CarbonCure Ready-Mix Technology – Optimized Concrete Mixture

Type I/II Low Alkali Cement and Metakaolin

Abstract

The CarbonCure ready-mix technology produced concrete with a binder system comprising 89% Type I/II low alkali cement and 11% Metakaolin. 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 89% Type I/II low alkali cement and 11% metakaolin 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 19 samples for the reference mix and 17 samples for the CarbonCure mix. Both mixes also included a low-range water-reducing admixture. The reference cement content of 237 kg/m^3 (400 lb/yd^3) was adjusted to 223 kg/m^3 (376 lb/yd^3) for the CarbonCure mix to leverage a strength increase demonstrated in technology commissioning. The total cementitious reduction of 6% was accompanied by a 1.8% increase in 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 I/II Low Alkali Cement	kg/m^3 (lb/yd^3)	237 (400)	223 (376)	-6.0%
Metakaolin	kg/m^3 (lb/yd^3)	27 (45)	27 (45)	
Total Cementitious	kg/m^3 (lb/yd^3)	264 (445)	250 (421)	-5.4%
Coarse Aggregate	kg/m^3 (lb/yd^3)	934 (1,575)	934 (1,575)	
Intermediate Aggregate	kg/m^3 (lb/yd^3)	267 (450)	267 (450)	
Fine Aggregate	kg/m^3 (lb/yd^3)	786 (1,325)	800 (1,349)	+1.8%
Water	L/m^3 (gal/yd^3)	163 (33)	163 (33)	
Low-Range Water Reducer	mL/m^3 (oz/yd^3)	2,127 (55.0)	2,127 (55.0)	
CO_2	mL/m^3 (oz/yd^3)	-	468 (12.1)	
w/cm	-	0.62	0.65	+4.8%

Results

CO_2 effect on Fresh Slump Properties

The concrete field slump results are shown in **Figure 1** for the reference and CarbonCure mixes. The slump for the reference mix design averaged 120 millimetres (4.75 inches) while the slump for the optimized design averaged 125 millimetres (5 inches). In both cases, the slump was within the desired range of 75 – 125 millimetres (3 – 5 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 32.0 MPa (4,653 psi) for the reference mix and 31.0 MPa (4,527 psi) for the CarbonCure mix. The CarbonCure mix with 6% less cement had a similar strength performance at 28 days.

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

Metric	Unit	Reference	CarbonCure	Difference
Sample Count		19	17	
Average 7-day strength	MPa (psi)	23.5 (3,409)	20.8 (3,009)	-12%
St. Dev of 7-day strength	MPa (psi)	4.8 (702)	2.8 (411)	-41%
Average of 28-day strength	MPa (psi)	32.0 (4,653)	31.0 (4,527)	-2.7%
St. Dev of 28-day strength	MPa (psi)	4.7 (681)	2.5 (364)	-51%

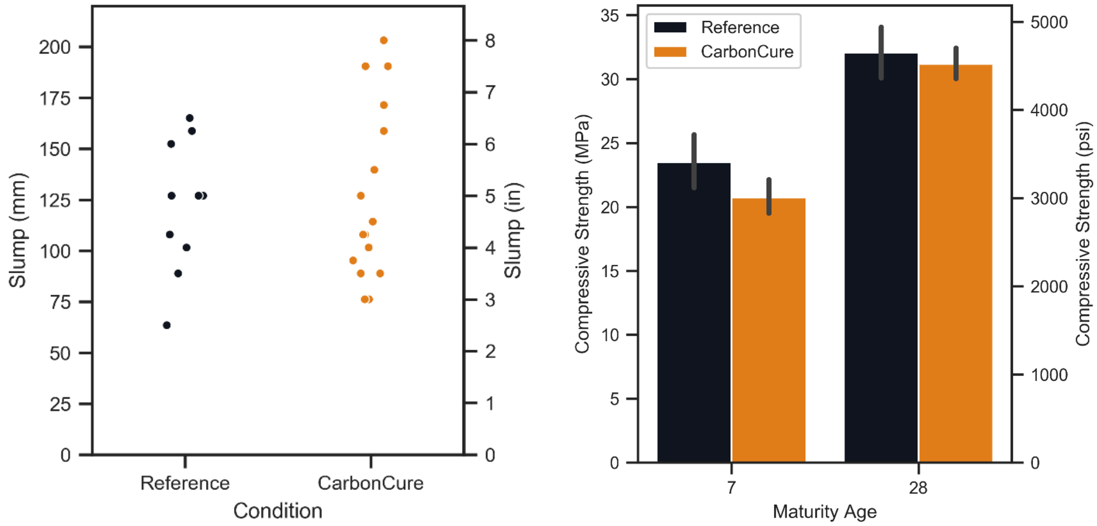

Figure 1: Fresh and hardened property results for the reference and CarbonCure mixes.

<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 0.135 MPa·kg^{-1}·m^{3} (11.63 psi·lb^{-1}·yd^{3}), while the CarbonCure mix demonstrates a cement efficiency of 0.139 MPa·kg^{-1}·m^{3} (12.04 psi·lb^{-1}·yd^{3}), an increase of 3%. A similar calculation of cementitious efficiency, using the mass of cementitious instead, shows 0.121 MPa·kg^{-1}·m^{3} (10.46 psi·lb^{-1}·yd^{3}) cementitious for the reference mix and 0.124 MPa·kg^{-1}·m^{3} (10.75 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})	0.135 (11.63)	0.139 (12.04)	+3%
Average Cementitious Efficiency	MPa·kg^{-1}·m^{3} (psi·lb^{-1}·yd^{3})	0.121 (10.46)	0.124 (10.75)	+3%

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 89% Type I/II low alkali cement and 11% metakaolin as the binder system. The addition of CO_2 as an admixture into the fresh concrete allowed for a 6% 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 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.