CarbonCure Ready-Mix Technology – Optimized 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 CO_2 which was added like an admixture. The added CO_2 enabled the use of less cement content without compromising the strength properties of the mix.

Introduction

CarbonCure Technologies (CCT) has developed a carbon dioxide (CO_2) utilization approach that injects CO_2 into fresh ready-mix concrete similar to introducing any other chemical admixture. The CO_2 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 CO_2 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 20 samples for the reference mix and 15 samples for the CarbonCure mix. Both mixes also included a multi-range water reducer and an air-entraining admixture. The reference cement content of 228 kg/m^3 (385 lb/yd^3) was adjusted to 221 kg/m^3 (373 lb/yd^3) for the CarbonCure mix to leverage a strength increase demonstrated in technology commissioning. The total cementitious reduction of 3.9% was accompanied by a 1.4% and 2.0% increase in the fine and coarse aggregate fractions to maintain yield. The water-to-cementitious materials ratio (w/cm) increased slightly as a result of the mix adjustment.

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

Component	Unit	Reference	CarbonCure	Adjustment
Type I/II Cement	kg/m^3 (lb/yd^3)	228 (385)	221 (373)	-3.1%
Class C Fly Ash	kg/m^3 (lb/yd^3)	78 (132)	73 (124)	-6.0%
Total Cementitious	kg/m^3 (lb/yd^3)	306 (517)	294 (497)	-3.9%
Coarse Aggregate	kg/m^3 (lb/yd^3)	886 (1,493)	904 (1,524)	+2.0%
Intermediate Aggregate	kg/m^3 (lb/yd^3)	92 (155)	92 (155)	
Fine Aggregate	kg/m^3 (lb/yd^3)	831 (1,400)	842 (1,420)	+1.4%
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)	-	460 (11.9)	
w/cm	-	0.5	0.52	+4.0%

Results

CO_2 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_2. The faster and higher heat release exhibited by the sample containing CO_2 is indicative of more reactivity in that sample. This is due to the formation of calcite nanoparticles from the CO_2 mineralization reaction and how they catalyzed the subsequent hydration [1]. This allowed for the reduction of about 3.1% of the cement content in the CarbonCure concrete to yield a similar strength performance to the reference concrete.

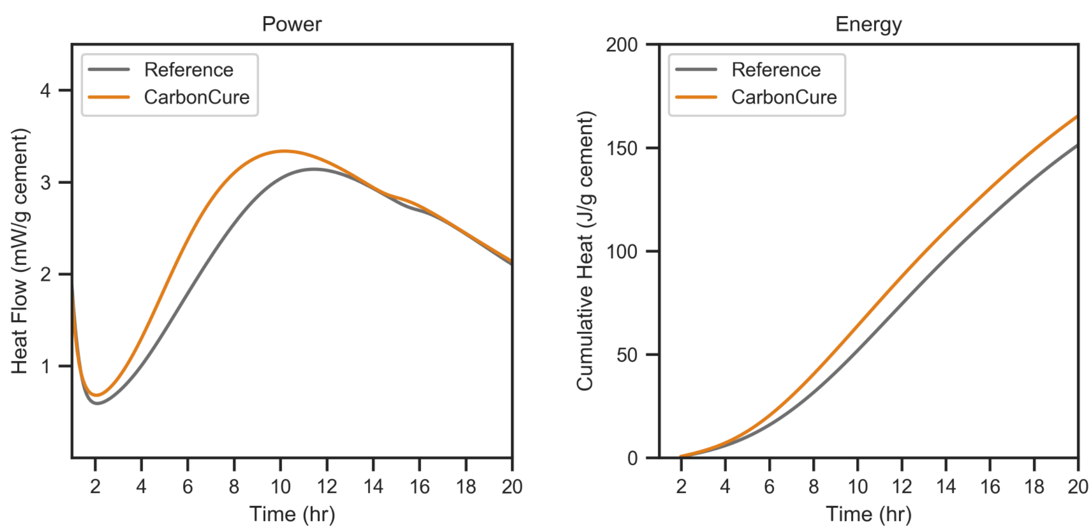

Figure 1: Isothermal calorimetry results on reference and CarbonCure cement paste samples.

CO_2 Effect on Field Compressive Strength

Table 2 and **Figure 2** 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 33.2 MPa (4,810 psi) for the reference mix and 34.6 MPa (5,020 psi) for the CarbonCure mix. The CarbonCure mix with 3.1% less cement had a 4% higher average 28-day compressive strength than the reference mix.

