Frequently Asked Questions for Engineers

What is CarbonCure?

CarbonCure enables concrete producers to reduce their cement content without compromising quality or performance. Using an approach known as ***CO_2 utilization***, CarbonCure's technology introduces post-industrial carbon dioxide (CO_2) to freshly mixed concrete, where it converts to a solid mineral, calcium carbonate ($CaCO_3$). The addition of CO_2 allows producers to safely reduce the cement content in most production concrete mix designs where minimum cement thresholds allow. The addition of CO_2 is much like adding any other admixture for concrete and, as such, the technology has been categorized and shown to meet all the requirements for an ASTM C494 Type S admixture for concrete.

CO_2 Utilization vs. Atmospheric Carbonation

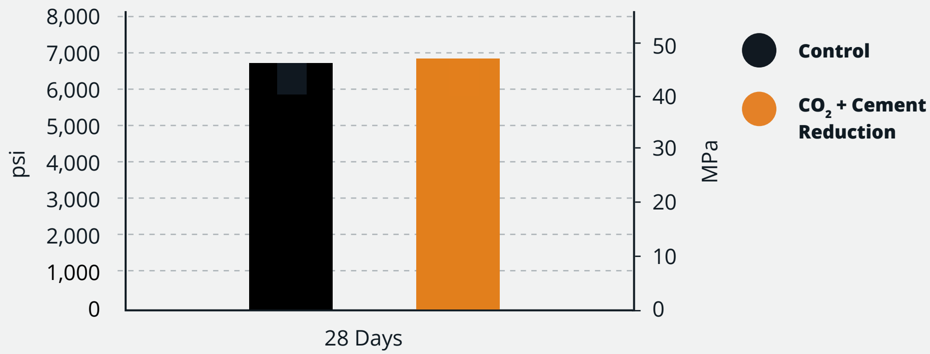
CarbonCure's technology involves the introduction of carbon dioxide into concrete as it is being batched and mixed. The CO_2 is mineralized in a chemical reaction that occurs alongside the earliest stages of the cement hydration. Subsequent hydration and phase development continue as normal after the CO_2 is added. The introduced CO_2 converts to a solid $CaCO_3$ mineral.

The mineralization reaction central to CO_2 utilization takes place within the first few minutes of hydration, whereas weathering (atmospheric) carbonation takes place in concrete in service over long time scales (e.g., months and years). The latter reaction sees CO_2 from the atmosphere react with cement hydration phases present in mature concrete which compromises durability. The CO_2 utilization process involves a reaction between deliberately added CO_2 and the earliest forming hydration phases and/or clinker phases in concrete that is in the fresh state. 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

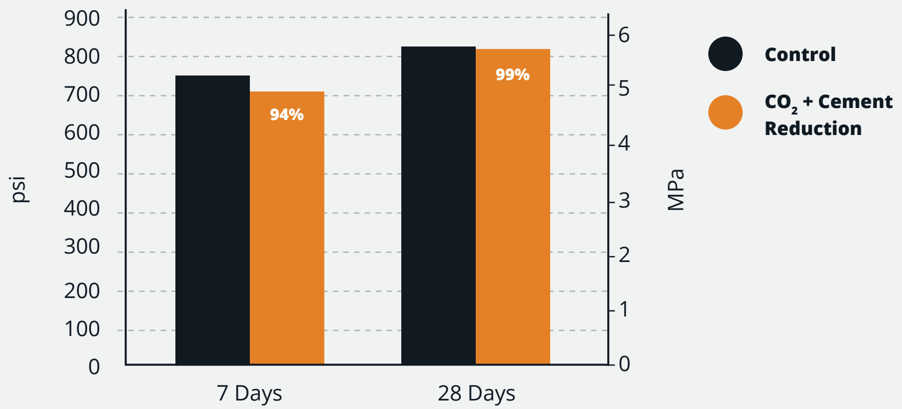
CarbonCure has been observed to provide ready mix concrete compressive strength improvements by up to 10% through and beyond 28 days. The improvement can be leveraged to support a reduction of cementitious materials in the mix design without compromising on strength performance.



