# CarbonCure Precast: Frequently Asked Questions for Structural Engineers

## What is CarbonCure?

CarbonCure helps precast producers reduce the carbon footprint of their concrete components without compromising quality or performance. The technology allows producers to inject captured carbon dioxide ($CO_2$) into concrete during mixing, where it converts to a solid mineral, calcium carbonate ($CaCO_3$).

The addition of $CO_2$ improves the compressive strength of precast concrete panels and components without impacting other fresh or hardened properties of the concrete. CarbonCure allows producers to reduce their cementitious material content while achieving equivalent—or greater—performance. CarbonCure is fully compliant with ASTM C494 Type S requirements.

### $CO_2$ Utilization vs. Atmospheric Carbonation

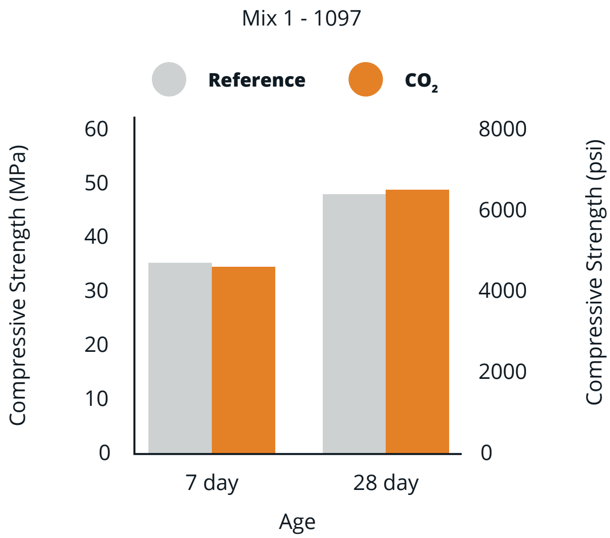
The $CO_2$ utilization process involves a reaction between deliberately added $CO_2$ during the earliest forming hydration phases and/or clinker phases in fresh state concrete (i.e. during the batching and mixing phase). During these early stages of cement hydration, the $CO_2$ mineralizes via chemical reaction. This mineralization is central to $CO_2$ utilization. Upon completion of the mineralization reaction, the added $CO_2$ converts to a solid $CaCO_3$ mineral. Subsequent hydration and phase developments are not impacted.

Another form of mineralization is weathering, also known as late stage or atmospheric carbonation, which takes place in concrete in service over extensive periods of time (e.g., months and years). Late stage or atmospheric carbonation reaction sees $CO_2$ from the atmosphere react with cement hydration phases in mature concrete. The durability of concrete can be compromised during atmospheric carbonation. Carbonation reduces the pH of the surface of the concrete, as its natural pH is a chemical repellent of molecules. As the pH becomes more neutral the surface has a lowered ability to repel those molecules. Comparatively, the in-situ development of calcium carbonate during mixing can improve performance without experiencing the negative effects of atmospheric carbonation.

## What is the impact of CarbonCure on the strength of concrete?

### Compressive Strength

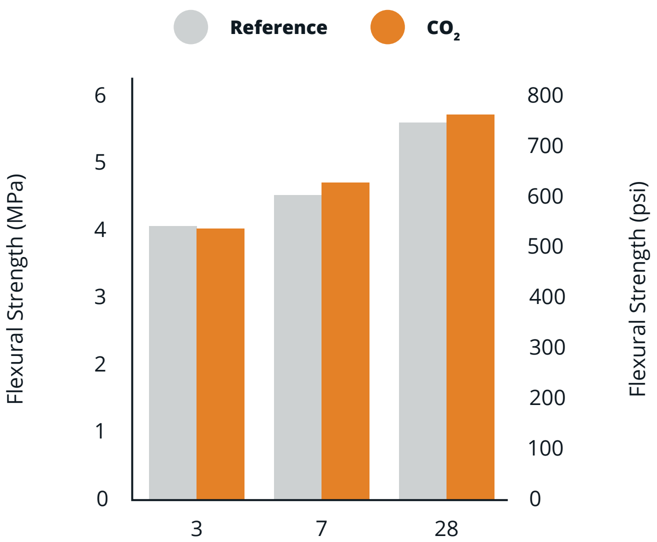
CarbonCure has been observed to provide concrete compressive strength improvements by up to 10% through and beyond 28 days. The improvement can be leveraged to support a reduction of cementitious materials in the mix design without compromising on strength performance. The compressive strengths of the modified mix designs that included the $CO_2$ injection are comparable to the reference conditions.




