Recognised Authors

Advancing Sustainable and Resilient Construction: Integrating Basic Magnesium Sulphate Cement into Reactive Powder Concrete for Low-Carbon Infrastructure

Daniel Johnson, Ghana

Daniel Johnson, is a materials engineer and the head of the materials and quality control unit at Constromart in Accra, Ghana. He is a registered engineering geologist with the Ghana Institution of Geoscientists. Daniel holds an MSc in materials science and engineering from the Southwest University of Science and Technology and a BSc in earth science from the University for Development Studies.

He has over seven years of professional experience and served as a works Inspector on Ghana's first output and performance-based road contract, a World Bank-funded project. His areas of specialisation include cement and concrete technology, materials investigation and testing, quality control inspection and construction supervision. Daniel also has extensive experience in engineering applications focused on low-carbon cement and concrete, contributing to sustainable construction practices in Ghana and beyond.

Yvonne Durowaa Ntow, Ghana

Yvonne Durowaa Ntow is an engineering geologist at Constromart in Accra, Ghana. Yvonne has extensive experience in materials testing, quality control, and geotechnical investigations. She has a solid foundation in Earth Sciences, holding a BSc from the University of Ghana, and is currently advancing her expertise through an MSc in environmental engineering and management at the University of Energy and Natural Resources.

A committed professional and member of the Ghana Institution of Geoscientists, she brings a strong interdisciplinary perspective to sustainable infrastructure development. Yvonne has been actively involved in several major infrastructure projects, including Ghana's first output and performance-based road contract, where she contributed to ensuring quality standards and geotechnical integrity. Her work integrates engineering geology with environmentally responsible practices, with a strong focus on delivering data-driven, resilient solutions for complex environments. Passionate about innovation and long-term impact, she continues to contribute meaningfully to infrastructure delivery.

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Introduction: Decarbonising the cement industry

The global construction industry is under increasing pressure to decarbonise, innovate, and adapt to the changing climate. Cement production alone is responsible for nearly 8% of global CO_2 emissions, a figure driven by the energy-intensive nature of clinker production and the calcination of limestone. In this context, new research is pointing to promising alternative materials that deliver high performance while minimising environmental impact. One such material is Basic Magnesium Sulphate Cement (BMSC), a binder system that shows exceptional mechanical and durability properties while offering a lower-carbon alternative to Ordinary Portland cement (OPC).

This article summarises findings from a research project focused on developing Reactive Powder Concrete (RPC) using BMSC as the primary binder. The objective was twofold: to explore a new cementitious system with strong technical performance and to support global efforts toward sustainable construction by reducing CO_2 emissions through innovative material selection and mix design.

Development and performance of BMSC-Based Reactive Powder Concrete

BMSC is a ternary system composed of light-burnt magnesia, magnesium sulphate and water. Unlike OPC, its production does not rely on high-temperature kilns or carbon-intensive raw materials such as limestone. This alone offers a significant reduction in embodied carbon. When combined with supplementary materials like circulating fluidised bed combustion (CFBC) ash, a by-product from power plants, BMSC transforms into a vehicle for both emissions' reduction and industrial waste vaporisation. In the laboratory, various mix designs were developed and tested using BMSC, CFBC ash, citric acid as a set retarder and superplasticisers to enhance fluidity. To further improve tensile strength and ductility, steel fibres were added in varying proportions. The resulting RPC mixes were evaluated for compressive and flexural strength, water resistance, shrinkage and microstructure through X-ray diffraction (XRD) and scanning electron microscopy (SEM).

The optimal mix without steel fibres achieved a 28-day compressive strength of 99.2 MPa and flexural strength of 23.2 MPa. With the inclusion of 2% steel fibres, these increased to 119.1 MPa and 25.3 MPa, respectively. Water resistance was also notably improved. The softening coefficient, a measure of strength retention after water exposure, increased from 0.88 (without fibres) to 0.95 (with fibres). SEM images revealed a dense, compact microstructure with reduced formation of deleterious magnesium hydroxide [$Mg(OH)_2$] phases, which are typically associated with durability issues in magnesia-based systems.

The curing regime also played a significant role in performance optimisation. The most effective method involved a combination of ambient curing for seven days, thermal curing at 70°C for another seven days, followed by 14 days of standard curing. This sequence produced compressive and flexural strengths of 108.8 MPa and 22.0 MPa, respectively suitable for high-strength, long-span infrastructure applications.

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A: MIXING WATER
B: MAGNESIUM CEMENT PASTE
C: ADDING CFBC ASH & SAND
F: POLYTHENE COVERING
E: MOULDING AND COMPACTION
D: BMSC MIX

FIGURE 1: PREPARATION OF BASIC MAGNESIUM SULFATE CEMENT-BASED RPC

Sustainability and practical implications

From a sustainability perspective, the results are compelling. First, BMSC production requires significantly lower temperatures than OPC, reducing fossil fuel consumption. Second, it eliminates the need for limestone calcination, one of the largest sources of CO_2 in traditional cement manufacturing. Third, incorporating CFBC ash not only enhances performance but also diverts industrial waste from landfills, aligning with circular economy principles. The lifecycle emissions of BMSC-based RPC are therefore substantially lower than conventional alternatives, especially when used in projects that prioritise long-term durability and low maintenance.

This research has clear implications for sustainable infrastructure development, particularly in regions facing rapid urbanisation and climate vulnerabilities. By leveraging locally available materials and industrial by-products, BMSC-based systems can support low-carbon construction strategies that are both cost-effective and technically sound. These solutions are critical for emerging economies looking to expand infrastructure responsibly without compromising environmental goals.