

# CarbonCure Ready-Mix Technology – Strength Improvement in Concrete Mixture

## Type GU Cement

### Abstract

The CarbonCure ready-mix technology produced concrete with a binder system comprising 100% Type GU cement. The mix was produced with CO<sub>2</sub> which was added like an admixture. The added CO<sub>2</sub> enhanced the 28-day compressive strength by 22% over a reference mix.

### Introduction

CarbonCure Technologies (CCT) has developed a carbon dioxide (CO<sub>2</sub>) utilization approach that injects CO<sub>2</sub> into fresh ready-mix concrete similar to introducing any other chemical admixture. The CO<sub>2</sub> reacts with the calcium silicate phases present in the cement to form calcite nanoparticles that can enhance the compressive strength by improving the cement hydration efficiency of concrete [1] without compromising durability [2]. This allows for the optimization of any concrete mix design by safely reducing cement content and lowering the carbon footprint of concrete with no impact on quality or performance. The technology can be applied to a wide range of ready-mix concrete designs.

### Case Study

The trial considered two conditions: 1) a reference concrete mixture using 100% Type GU cement designed to have a 28-day compressive strength of 30 MPa (4,350 psi), and 2) a concrete mixture incorporating CO<sub>2</sub> addition as an admixture (referred herein as the CarbonCure mix). The proportions for the two mix variations are presented in **Table 1**. The data set comprises 8 samples for the reference mix and 26 samples for the CarbonCure mix. All proportions were the same in both mix designs except for the CO<sub>2</sub> content, which was 731 mL/m<sup>3</sup> (18.9 oz/yd<sup>3</sup>) in the CarbonCure mix.

**Table 1: Mix design details for the reference and CarbonCure mixtures.**

Component	Unit	Reference	CarbonCure
Type GU	kg/m <sup>3</sup> (lb/yd <sup>3</sup> )	350 (590)	350 (590)
Coarse Aggregate	kg/m <sup>3</sup> (lb/yd <sup>3</sup> )	907 (1,529)	907 (1,529)
Fine Aggregate	kg/m <sup>3</sup> (lb/yd <sup>3</sup> )	865 (1,458)	865 (1,458)
Water	L/m <sup>3</sup> (gal/yd <sup>3</sup> )	160 (32.3)	160 (32.3)
Mid-Range Water Reducer	mL/m <sup>3</sup> (oz/yd <sup>3</sup> )	1138 (29.4)	1138 (29.4)
CO <sub>2</sub>	mL/m <sup>3</sup> (oz/yd <sup>3</sup> )	-	731 (18.9)
w/cm	-	0.46	0.46

### Results

#### CO<sub>2</sub> Effect on Cement Hydration

When cement reacts with water, an exothermic chemical reaction takes place and calcium-based hydration products are formed. These products provide strength and durability to the concrete material. The extent of the cement chemical reaction can be assessed using an isothermal calorimeter by measuring the heat released in a cement paste sample. **Figure 1** shows the heat flow (power) and cumulative heat (energy) released over the first 20 hours of reaction measured from lab-produced cement paste samples with and without CO<sub>2</sub>. The faster and higher heat release exhibited by the sample containing CO<sub>2</sub> is indicative of more reactivity in that sample. This is due to the formation of calcite nanoparticles from the CO<sub>2</sub> mineralization reaction and how they catalyzed the subsequent hydration [1]. This led to a strength increase for the CarbonCure mix, as detailed in subsequent sections.

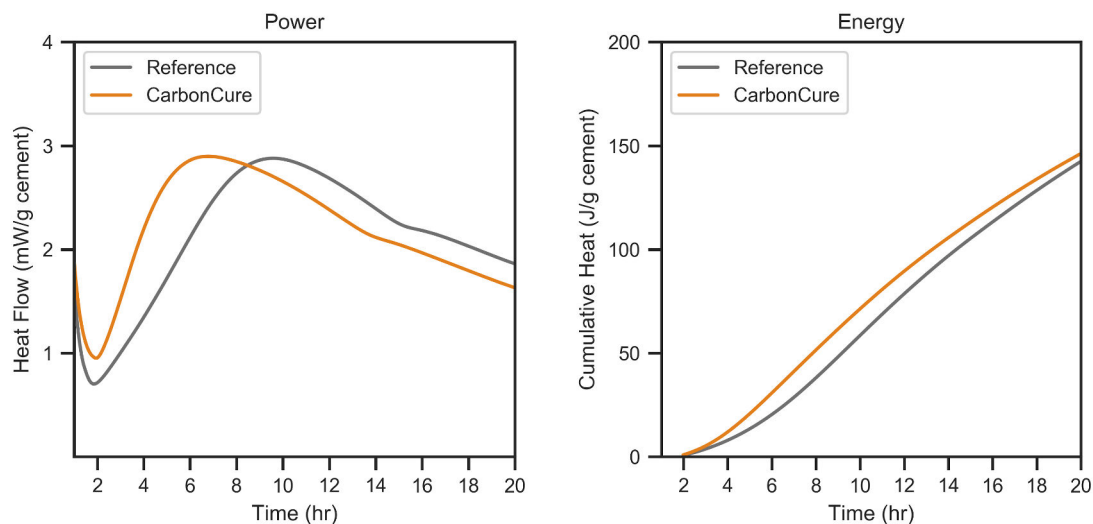


Figure 1: Isothermal calorimetry results on reference and CarbonCure cement paste samples.

