

Editorial: Advances in Mineral Carbonation

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Mineral carbonation stands out as a prominent technology aimed at reducing atmospheric CO₂ emissions, a major contributor to the greenhouse effect, through a variety of processes. Research in this field began modestly nearly two decades ago, with only a handful of companies globally advancing this technology towards commercial application. However, with the growing recognition of climate change's urgent threat, and as major industries and emitters acknowledge that maintaining the status quo is detrimental to climate solutions, there has been a significant shift. Recently, there has been a substantial movement toward adopting mineral carbonation technology in efforts to achieve cleaner industrial practices in sectors such as steel manufacturing, cement production, construction, and mining. Despite significant advancements in the field, knowledge gaps still exist that require further research to fully scale up the technology. In this Special Issue [1], we concentrate on the "Advances in Mineral Carbonation", aiming to inform researchers and companies active in this field about the latest research findings in this area. This focus seeks to bridge existing gaps and catalyse the adoption of mineral carbonation technologies, facilitating their integration into mainstream industrial practices.

This Special Issue includes seven articles consisting of two communication and five original research articles. The first communication by Zhang et al., (Contribution 1) discusses the enhancement of flexural strength in CO₂-activated materials (CAMs) through the addition of triethylamine (TEA) during carbonation. CAMs are typically brittle due to the primary carbonation product, i.e., calcium carbonate. Introducing TEA facilitated the cross-linking of oligomers, which increased both the grain size of the carbonated product and the intensity ratio of its crystal planes. This modification led to notable improvements in the flexural strength of CAMs with TEA, compared to those without it. The study explored varying TEA concentrations and found the optimal TEA concentration to be around 7%, which led to a flexural strength of 7.3 MPa without significantly affecting the degree of carbonation or compressive strength. Furthermore, the authors introduced two curing regimes, with one of the curing regimes boosting flexural strength to 9.6 MPa. This development lays a foundational framework for enhancing the application of CAMs in construction, paving the way for more durable and sustainable building materials.

The second article by Thamsiriprideeporn et al., (Contribution 2) explores the development of CO₂ absorption using blended alkanolamine absorbents for multicycle integrated absorption–mineralization. This process aims to transform CO₂ emissions into valuable carbonates using amine solvents and waste brine, enhancing the sustainability of industrial processes. This study found that a blend of 15 wt.% aminomethyl propanol (AMP) and 5 wt.% monoethanolamine (MEA) achieved high CO₂ absorption and conversion efficiencies, indicating a promising avenue for CCUS technologies. This approach not only improves the efficiency of capturing and converting CO₂ but also demonstrates the



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potential for substantial environmental benefits in reducing atmospheric CO₂ levels that can be widely adopted by industries.

The third article by Mesfin et al., (Contribution 3) discusses the carbon mineralization potential in saline aquifers and submarine basalts. The authors investigated the effects of ionic strength and salinity on the dissolution rates of basaltic glass and Ca-rich plagioclase (labradorite), which are critical for enhancing subsurface mineral carbonation processes. This study finds that increasing ionic strength slightly increases dissolution rates, which has implications for the practical application of carbon storage in saline aquifers. This work offers valuable insights into optimizing conditions for effective and secure underground CO₂ storage.

Sorrentino et al., (Contribution 4) discusses mineral composition and carbonation potential of various industrial byproducts and alkaline wastes including fly ash and slag. Their study emphasizes the significant variations in the reactivity and composition of these materials, suggesting tailored approaches for their use in carbonation processes. These results also suggest the stabilization of heavy metals through carbonation, and highlight the importance of specific characterization in utilizing industrial waste for environmental carbon sequestration, pointing towards more efficient recycling and reuse strategies in the construction sector.

The communication by Nielsen et al., (Contribution 5) discusses an innovative method to accurately quantify CO₂ uptake of construction products. The authors address a critical aspect of sustainable construction materials; i.e., accurate measurement of CO₂ uptake in products derived from mineral carbonation. They highlight the limitations of conventional methods that fail to account for hydration and dehydroxylation reactions, which can lead to significant errors in CO₂ uptake calculations. The authors propose a more reliable analytical method that adjusts for these factors, enhancing the accuracy of CO₂ uptake measurements and thereby supporting more precise assessments of environmental impact and compliance with carbon offset standards.

The article by Jacobs et al., (Contribution 6) introduces a novel tool called the MCP calculator designed for the mining industry to evaluate the mineral carbonation potential (MCP) of ultramafic rocks. By comparing the MCP results with XRD analyses, they establish the accuracy and effectiveness of the tool in assessing the carbonation potential of mine waste materials, specifically focusing on serpentine and olivine. This tool could significantly impact how mining industries assess and utilize their waste for carbon sequestration, providing a straightforward and economical method for estimating MCP using common lithogeochemical data.

The last article by Kohitlhetse et al., (Contribution 7) explores innovative methods for CO₂ sequestration through mineral carbonation, focusing on the use of ammonium-based lixiviants to extract calcium from iron-making blast furnace slag. The article presents experimental results on the effectiveness of different ammonium salts in dissolving calcium. It highlights their potential in reducing CO₂ emissions by transforming calcium-rich slag into marketable calcium carbonate. The study emphasizes the environmental benefits and industrial applicability of this method, suggesting it as a promising avenue for addressing the challenges of climate change and industrial waste.

In conclusion, the articles in this Special Issue highlight major improvements in both the quality of materials and the environmental benefits of CO₂-activated materials and carbon capture techniques. These advancements bring mineral carbonation closer to widespread use in industries. This issue serves as a key resource, offering the latest findings and encouraging a greater understanding and use of mineral carbonation. This supports more sustainable industrial methods and contributes to reducing global carbon emissions.

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List of Contributions:

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2. Thamsiriprideeporn, C.; Tetsuya, S. Development of CO₂ Absorption Using Blended Alkanolamine Absorbents for Multicycle Integrated Absorption–Mineralization. *Minerals* **2023**, *13*, 487.
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5. Nielsen, P.; Quaghebeur, M. Determination of the CO₂ Uptake of Construction Products Manufactured by Mineral Carbonation. *Minerals* **2023**, *13*, 1079.
6. Jacobs, A.; Hitch, M.; Mosallanejad, S.; Bhatelia, T.; Li, J.; Farhang, F. Mineral Carbonation Potential (MCP) of Mine Waste Material: Derivation of an MCP Parameter. *Minerals* **2023**, *13*, 1129.
7. Kohitlhetse, I.C.; Manono, M.S.; Motsetse, C.K.; Mendonidis, P.M. A Step towards CO₂ Sequestration through Mineral Carbonation: Using Ammonium-Based Lixiviants for the Dissolution of Calcium from Iron-Making Blast Furnace Slag. *Minerals* **2024**, *14*, 695.

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