- **Chemical Resistance:** Nano-modified samples experienced significantly less mass loss and strength reduction when exposed to acid and sulfate environments.
- **Permeability:** Water absorption and sorptivity decreased substantially, indicating reduced pore connectivity.
- **Microstructural Analysis:** SEM observations confirmed a smoother, more compact matrix with fewer unreacted fly ash particles and micro-cracks compared to the control mix.

4. Conclusion

The integration of silica fume and nano-silica (optimal at 2–3%) significantly enhances the structural integrity and chemical stability of geo-polymer concrete. By refining the microstructure and accelerating geo polymerization, these additives enable the production of high-performance building materials that support circular economy principles and global de-carbonization goals.

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