Representative concrete samples showing compressive strength profile of concrete mixes with a cement reduction and $CO_2$, versus a control mix made without $CO_2$ or cement reduction. Data shown represents the average of 19 control samples and 30 samples treated with $CO_2$ and the cement reduction.

### Flexural Strength

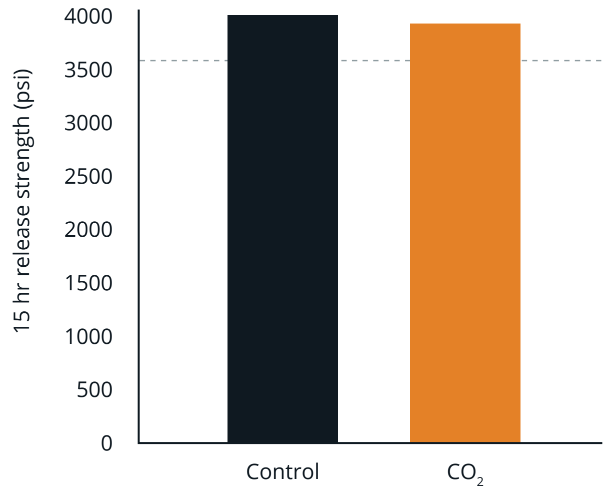
The flexural strength of concrete is unaffected by the $CO_2$ addition. A 4000 psi (27.6 MPa) CarbonCure concrete mix with a cement reduction demonstrates comparable flexural strength to an unmodified control mix after 28 days.

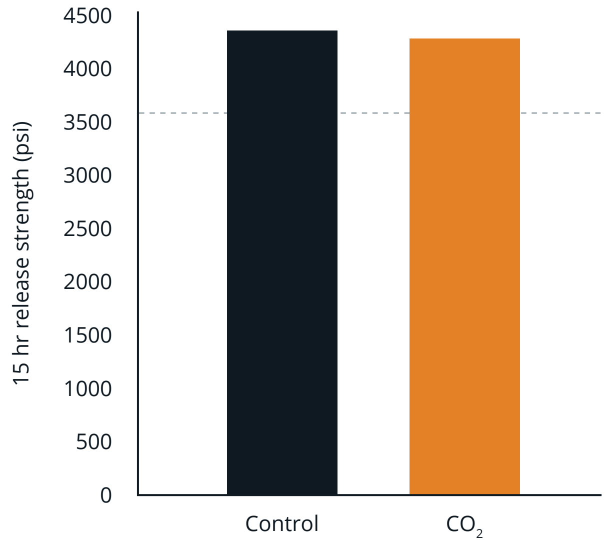



ASTM C78 test results comparing the flexural strength of a 4000 psi (27.6 MPa) CarbonCure mix with a reduction in cement vs. a control mix without $CO_2$ or cement reduction. After 28 days, the flexural strength is equivalent with the reduced cement mix, indicating that the addition of $CO_2$ had no impact on flexural strength.

## Release Strength

The release strength of precast concrete is unaffected by the $CO_2$ addition. In an example requiring a 3500 psi (24.1 MPa) strength at 11 hours, a CarbonCure concrete mix with a cement reduction saved 23 lbs/yd$^3$ (14 kg/m$^3$) and did not impact the release strength. In another example with a release at 15 hours, the 4000 psi (27.6 Mpa) release strength was achieved while 33 lbs/yd$^3$ (20 kg/m$^3$) of cement were saved.




**Goal strength: 3500 psi (24 Mpa) at 11 hour release**

**Control mix:**

- 800 lbs/yd$^3$ (475 kg/m$^3$)
- 82% cement, 18% FA

**At a 3.5% binder reduction:**

- 23 lbs (10 kg) of cement saved
- 35 lbs/yd$^3$ (21 kg/m$^3$) of $CO_2$ saved
- dose of $CO_2$ - 0.1%
- no change in slump

**At a 5% binder reduction:**

- 33lbs (15kg) of cement saved
- 51 lbs/yd$^3$ (30 kg/m$^3$) of $CO_2$ saved
- dose of $CO_2$ - 0.1%
- no change in slump