Representative concrete samples showing compressive strength profile of concrete mixes with a cemen 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

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



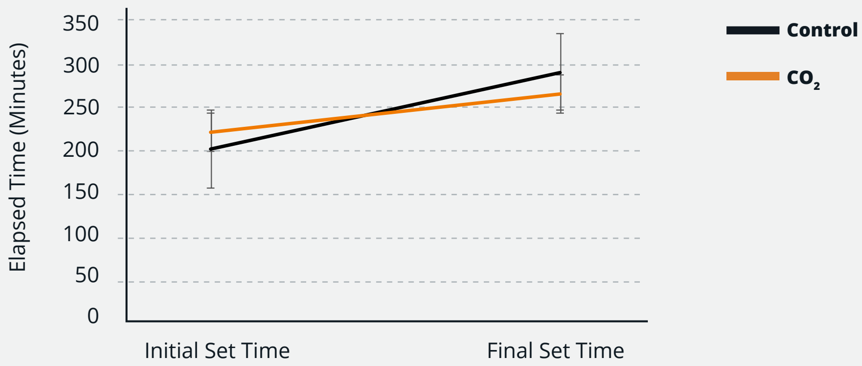
ASTM C78 test results comparing the flexural strength of a 4000 psi (27.6 MPa) CarbonCure mix with a reduction in cement vs. a control mix without CO_2 or cement reduction. After 28 days, the flexural strength is equivalent with the reduced cement mix, indicating that the addition of CO_2 had no impact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

What is the impact of CarbonCure on the durability of concrete?

How does CarbonCure influence fresh concrete properties?

Set Time

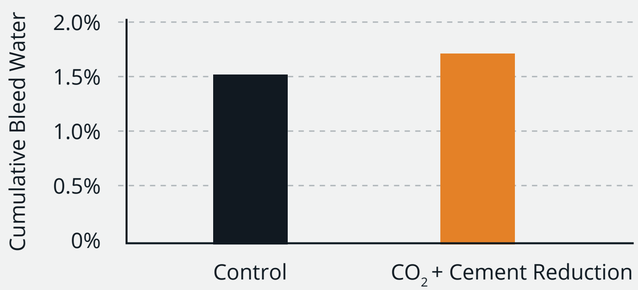
The addition of CO_2 to concrete mixes does not impart any significant change to the concrete set time relative to a control mix as measured by ASTM C403. Note that when pouring concrete in cold weather it is recommended to follow ACI 306R-16 guidelines for cold weather concreting.



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 s t was within the acceptable limits of this test (defined as no more than 1 hour arlier or 1.5 hours later than the control).

Bleed Rate

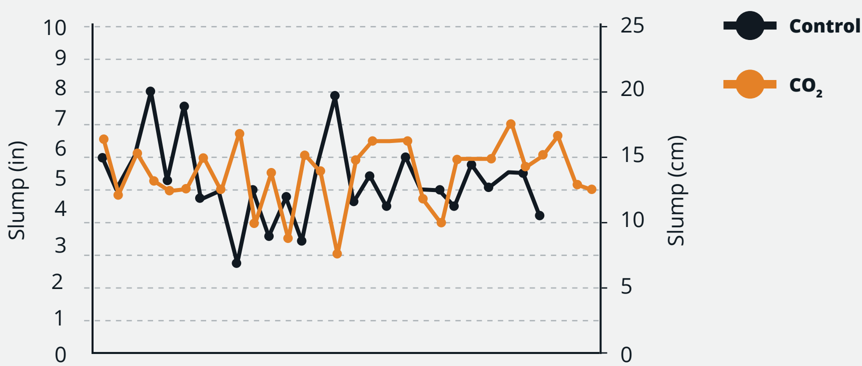
The addition of CO_2 to concrete mixes with a cement reduction does not impart any change to the bleed rate of a concrete mix as measured by ASTM C232.



