WHITE PAPER

Role of CO_2 Injection in Concrete: Cement Hydration Reaction Enhancer

CarbonCure Ready Mix technology injects CO_2 into fresh concrete while it is being mixed where it mineralizes, creating calcium carbonate nano-particles. This reaction offers a dual benefit: 1) improving the cement hydration reaction, enabling cement reductions in concrete, and 2) CO_2 mineralization to permanently sequester it within the concrete microstructure. This enables cost savings for producers thanks to cement reduction and mix adjustment.

What is cement hydration?

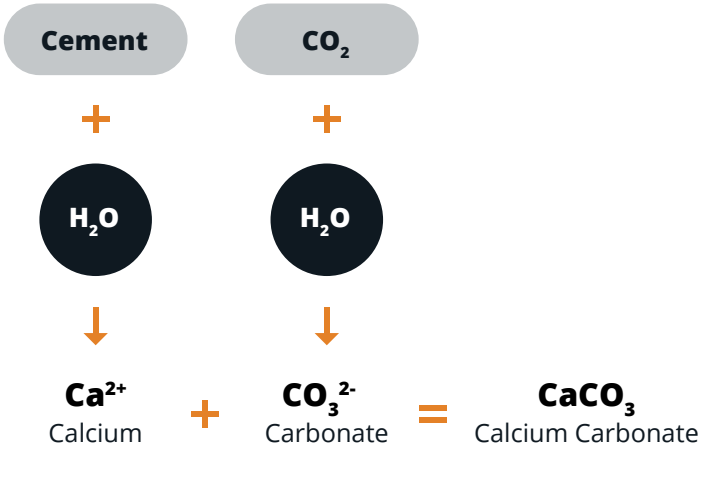
In the standard cement hydration process, water reacts with cement particles to form hydration products such as calcium silicate hydrate (C-S-H) and calcium hydroxide (CH), which bind aggregates like sand and gravel into a solid structure. These hydration products are crucial for the concrete's strength and durability.

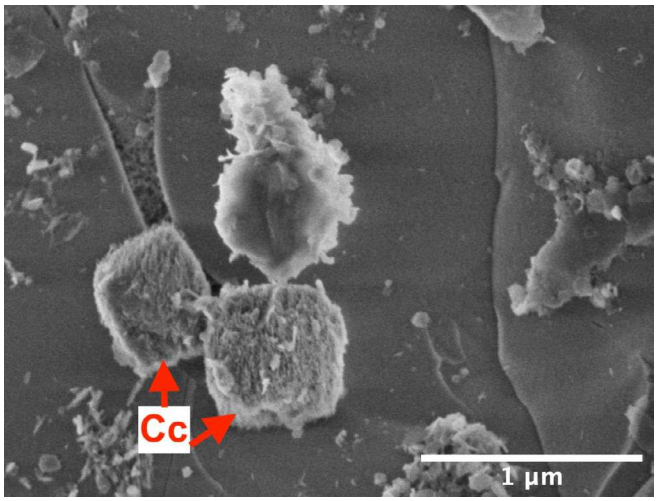
However, when CO_2 is injected into the mix, it accelerates and enhances this reaction, increasing the production of C-S-H and CH, leading to better overall performance compared to using water alone.

CO_2 Injection & Hydration Enhancement in Concrete

When CO_2 is injected into fresh concrete, a series of reactions occur that fundamentally alter the behavior of the material. The primary reaction is CO_2 mineralization, where the injected CO_2 dissolves into water releasing carbonate and bicarbonate ions which then combine chemically with calcium ions released from the dissolution of un-hydrated cement and hydrate phases. Consequently, nano-sized particles of calcium carbonate ($CaCO_3$) precipitate.

CO_2 Mineralization Reaction





This CO_2 mineralization reaction occurs while the concrete is still fresh, and differs from atmospheric carbonation, where CO_2 predominantly reacts with CH. The formation of calcium carbonate minerals positively influences the cement hydration process, contributing to overall performance improvements and without affecting pore water pH.

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Mechanisms of Hydration Enhancements

The CO_2 injection into fresh concrete enhances the cement hydration process through three primary mechanisms: the filler effect, nucleation effect, and chemical effect.

1. Filler Effect

CO_2 mineralization leads to the formation of fine calcium carbonate particles, which reduce nano-porosity in the cement matrix by filling microscopic voids. The extent of this porosity reduction depends largely on the particle size. This process, known as the filler effect, improves the concrete's overall structure and durability.

2. Nucleation Effect

The nucleation effect occurs as the injection of CO_2 provides additional nucleation sites for the formation of hydration products, such as calcium silicate hydrate (C-S-H), the primary binder in concrete. This improves the cement hydration reaction process.

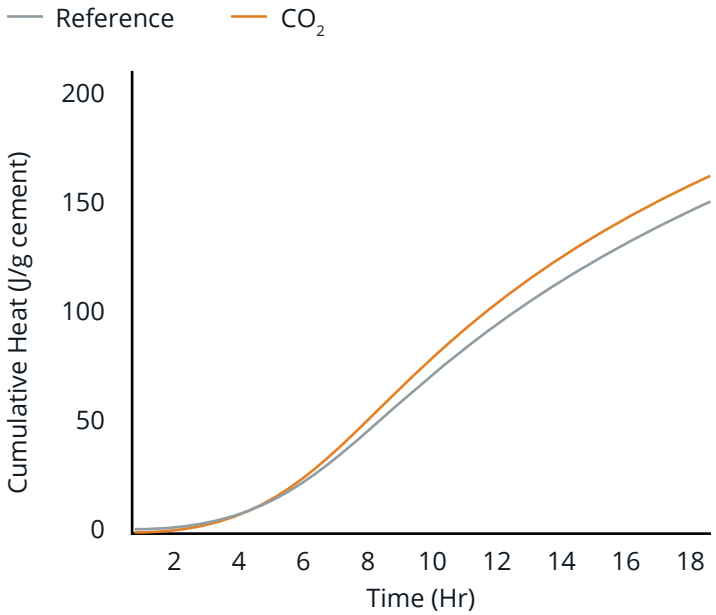
3. Chemical Effect

When CO_2 is injected into fresh concrete, it triggers a chemical effect that results in the formation of a lower Ca/Si ratio in the calcium silicate hydrate (C-S-H) gel. This change can also lead to a potential reaction with aluminates in the cement, forming carboaluminates. These reactions contribute to the overall improvement of the concrete's chemical structure.

Measuring hydration enhancements

The hydration enhancements are measurable using scientific methods like isothermal calorimetry, scanning electron microscopy (SEM), and Fourier Transform Infrared Spectroscopy (FTIR), among others. For instance, isothermal calorimetry allows researchers to assess the cement hydration kinetics in the concrete. The hydration reaction in cement is exothermic, meaning it releases heat as the cement reacts with water. This release of energy can be measured with an isothermal calorimeter and is indicative of the progress and efficiency of the hydration reaction. Researchers have observed that samples with CO_2 release more heat, indicating a higher reactivity rate and a higher degree of hydration.

Energy



CO_2 injection improves cement hydration, allowing for up to 5% reduction in cement content without compromising performance. By optimizing CO_2 dosage, both technical efficiency and economic viability are enhanced, achieving equal or superior concrete performance with less cement. This leads to cost savings and a reduced environmental footprint.

Conclusion

This hydration enhancement allows for a reduction in cement content by up to 5% without sacrificing performance. By optimizing the CO_2 dosage rate, both the technical efficiency and economic viability of the concrete mix are improved, achieving equivalent or even superior performance while using less cement. This contributes to cost savings and reduces the overall environmental impact of concrete production.