Abstract

In the modern construction industry, the pursuit of sustainable development and environmental protection has spotlighted problems with traditional building materials. Portland cement, a commonly used material, consumes a large amount of energy and emits greenhouse gases during production, contributing to pollution and climate change. Meanwhile, disposing of industrial by-products like sludge and marble powder is challenging, as improper handling can cause environmental contamination and resource waste. Foamed concrete (FC) and geopolymer foamed concrete (GFC) are promising alternatives. They can address environmental issues and offer features such as lightweight, insulation, and soundproofing. However, current research has limitations. We lack a deep understanding of how factors like raw material composition, manufacturing processes, and environmental conditions interact and affect the properties of FC and GFC. The optimal mix designs for different uses and the long-term performance of these materials in various service conditions haven't been fully explored. Also, their economic viability and environmental benefits in real-world situations aren't comprehensively evaluated.

To fill these research gaps, this study conducts systematic experimental exploration. For FC, a series of specimens were carefully made with changes in metakaolin addition, superplasticizer content, fine aggregate particle size, and dry density. The raw materials, like Portland cement, natural siliceous sand, high-reactivity metakaolin, a protein-based foaming agent, a polycarboxylate superplasticizer, and a viscosity enhancing agent, were carefully chosen and proportioned. The specimens were cured under specific conditions, and their fresh (e.g., slump) and hardened properties (flexural strength, compressive strength, elastic modulus) were fully tested. Microstructural analysis was

also carried out to understand the internal pore structure and its link to mechanical properties.

For GFC, specimens with different sludge/marble powder ratios (from 100/0 to 0/100) and dry densities (1500, 1300, 1200, and 700 kg/m^3) were produced. The sludge and marble powder were sourced and pre-treated properly. The alkaline activator was made by mixing sodium hydroxide and sodium silicate solution. The specimens were cured naturally, and their mechanical properties and microstructural characteristics were thoroughly studied.

The key findings of this research are reported as follows: For FC, increasing the superplasticizer-to-cement ratio while reducing the water + foam-to-cement ratio can enhance the flexural strength by over 18% on average. Reducing the maximum aggregate diameter from 0.5 mm to 0.25 mm leads to an approximate 18% increase in compressive strength. The presence of metakaolin significantly improves the overall mechanical properties, with an average increase of 15% in flexural strength, 16% in compressive strength, and 6% in elastic modulus. In the case of GFC, as the dry density decreases, both the compressive and flexural strengths decline significantly due to increased porosity and larger pore sizes. The sludge - to - marble powder ratio plays a crucial role, and the 50/50 ratio exhibits the best overall performance, achieving the highest compressive and flexural strengths. The addition of marble powder, especially in moderate proportions, can optimize the pore structure and enhance the mechanical properties, but excessive addition reduces the pozzolanic activity and weakens the strength.

When comparing FC and GFC, at the same dry density, FC-S1P3 generally outperforms GFC-50/50 in terms of mechanical strength. However, GFC-50/50 has distinct advantages in environmental sustainability, as it effectively utilizes industrial waste, reducing waste disposal and environmental pollution. Linear regression analysis shows that both materials have a strong linear relationship between mechanical properties and dry density, and GFC - 50/50 demonstrates a better linear correlation in some respects.

This study makes several significant contributions. It provides a comprehensive and in-depth understanding of the properties of FC and GFC under different conditions, which is essential for rational material selection in practical engineering applications. The research findings can guide the design and production of building materials, helping to balance the requirements of mechanical performance and environmental friendliness. Moreover, it paves the way for future research on optimizing the formulation and preparation methods of GFC. By improving the content and reactivity of active components in GFC, it is possible to enhance its microstructure and mechanical performance, thereby expanding its application scope in the construction industry. Additionally, this study sets a foundation for further investigations into the long-term performance of these materials under various environmental conditions, which is crucial for ensuring the durability and reliability of structures in real - world applications.