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 dem nstrates an equivalent water bleed rate indicating that the CO_2 has a neutral effect

Workability

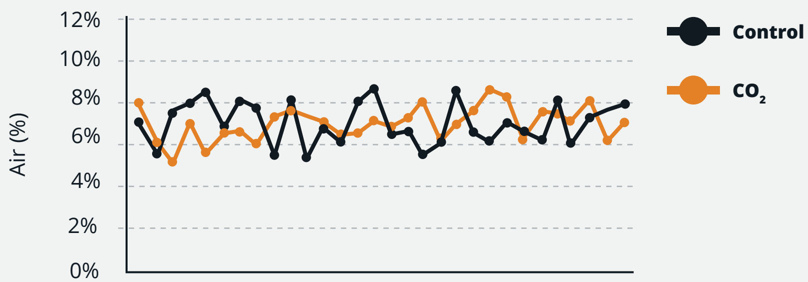
Concrete produced using a CO_2 injection maintains desired workability. The CO_2 addition does not impact the effectiveness of the plasticizing admixtures, the amount of workability, nor the batch-to-batch consistency of the workability. Occasional slump reductions are possible, which present opportunities for optimizing the synergy between CO_2 injection and customized admixture design.



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.

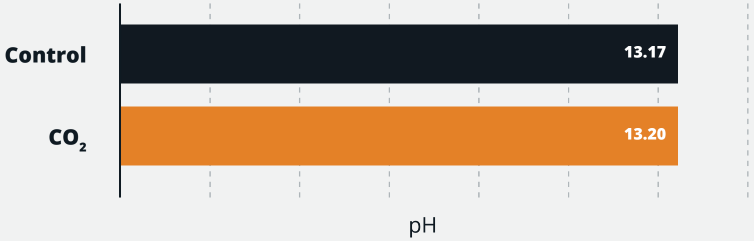


The air content of concrete produced with CO_2 is identical to and within the control limits of control concrete samples.

How does CarbonCure influence hardened concrete properties?

pH

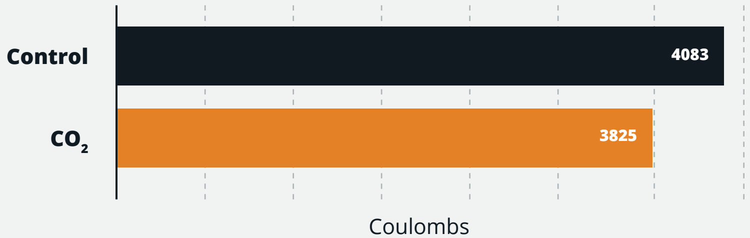
The pore solution pH of concrete produced with CO_2 is equivalent to that of conventionally produced concrete. CO_2 introduced to concrete mixes through the CarbonCure process rapidly converts to calcium carbonate. This does not reduce the formation of calcium hydroxide during later hydration and therefore does not reduce the pore solution alkalinity and pH levels.



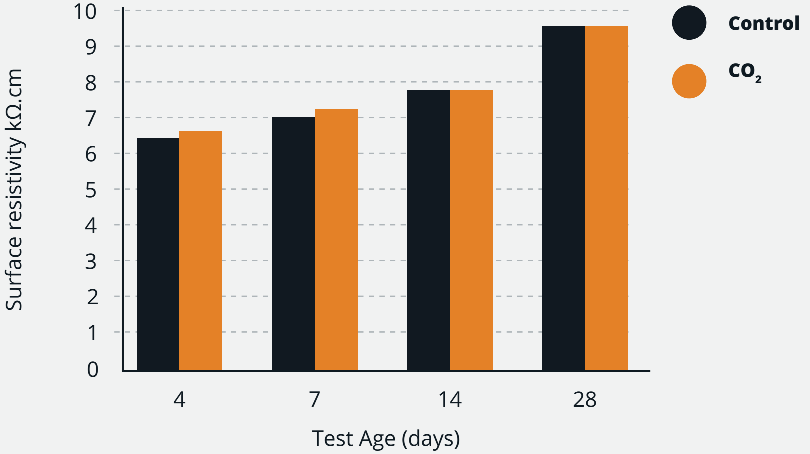
Pore solution pH at 56 days is unchanged by the addition of CO_2.

