CarbonCure Ready-Mix Technology – Optimized Concrete Mixture

Type IL Cement and Class F Fly Ash

Abstract

The CarbonCure ready-mix technology produced concrete with a binder system comprising 80% Type IL cement and 20% Class F 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 while achieving an increase in compressive strength of 8% 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 80% Type IL cement and 20% Class F 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 26 samples for the reference mix and 13 samples for the CarbonCure mix. Both mixes also included a high-range water-reducing admixture. The reference cement content of 237 kg/m^3 (400 lb/yd^3) was adjusted to 230 kg/m^3 (388 lb/yd^3) for the CarbonCure mix to leverage a strength increase demonstrated in technology commissioning. The total cementitious reduction of 3% was accompanied by a 1% increase in the fine aggregate 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 IL Cement	kg/m^3 (lb/yd^3)	237 (400)	230 (388)	-3.0%
Class F Fly Ash	kg/m^3 (lb/yd^3)	59 (100)	58 (97)	-3.0%
Coarse Aggregate	kg/m^3 (lb/yd^3)	1,098 (1,850)	1,098 (1,850)	
Fine Aggregate	kg/m^3 (lb/yd^3)	825 (1,390)	833 (1,405)	+1.0%
Water	L/m^3 (gal/yd^3)	168 (34)	168 (34)	
High-Range Water Reducer	mL/m^3 (oz/yd^3)	773 (20)	773 (20)	
CO_2	mL/m^3 (oz/yd^3)	-	1,203 (31.1)	
w/cm	-	0.57	0.58	+1.7%

Results

CO_2 Effect on Field Fresh Properties

The slump results are shown in **Figure 1** for the reference and CarbonCure mixes. The slump for the reference mix design averaged 175 millimetres (7.0 inches) while the slump for the CarbonCure mix averaged 110 millimetres (4.25 inches).

CO_2 Effect on Field Compressive Strength

Table 2 and **Figure 1** 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 25.2 MPa (3,657 psi) for the reference mix and 27.1 MPa (3,935 psi) for the CarbonCure mix. The CarbonCure mix with 3% less cement had an 8% 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		26	13	
Average 7-day strength	MPa (psi)	17.5 (2,532)	17.4 (2,529)	+0%
St. Dev of 7-day strength	MPa (psi)	2.5 (361)	3.4 (491)	+36%
Average of 28-day strength	MPa (psi)	25.2 (3,657)	27.1 (3,935)	+8%
St. Dev of 28-day strength	MPa (psi)	3.3 (481)	4.0 (579)	+20%

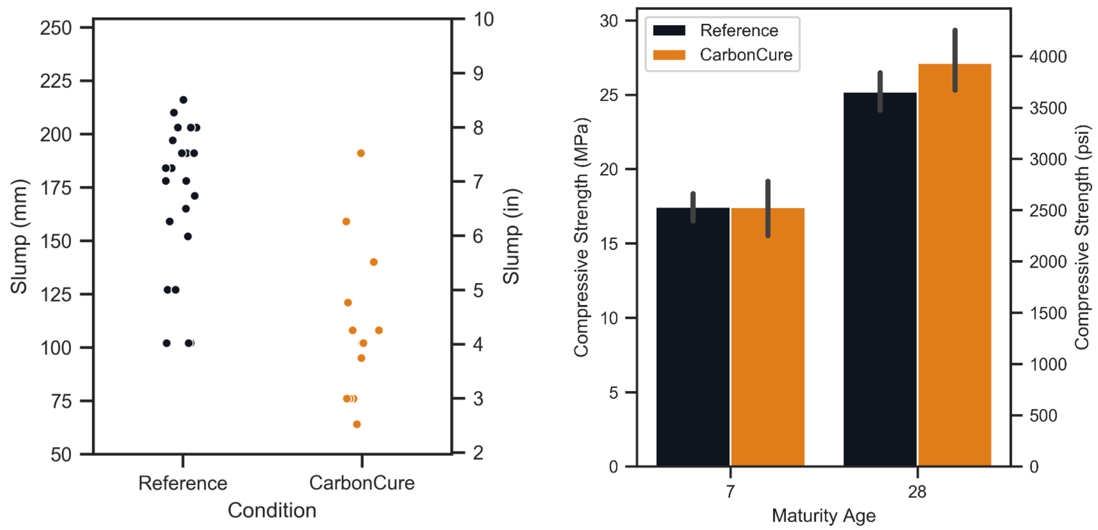

Figure 1: Fresh and hardened property results for the reference and CarbonCure mixes.

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 0.106 MPa·kg^{-1}·m^{3} (9.14 psi·lb^{-1}·yd^{3}), while the CarbonCure mix demonstrates a cement efficiency of 0.118 MPa·kg^{-1}·m^{3} (10.14 psi·lb^{-1}·yd^{3}), an increase of 11%. A similar calculation of cementitious efficiency, using the mass of cementitious instead, shows 0.085 MPa·kg^{-1}·m^{3} (7.31 psi·lb^{-1}·yd^{3}) cementitious for the reference mix and 0.094 MPa·kg^{-1}·m^{3} (8.11 psi·lb^{-1}·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·kg^{-1}·m^{3} (psi·lb^{-1}·yd^{3})	0.106 (9.14)	0.118 (10.14)	+11%
Average Cementitious Efficiency	MPa·kg^{-1}·m^{3} (psi·lb^{-1}·yd^{3})	0.085 (7.31)	0.094 (8.11)	+11%

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 80% Type IL cement and 20% Class F fly ash as the binder system. The addition of CO_2 as an admixture into the fresh concrete allowed for a 3% reduction in the cement content of the CarbonCure mixture while achieving a compressive strength increase of 8% over a reference concrete mixture without CO_2. The addition of CO_2 has been demonstrated to cause additional cement hydration reactions 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.