

CarbonCure Ready-Mix Technology – Strength Improvement in Concrete Mixture

Type I/II Cement and Class C Fly Ash

Abstract

The CarbonCure ready-mix technology produced concrete with a binder system comprising 75% Type I/II cement and 25% Class C fly ash. The mix was produced with CO₂ which was added like an admixture. The added CO₂ enhanced the 28-day compressive strength by 13% over a reference mix.

Introduction

CarbonCure Technologies (CCT) has developed a carbon dioxide (CO₂) utilization approach that injects CO₂ into fresh ready-mix concrete similar to introducing any other chemical admixture. The CO₂ 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 75% Type I/II cement and 25% Class C fly ash designed to have a 28-day compressive strength of 21 MPa (3,000 psi), and 2) a concrete mixture incorporating CO₂ 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 28 samples for the reference mix and 30 samples for the CarbonCure mix. All proportions were the same in both mix designs except for the CO₂ content, which was 480 mL/m³ (12.4 oz/yd³) in the CarbonCure mix.

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

Component	Unit	Reference	CarbonCure
Type I/II Cement	kg/m ³ (lb/yd ³)	228 (385)	228 (385)
Class C Fly Ash	kg/m ³ (lb/yd ³)	78 (132)	78 (132)
Coarse Aggregate	kg/m ³ (lb/yd ³)	904 (1,524)	904 (1,524)
Intermediate Aggregate	kg/m ³ (lb/yd ³)	92 (155)	92 (155)
Fine Aggregate	kg/m ³ (lb/yd ³)	831 (1,400)	831 (1,400)
Water	L/m ³ (gal/yd ³)	153 (31.0)	153 (31.0)
Air Entrainer	mL/m ³ (oz/yd ³)	77 (2.0)	77 (2.0)
Multi-Range Water Reducer	mL/m ³ (oz/yd ³)	1,586 (41.0)	1,586 (41.0)
CO ₂	mL/m ³ (oz/yd ³)	-	480 (12.4)
w/cm	-	0.5	0.5

Results

CO₂ 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 18 hours of reaction measured from lab-produced cement paste samples with and without CO₂. The faster and higher heat release exhibited by the sample containing CO₂ is indicative of more reactivity in that sample. This is due to the formation of calcite nanoparticles from the CO₂ 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.

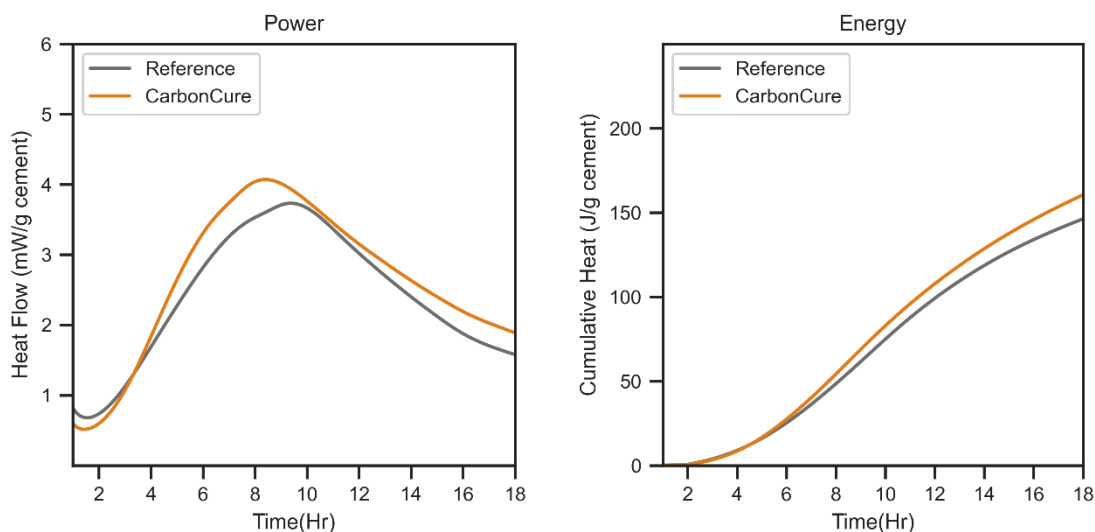


Figure 1: Isothermal calorimetry results on reference and CarbonCure cement paste samples.