#### CO<sub>2</sub> Effect on Field Fresh Properties

The concrete field slump and air content results are shown in **Figure 2** for the reference and CarbonCure mixes. The slump for the reference averaged 125 millimetres (5 inches) while the CarbonCure mix averaged 105 millimetres (4.25 inches). The air content for the reference mix design averaged 6.9% while the CarbonCure mix averaged 6.1%. In both cases, the air content was very similar and within the desired range of 4 - 7%.

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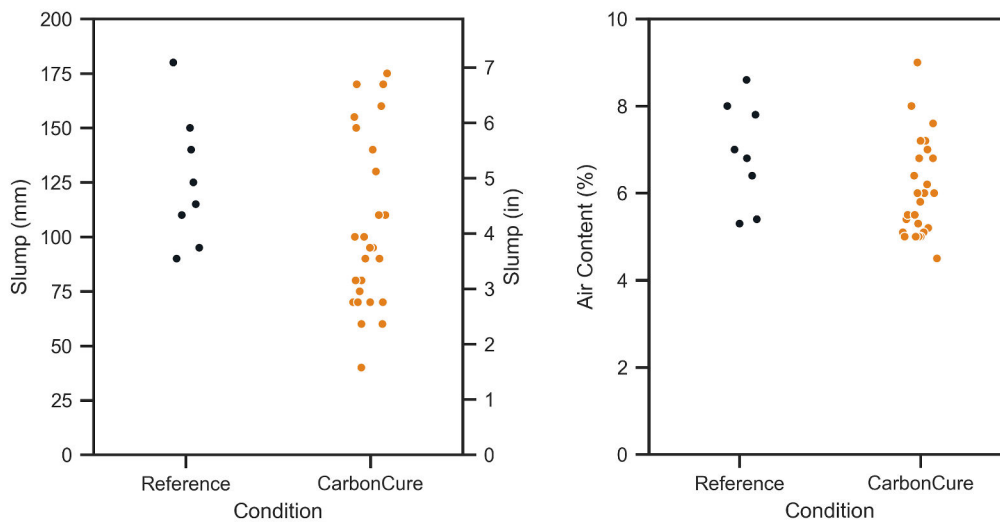


Figure 2: Slump and air content of reference and CarbonCure concrete.

### CO<sub>2</sub> Effect on Field Compressive Strength

**Table 2** and **Figure 3** show compressive strength data for both the reference and CarbonCure mixes at 7- and 28-day age intervals. The average compressive strength at 28 days was 29.2 MPa (4,235 psi) for the reference mix and 35.8 MPa (5,192 psi) for the CarbonCure mix. The CarbonCure mix had a 22% higher average compressive strength than the reference mix.

Table 2: Strength performance details for reference and CarbonCure mixes.

Metric	Unit	Reference	CarbonCure	Difference
Sample Count		8	26	
Average 7-day strength	MPa (psi)	23.3 (3,379)	29.1 (4,221)	+25%
St. Dev of 7-day strength	MPa (psi)	2.9 (421)	2.6 (377)	-15%
Average of 28-day strength	MPa (psi)	29.2 (4,235)	35.8 (5,192)	+22%
St. Dev of 28-day strength	MPa (psi)	3.0 (435)	2.6 (377)	-15%