**Goal strength: 4000 psi (27.6 Mpa) at 15 hour release**

**Control mix:**

- 475 lbs/yd$^3$ (282 kg/m$^3$)
- 82% cement, 18% FA

**At a 3.5% binder reduction:**

- 14 lbs (6.4 kg) of cement saved
- 22 lbs/yd$^3$ (13 kg/m$^3$) of $CO_2$ saved
- dose of $CO_2$ - 0.1%
- no change in slump

**At a 5% binder reduction:**

- 19 lbs (9 kg) of cement saved
- 30 lbs/yd$^3$ (18 kg/m$^3$) of $CO_2$ saved
- dose of $CO_2$ - 0.1%
- no change in slump

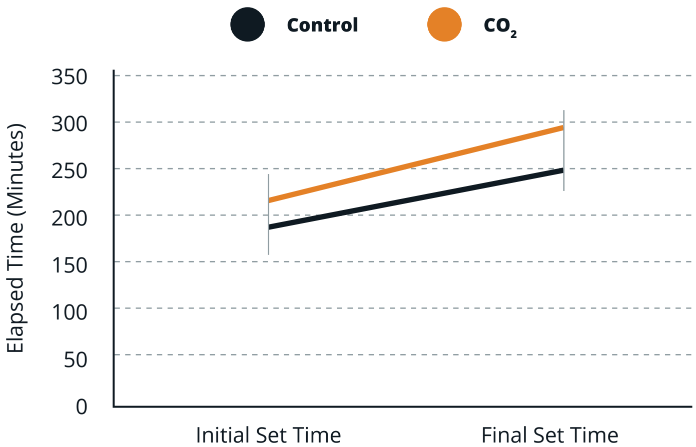
Representative concrete samples showing compressive strength profile of concrete mixes with a cement reduction and $CO_2$, versus a control mix made without $CO_2$ or cement reduction. Data shown represents the average of 19 control samples and 30 samples treated with $CO_2$ and the cement reduction.

ASTM C78 test results comparing the flexural strength of a 4000 psi (27.6 MPa) CarbonCure mix with a reduction in cement versus a control mix without $CO_2$ or cement reduction. After 28 days, the flexural strength is equivalent with the reduced cement mix, indicating that the addition of $CO_2$ had no impact on flexural strength.

## How does CarbonCure influence fresh concrete properties?

### Set Time

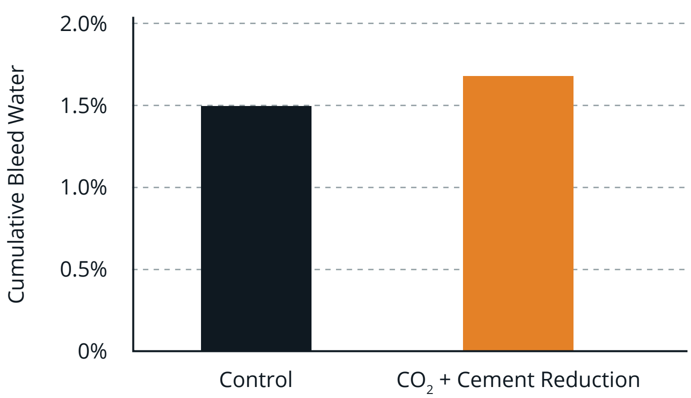
The addition of $CO_2$ to concrete mixes does not impart any significant change to the concrete set time relative to a control mix as measured by ASTM C403. Note that when pouring concrete in cold weather it is recommended to follow ACI 306R-16 guidelines for cold weather concreting.




ASTM C403 test results comparing the set time of three concrete mixes with $CO_2$ added versus three control samples without $CO_2$. As shown, the average final set time for the CarbonCure mix set was within the acceptable limits of this test (defined as no more than 1 hour earlier or 1.5 hours later than the control).