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.



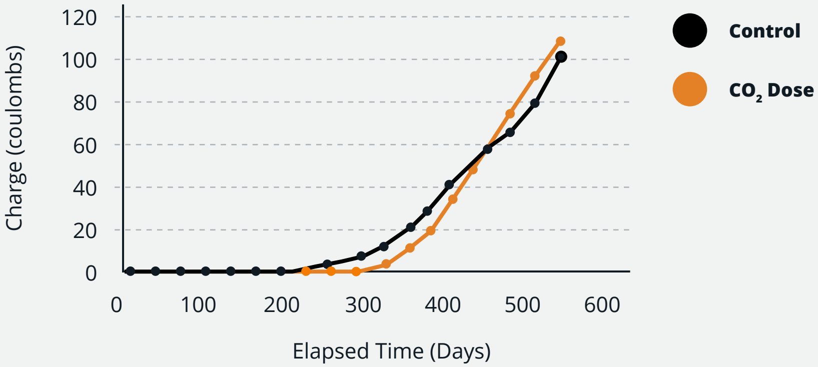
Rapid chloride permeability test (ASTM C1202) results at 28 days show that the performance of concrete produced with CO_2 is equivalent to that of a control concrete sample. A charge passed > 4,000 coulombs is considered to indicate high chloride penetrability while when between 2,000 – 4,000 coulombs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

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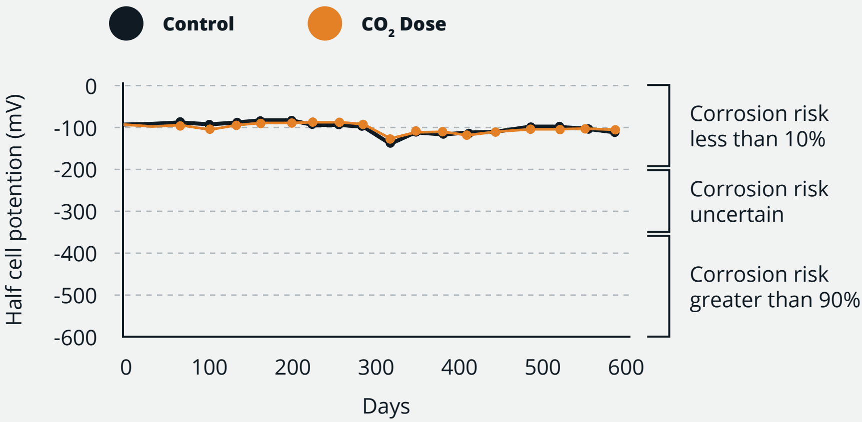
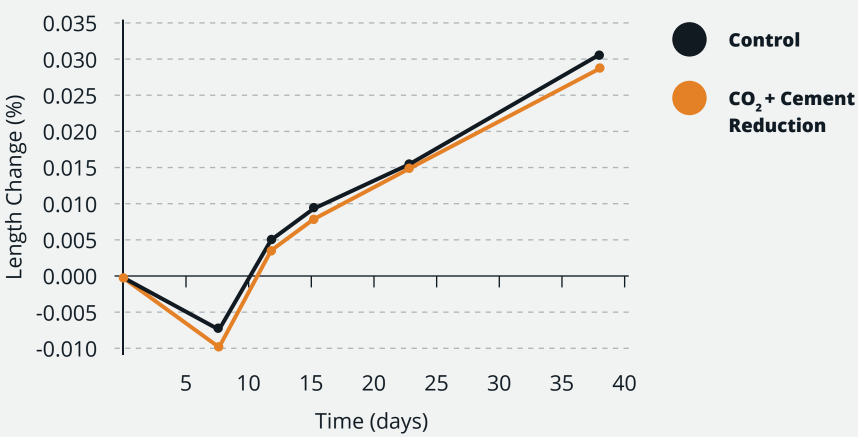


Half cell potential (ASTM C876) results show that the performance of concrete produced with CO_2 is comparable to that of a control concrete mix.

