CarbonCure Ready-Mix Technology – Strength Improvement in Concrete Mixture

Type CEM II/A-L 42.5 (14% Limestone) Cement and 30% GGBS

Abstract

The CarbonCure ready-mix technology produced concrete with a binder system comprising 70% CEM II/A-L 42.5 cement containing 14% limestone and 30% ground granulated blast-furnace slag (GGBS). The mix was produced with CO_2 which was added like an admixture. The added CO_2 enhanced the 28-day compressive strength by 7% over a reference 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 70% CEM II/A-L 42.5 cement containing 14% limestone and 30% GGBS designed to have a 28-day compressive strength of 40 MPa (5,800 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 19 samples for the reference mix and 23 samples for the CarbonCure mix. All proportions were the same in both mix designs except for the CO_2 content, which was 1.05 kg/m^3 (1.77 lb/yd^3) in the CarbonCure mix.

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

Component	Unit	Reference	CarbonCure
CEM II/A-L 42.5	kg/m^3 (lb/yd^3)	262.5 (442)	262.5 (442)
GGBS	kg/m^3 (lb/yd^3)	112.5 (190)	112.5 (190)
Coarse Aggregate	kg/m^3 (lb/yd^3)	732 (1,234)	732 (1,234)
Intermediate Aggregate	kg/m^3 (lb/yd^3)	246 (415)	246 (415)
Fine Aggregate	kg/m^3 (lb/yd^3)	666 (1,122)	666 (1,122)
Crusher Dust	kg/m^3 (lb/yd^3)	166 (280)	166 (280)
Water	L/m^3 (gal/yd^3)	187 (37.8)	187 (37.8)
Mid-Range Water Reducer	kg/m^3 (lb/yd^3)	2.70 (4.55)	2.70 (4.55)
CO_2	kg/m^3 (lb/yd^3)	-	1.05 (1.77)
w/cm	-	0.5	0.5

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 24 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 led to a strength increase for the CarbonCure mix, as detailed in subsequent sections.

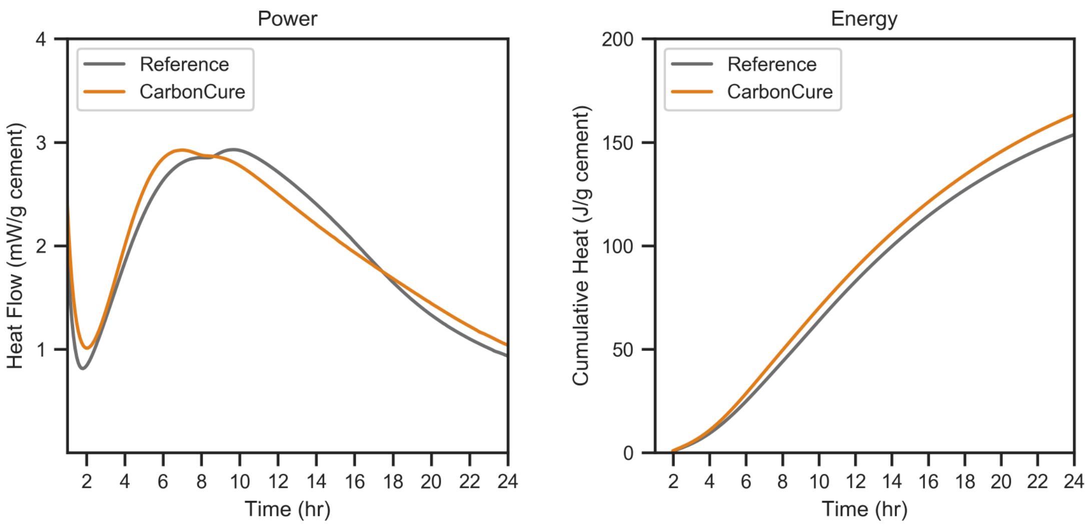

Figure 1: Isothermal calorimetry results on reference and CarbonCure cement paste samples.

CO_2 Effect on Field Fresh Properties

The slump results are shown in **Figure 2** for the reference and CarbonCure mixes. The slump for the reference mix design averaged 190 millimetres (7.5 inches) while the slump for the CarbonCure mix averaged 175 millimetres (7 inches).