### Bleed Rate

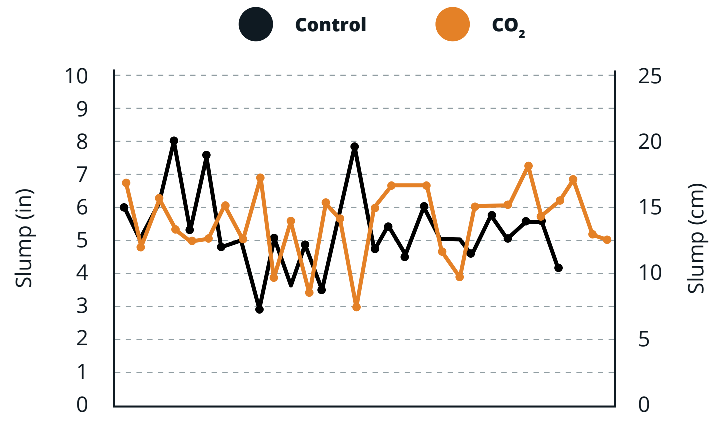
The addition of $CO_2$ to concrete mixes with a cement reduction does not impart any change to the bleed rate of a concrete mix as measured by ASTM C232.




ASTM C232 test results comparing the bleed rate of a 4000 psi (27.6 MPa) CarbonCure mix with a cement reduction vs. an unmodified control mix. The CarbonCure mix demonstrates an equivalent water bleed rate indicating that the $CO_2$ has a neutral effect.

### Workability

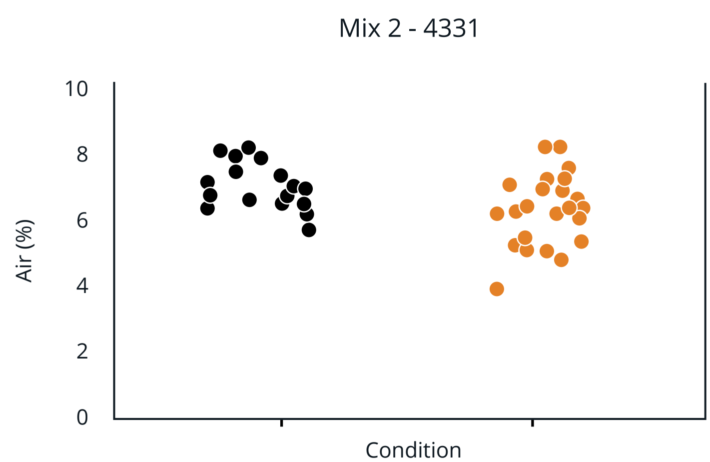
Concrete produced using a $CO_2$ injection maintains desired workability. The $CO_2$ addition does not impact the effectiveness of the plasticizing admixtures, the amount of workability, nor the batch-to-batch consistency of the workability.




The slump of concrete produced with $CO_2$ is identical to and within the control limits of control concrete samples.

### Air content

Concrete produced using a $CO_2$ injection and a cement reduction maintains desired air content. The $CO_2$ addition impacts neither the amount of air nor the batch-to-batch consistency of the air.




The air content of concrete produced with $CO_2$ is identical to and within the control limits of control concrete samples.

## How does CarbonCure effect the properties of self consolidating concrete?

Testing has shown similar increases to typical traditional concrete. $CO_2$ has no impact on spread flow or air permeability. CarbonCure has successfully integrated into SCC mixes with no impact on quality or performance.

### Exothermic Reactions

The addition of $CO_2$ does not impact the mixing temperatures of the concrete. Despite the low temperatures of $CO_2$ injection, the mineralization process is exothermic, leading to no disruption of the intended mixing temperatures.

### Volume and Yield

Mix design adjustments should serve to maintain volume and yield. In the event that binder is reduced, the volume of concrete can be maintained by increasing the amount of fine aggregate by a volume equivalent to that of the removed binder.

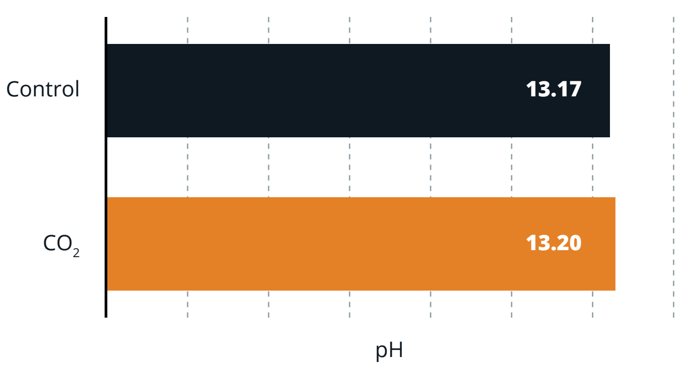
### Admixture Loading

Where admixtures are dosed on the basis of cement, a reduced cement loading may reduce the quantity of admixtures required to achieve the same performance outcome.