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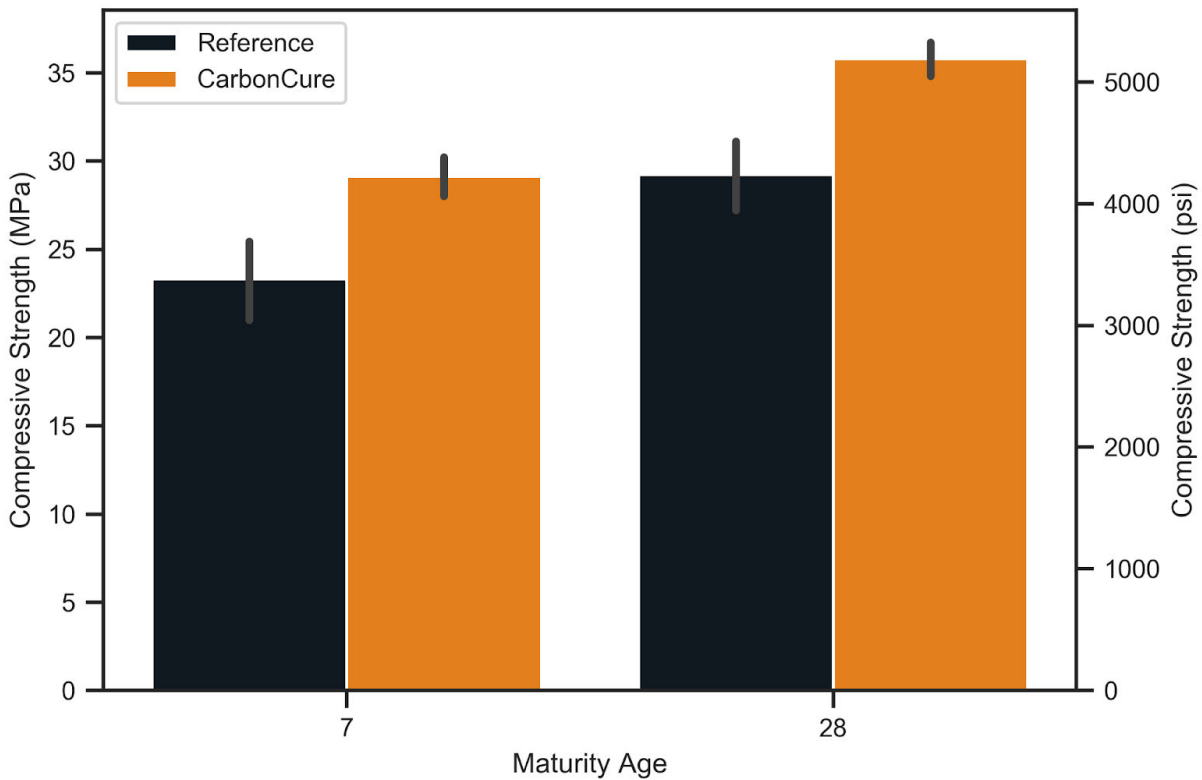


Figure 3: Hardened property results for the reference and CarbonCure mixes.

### Mix Performance

The performance of the two mix designs in terms of cement efficiency is outlined in **Table 3** below. The cement efficiency is calculated using **Equation 1**:

$$\text{cement efficiency} = \frac{\text{compressive strength}}{\text{cement mass per unit of concrete}} \quad (1)$$

The reference mix design demonstrates a 28-day cement efficiency of  $0.082 \text{ MPa} \cdot \text{kg}^{-1} \cdot \text{m}^3$  ( $7.09 \text{ psi} \cdot \text{lb}^{-1} \cdot \text{yd}^3$ ), while the CarbonCure mix demonstrates a cement efficiency of  $0.101 \text{ MPa} \cdot \text{kg}^{-1} \cdot \text{m}^3$  ( $8.68 \text{ psi} \cdot \text{lb}^{-1} \cdot \text{yd}^3$ ), an increase of 22%.

Table 3: Cement and Cementitious Efficiency for reference and CarbonCure mixes.

Metric	Unit	Reference	CarbonCure	Difference
Average Cement Efficiency	$\text{MPa} \cdot \text{kg}^{-1} \cdot \text{m}^3$ ( $\text{psi} \cdot \text{lb}^{-1} \cdot \text{yd}^3$ )	0.082 (7.09)	0.101 (8.68)	+22%

### Concluding Remarks

This case study showed the feasibility of using the CarbonCure ready-mix technology in a 30 MPa (4,350 psi) commercially available concrete mixture with 100% Type GU cement as the binder system. The addition of  $\text{CO}_2$  as an admixture into the fresh concrete enhanced the 28-day compressive strength by 22% while providing a similar slump and air content. The

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addition of CO<sub>2</sub> has been demonstrated to cause additional cement hydration reactions via isothermal calorimetry laboratory experiments, attributed to the formation of calcite nanoparticles which increase the compressive strength of concrete by reducing porosity and providing additional nucleation sites for the cement hydration reaction. This is translated into a better cement hydration efficiency in the optimized CarbonCure mixture.

## References

- [1] Monkman, S., Kenward, P. A., Dipple, G., MacDonald, M., & Raudsepp, M. (2018). Activation of cement hydration with carbon dioxide. *Journal of Sustainable Cement-Based Materials*, 7(3), 160-181.
- [2] Monkman, S., MacDonald, M., Hooton, R. D., & Sandberg, P. (2016). Properties and durability of concrete produced using CO<sub>2</sub> as an accelerating admixture. *Cement and Concrete Composites*, 74, 218-224.