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 47.6 MPa (6,908 psi) for the reference mix and 50.8 MPa (7,370 psi) for the CarbonCure mix. The CarbonCure mix had a 7% higher average compressive strength than the reference mix.

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

Metric	Unit	Reference	CarbonCure	Difference
Sample Count		19	23	
Average 7-day strength	MPa (psi)	32.9 (4,766)	35.6 (5,517)	+8%
St. Dev of 7-day strength	MPa (psi)	2.6 (383)	3.9 (566)	+48%
Average of 28-day strength	MPa (psi)	47.6 (6,908)	50.8 (7,370)	+7%
St. Dev of 28-day strength	MPa (psi)	3.5 (504)	3.9 (559)	+11%

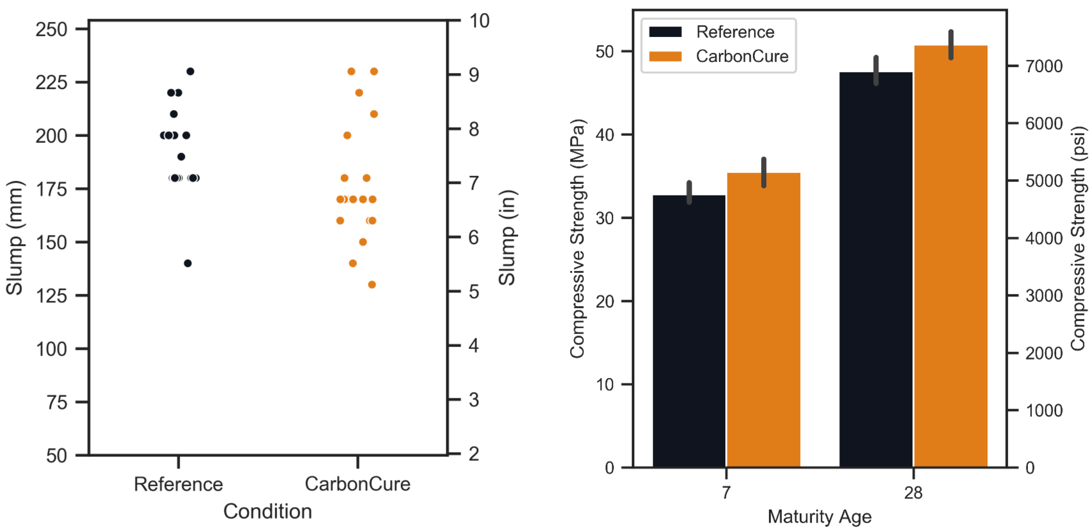

Figure 2: Fresh and hardened property results for the reference and CarbonCure mixes.

<u>Mix Performance</u>
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 0.181 $MPa \cdot kg^{-1} \cdot m^3$ (15.63 $psi \cdot lb^{-1} \cdot yd^3$), while the CarbonCure mix demonstrates a cement efficiency of 0.194 $MPa \cdot kg^{-1} \cdot m^3$ (16.67 $psi \cdot lb^{-1} \cdot yd^3$), an increase of 7%. A similar calculation of cementitious efficiency, using the mass of cementitious instead, shows 0.127 $MPa \cdot kg^{-1} \cdot m^3$ (10.93 $psi \cdot lb^{-1} \cdot yd^3$) cementitious for the reference mix and 0.136 $MPa \cdot kg^{-1} \cdot m^3$ (11.66 $psi \cdot lb^{-1} \cdot yd^3$) cementitious for the CarbonCure mix.

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

Metric	Unit	Reference	CarbonCure	Difference
Average Cement Efficiency	$MPa \cdot kg^{-1} \cdot m^3$ ($psi \cdot lb^{-1} \cdot yd^3$)	0.181 (15.63)	0.194 (16.67)	+7%
Average Cementitious Efficiency	$MPa \cdot kg^{-1} \cdot m^3$ ($psi \cdot lb^{-1} \cdot yd^3$)	0.127 (10.93)	0.136 (11.66)	+7%

Concluding Remarks

This case study showed the feasibility of using the CarbonCure ready-mix technology in a 40 MPa (5,800 psi) commercially available concrete mixture with 70% CEM II/A-L 42.5 containing 14% limestone and 30% GGBS as the binder system. The addition of CO_2 as an admixture into the fresh concrete enhanced the 28-day compressive strength by 7% while providing a similar slump. 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.