## How does CarbonCure influence hardened concrete properties?

### pH

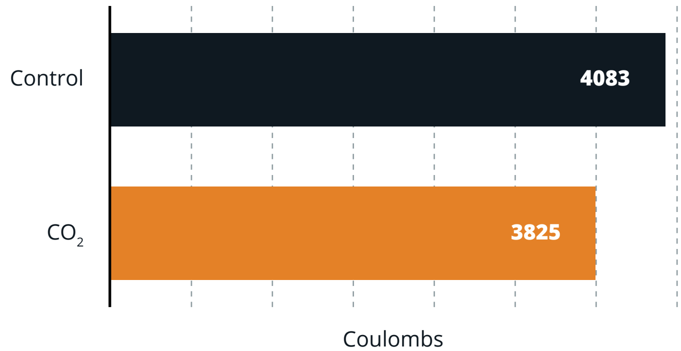
The pore solution pH of concrete produced with $CO_2$ is equivalent to that of conventionally produced concrete. $CO_2$ introduced to concrete mixes through the CarbonCure process rapidly converts to calcium carbonate, and there is therefore no reduction in the formation of calcium hydroxide during later hydration that would lead to reduced pore solution alkalinity and pH levels.



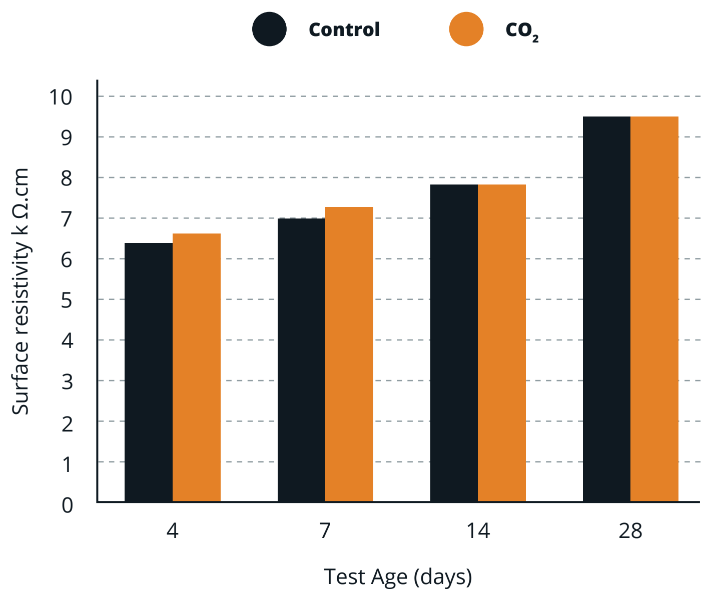

Pore solution pH at 56 days is unchanged by the addition of $CO_2$.

### Chloride Ion Penetrability – RCPT and Surface Resistivity

Concrete samples dosed with $CO_2$ and a cement reduction, as tested according to ASTM C1202 and AASHTO T358, demonstrated resistance to chloride ion penetration that was equivalent to control concrete mixes.



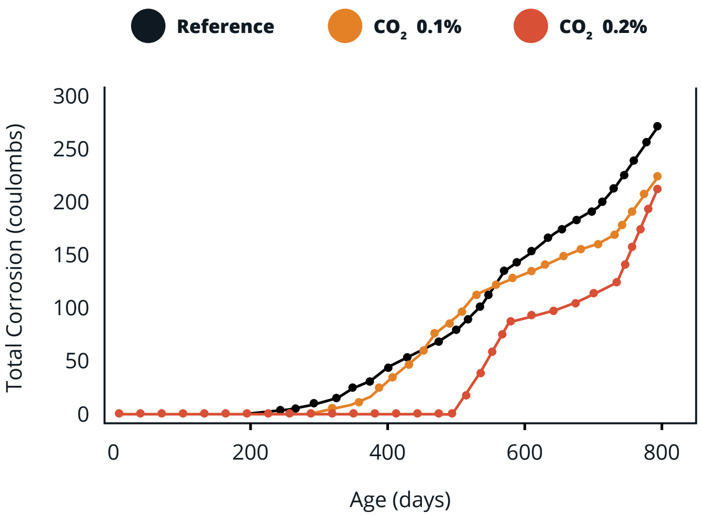

Rapid chloride permeability test (ASTM C1202) results at 28 days show that the performance of concrete produced with $CO_2$ is equivalent to that of a control concrete sample. A charge passed > 4,000 coulombs is considered to indicate high chloride penetrability while when between 2,000 – 4,000 coulombs it indicates moderate chloride penetrability.