CO₂ Effect on Field Fresh Properties

The slump and air content results are shown in **Figure 2** for the reference and CarbonCure mixes. The slump for the reference mix design averaged 135 millimetres (5.25 inches) while the slump for the CarbonCure mix averaged 125 millimetres (5 inches). The air content for the reference mix design averaged 6.8% while the CarbonCure mix averaged 7.6%. In both cases, the air content was within the desired range of 5 – 8%.

Type I/II Cement and Class C Fly Ash

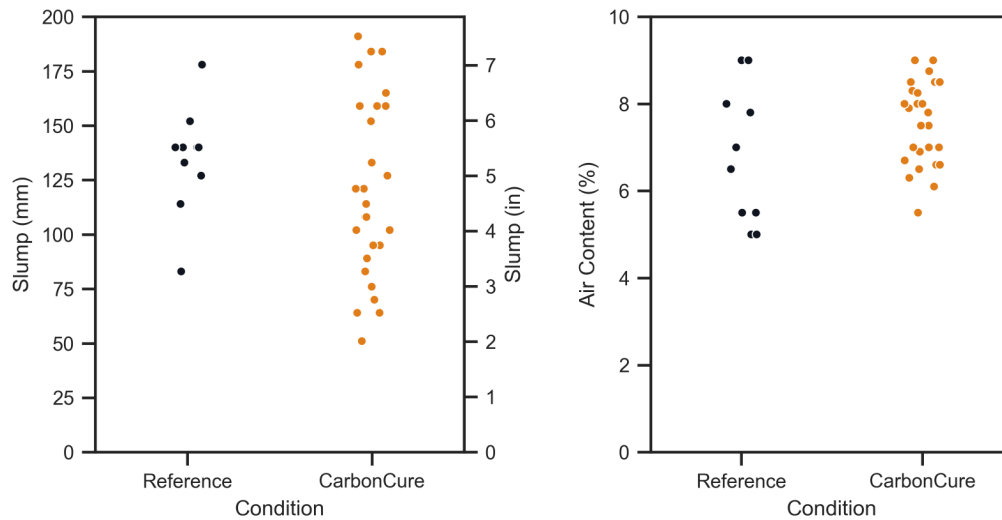


Figure 2: Slump and air content of reference and CarbonCure concrete

CO₂ 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 35.2 MPa (5,098 psi) for the reference mix and 39.8 MPa (5,773 psi) for the CarbonCure mix. The CarbonCure mix had a 13% 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		28	30	
Average 7-day strength	MPa (psi)	28.4 (4,114)	31.5 (4,563)	+11%
St. Dev of 7-day strength	MPa (psi)	3.4 (497)	3.9 (564)	+13%
Average of 28-day strength	MPa (psi)	35.2 (5,098)	39.8 (5,773)	+13%
St. Dev of 28-day strength	MPa (psi)	4.4 (644)	3.9 (564)	-12%