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 ix demonstrates a potential reduction in drying shrinkage vs. the control mix, indicating a neutral to positive effect

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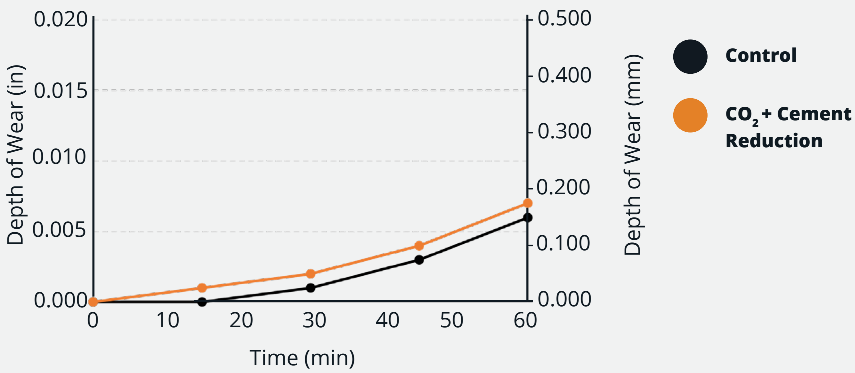
Abrasion Resistance

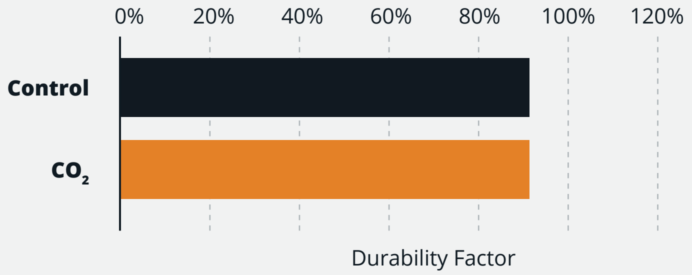
The impact of the CO_2 addition on abrasion resistance has been examined according to ASTM C779. Concrete samples produced with CO_2 and a reduced cement content demonstrate equivalent abrasion resistance to control samples.



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

Freeze-Thaw

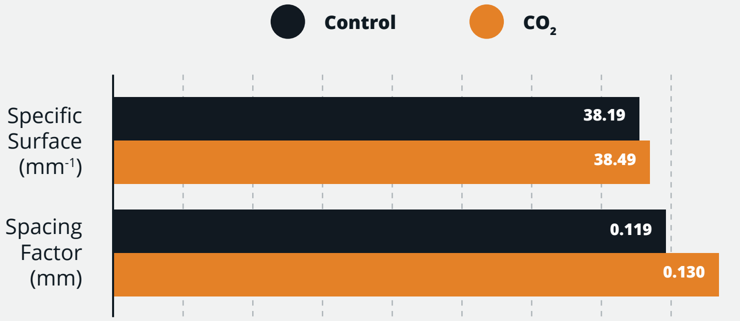
The impact of the CO_2 addition on the freeze-thaw durability has been examined according to ASTM C666. Concrete samples produced with CO_2 and a reduced cement content demonstrate equivalent freeze-thaw resistance to control concrete samples.



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 i 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.

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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 by up to 6%. 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 (2.4 kilograms per cubic metre) less of fly ash and 16 pounds (9.5 kilograms per cubic metre) 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 affected 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. Occasional slump reductions are possible, which present opportunities for optimizing the synergy between CO_2 injection and customized admixture design.

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 North America and Asia. 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.

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For any other questions on CarbonCure that were not addressed in this document, reach out to us at **info@carboncure.com.**