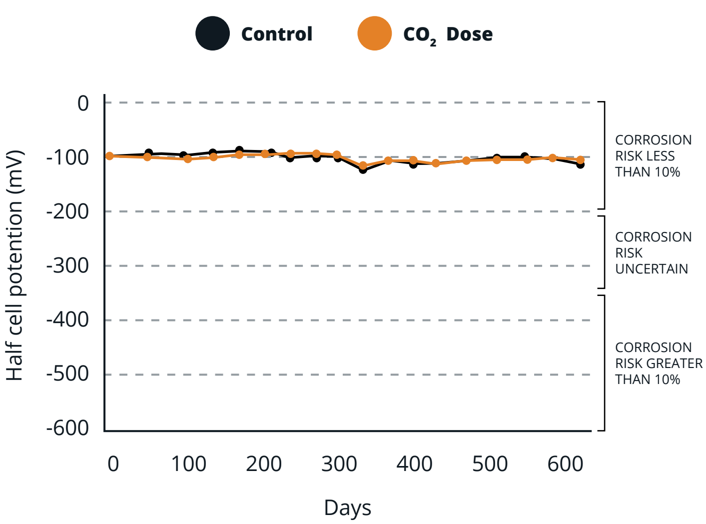

Surface resistivity (AASHTO T358) results show that the performance of concrete produced with $CO_2$ is equivalent to that of a control concrete sample.

## Corrosion testing

The corrosion performance of reinforced concrete dosed with $CO_2$ has been examined through testing under ASTM G019 (corrosion) and ASTM C876 (half cell potential). The results indicate that the addition of $CO_2$ does not affect the corrosion performance of reinforcing steel.



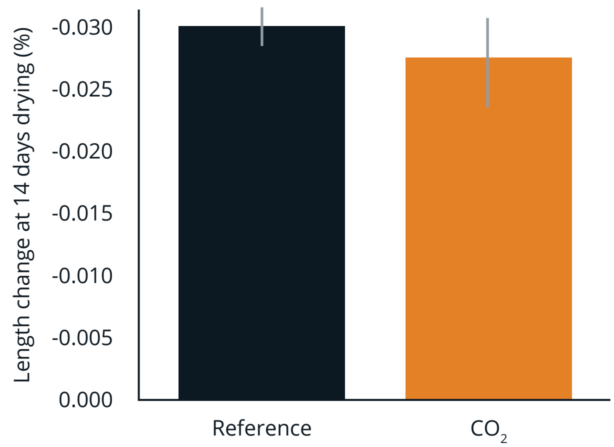

Total Corrosion (ASTM G109) results show that the performance of concrete produced with $CO_2$ is comparable or better than that of a control concrete mix.




Half cell potential (ASTM C876) results show that the performance of concrete produced with $CO_2$ is comparable to that of a control concrete mix.

## Drying Shrinkage

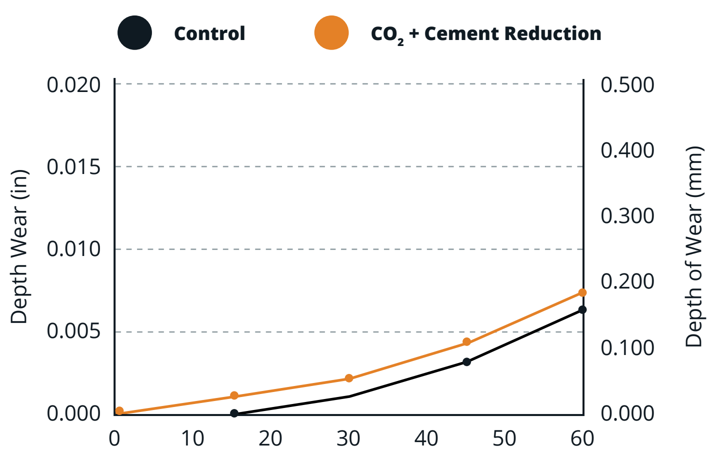
The addition of $CO_2$ to concrete mixes does not impart any change to the drying shrinkage relative to a concrete mix as measured by ASTM C157.