Type I/II Cement and Class C Fly Ash

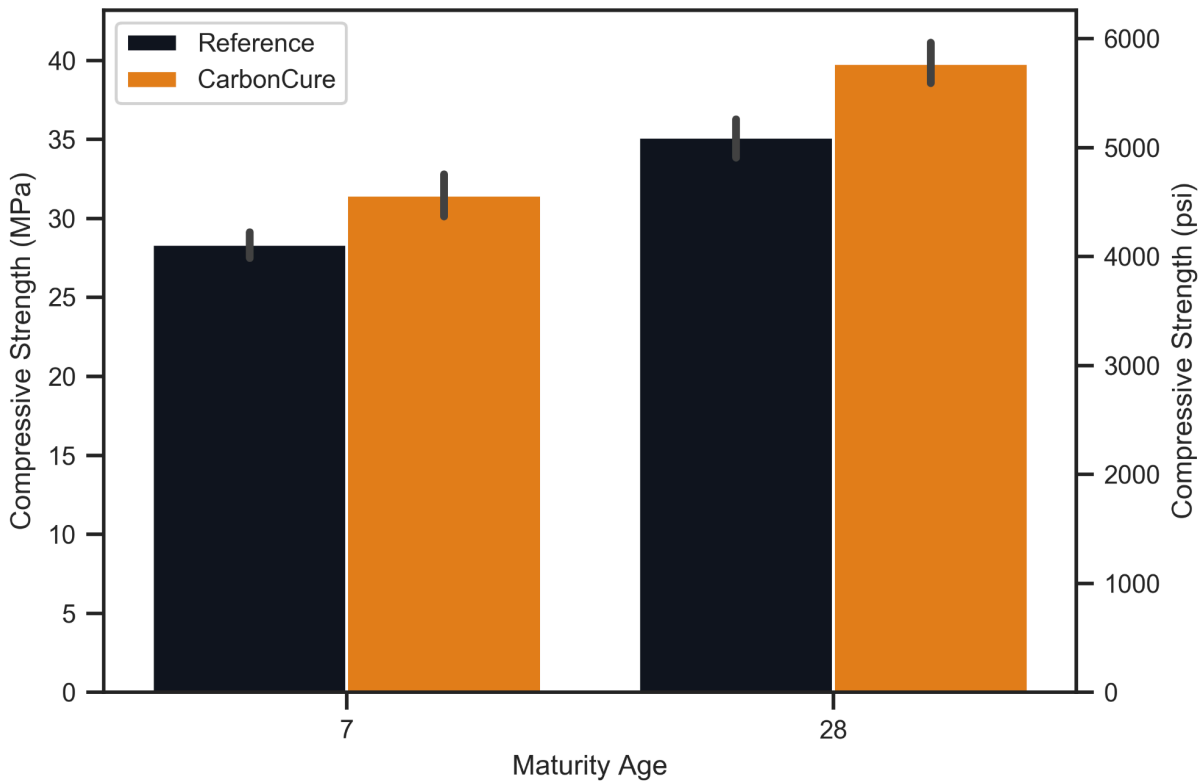


Figure 3: Hardened property results for the reference and CarbonCure mixes.

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**:

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

The reference mix design demonstrates a 28-day cement efficiency of 0.154 MPa·kg⁻¹·m³ (13.28 psi·lb⁻¹·yd³), while the CarbonCure mix demonstrates a cement efficiency of 0.175 MPa·kg⁻¹·m³ (15.03 psi·lb⁻¹·yd³), an increase of 13%. A similar calculation of cementitious efficiency, using the mass of cementitious material instead, shows 0.115 MPa·kg⁻¹·m³ (9.90 psi·lb⁻¹·yd³) cementitious for the reference mix and 0.130 MPa·kg⁻¹·m³ (11.17 psi·lb⁻¹·yd³) cementitious for the CarbonCure mix.

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

Metric	Unit	Reference	CarbonCure	Difference
Average Cement Efficiency	MPa·kg ⁻¹ ·m ³ (psi·lb ⁻¹ ·yd ³)	0.154 (13.28)	0.175 (15.03)	+13%
Average Cementitious Efficiency	MPa·kg ⁻¹ ·m ³ (psi·lb ⁻¹ ·yd ³)	0.115 (9.90)	0.130 (11.17)	+13%

Concluding Remarks

Type I/II Cement and Class C Fly Ash

This case study showed the feasibility of using the CarbonCure ready-mix technology in a 21 MPa (3,000 psi) commercially available concrete mixture with 75% Type I/II cement and 25% Class C fly ash as the binder system. The addition of CO₂ as an admixture into the fresh concrete enhanced the 28-day compressive strength by 13% while providing a similar slump and air content. The addition of CO₂ 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 CO₂ as an accelerating admixture. *Cement and Concrete Composites*, 74, 218-224.