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

Metric	Unit	Reference	CarbonCure	Difference
Sample Count		20	15	
Average 7-day strength	MPa (psi)	25.0 (3,630)	30.1 (4,360)	+20%
St. Dev of 7-day strength	MPa (psi)	3.5 (510)	2.9 (418)	-17%
Average of 28-day strength	MPa (psi)	33.2 (4,810)	34.6 (5,020)	+4%
St. Dev of 28-day strength	MPa (psi)	4.7 (687)	2.3 (333)	-51%

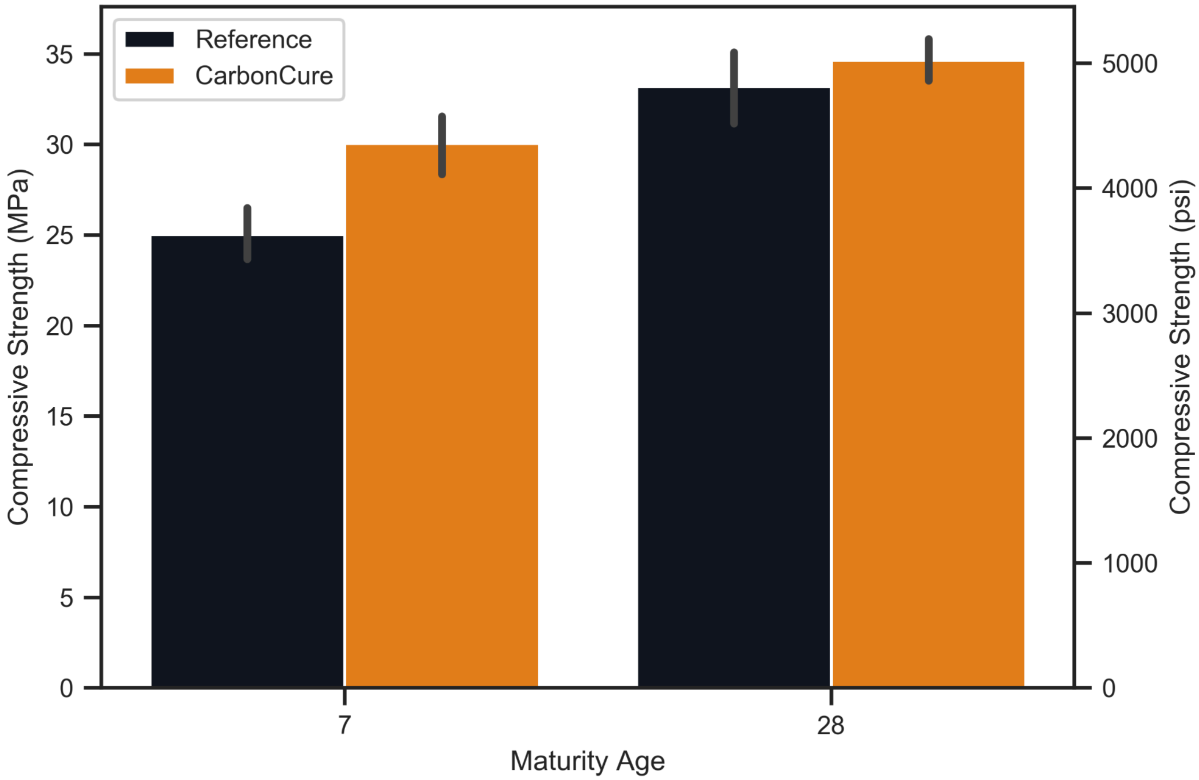

Figure 2: Compressive strength at 7- and 28-day age intervals for the reference and CarbonCure mixes.

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 0.146 $MPa{\cdot}kg^{-1}{\cdot}m^3$ (12.49 $psi{\cdot}lb^{-1}{\cdot}yd^3$), while the CarbonCure mix demonstrates a cement efficiency of 0.157 $MPa{\cdot}kg^{-1}{\cdot}m^3$ (13.46 $psi{\cdot}lb^{-1}{\cdot}yd^3$), an increase of 8%. A similar calculation of cementitious efficiency, using the mass of cementitious instead, shows 0.108 $MPa{\cdot}kg^{-1}{\cdot}m^3$ (9.30 $psi{\cdot}lb^{-1}{\cdot}yd^3$) cementitious for the reference mix and 0.118 $MPa{\cdot}kg^{-1}{\cdot}m^3$ (10.10 $psi{\cdot}lb^{-1}{\cdot}yd^3$) cementitious for the CarbonCure mix.

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

Metric	Unit	Reference	CarbonCure	Difference
Average Cement Efficiency	$MPa{\cdot}kg^{-1}{\cdot}m^3$ ($psi{\cdot}lb^{-1}{\cdot}yd^3$)	0.146 (12.49)	0.157 (13.46)	+8%
Average Cementitious Efficiency	$MPa{\cdot}kg^{-1}{\cdot}m^3$ ($psi{\cdot}lb^{-1}{\cdot}yd^3$)	0.108 (9.30)	0.118 (10.10)	+9%

Concluding Remarks

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 CO_2 as an admixture into the fresh concrete allowed for a 3.1% reduction in the cement content of the CarbonCure mixture while providing a similar compressive strength performance to the reference concrete mixture without CO_2. The addition of CO_2 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.