ASTM C157 test results comparing the drying shrinkage of a 4000 psi (27.6 MPa) CarbonCure mix with a cement reduction vs. an unmodified control mix. The CarbonCure mix demonstrates a potential reduction in drying shrinkage versus the control mix, indicating a neutral to positive effect.

## Abrasion Resistance

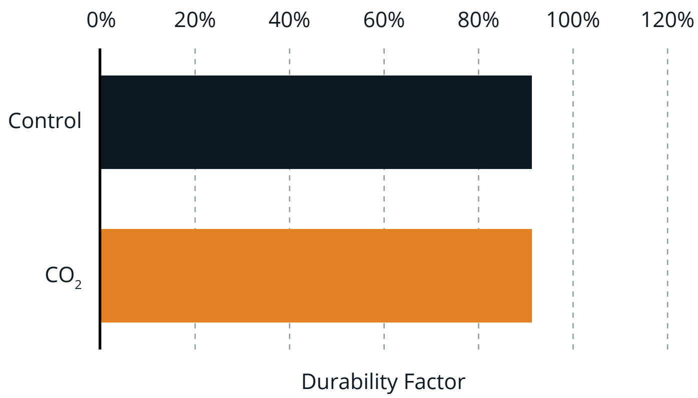
The impact of the $CO_2$ addition on abrasion resistance has been examined according to ASTM C779. Concrete samples produced with $CO_2$ and a reduced cement content demonstrate equivalent abrasion resistance to control samples.




ASTM C779 Procedure B test results comparing the abrasion resistance of the finished surface of a 4000 psi (27.6 MPa) CarbonCure mix with a cement reduction versus an unmodified control mix. After 60 days, the final depth of wear of the CarbonCure mix was within 0.001 inches (0.0254 mm), indicating a neutral effect.

## Freeze-Thaw

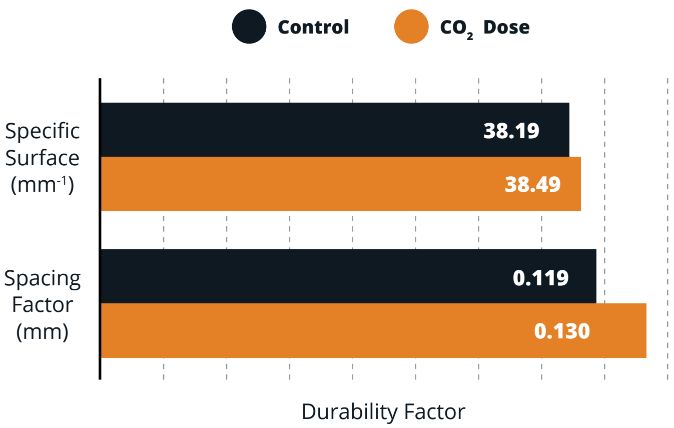
The impact of the $CO_2$ addition on the freeze-thaw durability has been examined according to ASTM C666. Concrete samples produced with $CO_2$ and a reduced cement content demonstrate equivalent freeze-thaw resistance to control concrete samples.




Freeze-thaw durability of concrete produced with $CO_2$ and a cement reduction is equivalent to that of a control concrete mix.

## Hardened Air

The impact of the $CO_2$ addition on the hardened air void characteristics of air entrained concrete has been examined according to ASTM C457. The addition of carbon dioxide does not impact the effectiveness of air entraining admixtures.




Hardened air void characteristics of concrete produced with $CO_2$ is equivalent to that of a control concrete mix. For air-entrained concrete designed in accordance with ACI 201.2R and ACI 211.1, the specific surface is usually in the range of 25 to 45 $mm^{-1}$ and then spacing factor is usually in the range of 0.1 to 0.2 mm.

# What mix design adjustments are made for a CarbonCure concrete mix?

## Cement Reduction

Strength improvements attributable to the $CO_2$ addition can be leveraged to create a more efficient or optimized concrete mix. Often the adjustment involves a reduction in the cement content of the mix an average of 3%. Where the concrete mixes contain supplementary cementitious materials, the total cementitious content is reduced (rather than just a reduction of the cement). For example, if the cementitious materials used in a concrete mix is 20% fly ash and 80% cement, and the use of $CO_2$ enables a reduction of 20 pounds per cubic yard (11.9 kilograms per cubic metre) of cementitious material, the adjusted mix would have 4 pounds (1.8 kilograms) less of fly ash and 16 pounds (7.3 kilograms) less of cement in keeping with the original ratio of cement to fly ash. Alternatively, a cement reduction can be paired with an increase in or addition of another binder or filler (e.g., fly ash, slag, limestone) that has a lower carbon footprint.

## Water to Cement Ratio

Where CarbonCure is used to achieve a reduction in the cementitious material content, the water to cement ratio is necessarily unaffected as the total volume of water remains unchanged. Typical adjustments to the CarbonCure mixes may see the water to cement ratio increase by 0.02 relative to the equivalent control mix.

## Volume and Yield

Mix design adjustments should serve to maintain volume and yield. In the event that binder is reduced, the volume of concrete can be maintained by increasing the amount of fine aggregate by a volume equivalent to that of the removed binder.

## Admixture Loading

Where admixtures are dosed on the basis of cement, a reduced cement loading may reduce the quantity of admixtures required to achieve the same performance outcome. Comprehensive testing and customer feedback have indicated that CarbonCure is compatible with commonly used admixtures available on the market. The $CO_2$ addition has not been associated with any performance changes for plasticizing, high-range water reducing, air entraining or set accelerating admixtures. These admixtures have been regularly used in concrete made with CarbonCure.

## Have you tested CarbonCure in prestressed concrete with higher strengths, i.e. C50/60?

CarbonCure has been used in concrete with strengths up to C50/C60. CarbonCure has been successfully proven in concrete applications with up to 10,000 - 14,000 psi (69 - 97 MPa).

## Does equipment require any modifications to protect against acid corrosion from injected $CO_2$?

CarbonCure mineralization does not impact structural performance or durability and does not increase risk of corrosion. Late stage and early stage mineralization affect corrosion differently. CarbonCure's reaction is early stage, resulting in nanoparticles within the mix design with the same pH as a typical coarse aggregate, so there is no increased risk of corrosion.

## How does CarbonCure account for transportation of the industrial $CO_2$ to the precast facility?

CarbonCure's Technical Services & Support team helps producers to develop each specific mix design, which are then accessible via the online platform called myCarbonCure. All mix design inputs allow for the $CO_2$ impact of transportation from your local industrial supplier, and the final calculation reflects this variable.

## Who else in our industry is using CarbonCure?

To date, North American precast customers have produced 413,569 cubic yards (316,196 cubic metres) of concrete using CarbonCure. Reporting data from these organizations indicates that performance and quality are not impacted by using $CO_2$ in mixing, and have resulted in a total of 4,092 metric tons of $CO_2$ saved instead of being released into Earth's atmosphere.

## Can CarbonCure be used with other materials, technologies, and approaches to reducing the carbon footprint of concrete?

CarbonCure has been used in thousands of different concrete mixes across continents. Concrete mixes made with traditional Ordinary Portland Cement and commonly used supplementary cementitious materials like fly ash and blast furnace slag are being placed every day. Comprehensive testing and customer feedback have indicated that CarbonCure is compatible with commonly used admixtures available on the market. The $CO_2$ addition has not been associated with any performance changes for plasticizing, high-range water reducing, air-entraining or set accelerating admixtures. These admixtures have been regularly used in concrete made with CarbonCure.

## How can I use CarbonCure on my project?

Regulations, codes, and standards that govern the purchasing of concrete often rely on the use of prescriptive specifications which set specific limits on how concrete can be made. Although these specifications do not directly restrict the use of $CO_2$, they can inadvertently create barriers by using requirements that prevent innovation by concrete producers. Common restrictions include:

- Mandated minimum cement requirements
- Overly strict water to cement ratio requirements

Updating specifications to meet the performance needs of owners, designers, contractors and producers is critical to empowering innovation and achieving lower carbon concrete products. Promote sustainable concrete production by adopting performance-based specifications. Recommendations and guidance are provided by the National Ready Mixed Concrete Association and Structural Engineers 2050.

## Get in Touch

For any other questions about CarbonCure Precast that were not addressed in this document, visit **carboncure.com/precast**, reach out to us at **sales@carboncure.com** or give us a call at **+1 (844) 407-0032** (toll-free).