CarbonCure Ready-Mix Technology – Strength Improvement in Concrete Mixture

Type IP Cement

Abstract

The CarbonCure ready-mix technology produced concrete with a binder system comprising 100% Type IP cement. The mix was produced with CO_2 which was added like an admixture. The added CO_2 enhanced the 28-day compressive strength by 5% 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 100% Type IP cement designed to have a 28-day compressive strength of 21 MPa (3,050 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 30 samples for the reference mix and 30 samples for the CarbonCure mix. All proportions were the same in both mix designs except for the CO_2 content, which was 688 mL/m^3 (23.3 oz/yd^3) in the CarbonCure mix.

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

Component	Unit	Reference	CarbonCure
Type IP Cement	kg/m^3 (lb/yd^3)	275 (464)	275 (464)
Coarse Aggregate	kg/m^3 (lb/yd^3)	943 (1,589)	943 (1,589)
Fine Aggregate	kg/m^3 (lb/yd^3)	1,021 (1,721)	1,021 (1,721)
Water	L/m^3 (gal/yd^3)	160 (32.3)	160 (32.3)
High-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)	-	688 (23.3)
w/cm	-	0.60	0.60

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 155 millimetres (6.25 inches) while the slump for the CarbonCure mix averaged 150 millimetres (6.0 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 26.4 MPa (3,829 psi) for the reference mix and 27.8 MPa (4,032 psi) for the CarbonCure mix. The CarbonCure mix had a 5% 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		30	30	
Average 7-day strength	MPa (psi)	20.5 (2,979)	21.1 (3,063)	+3%
St. Dev of 7-day strength	MPa (psi)	1.5 (223)	1.6 (235)	+5%
Average of 28-day strength	MPa (psi)	26.4 (3,829)	27.8 (4,032)	+5%
St. Dev of 28-day strength	MPa (psi)	1.9 (268)	2.1 (297)	+11%

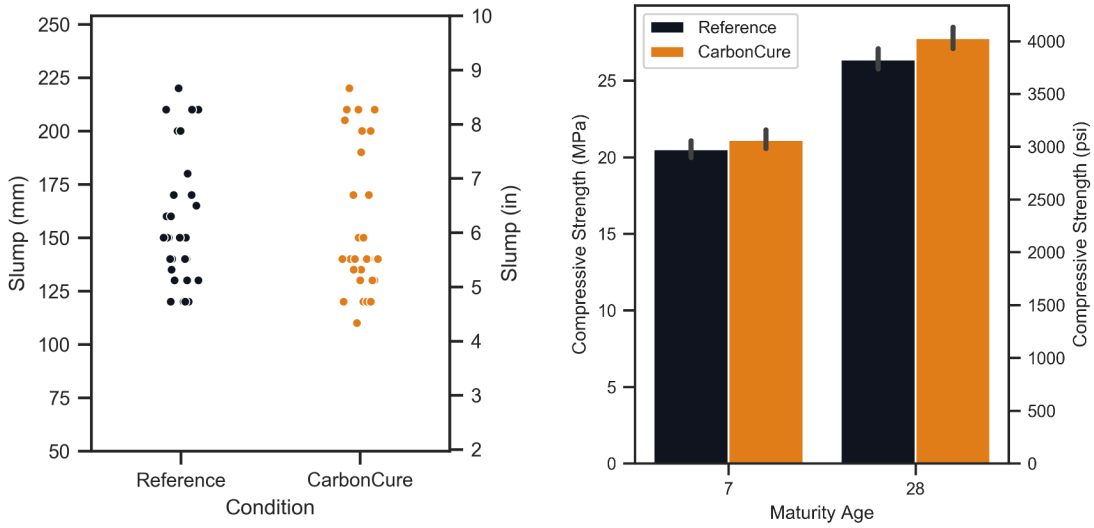

Figure 1: Fresh and hardened property results for the reference and CarbonCure mixes.

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 0.096 MPa·kg^{-1}·m^3 (8.25 psi·lb^{-1}·yd^3), while the CarbonCure mix demonstrates a cement efficiency of 0.101 MPa·kg^{-1}·m^3 (8.69 psi·lb^{-1}·yd^3), an increase of 5%.

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)	0.096 (8.25)	0.101 (8.69)	+5%

Concluding Remarks

This case study showed the feasibility of using the CarbonCure ready-mix technology in a 21 MPa (3,050 psi) commercially available concrete mixture with 100% Type IP cement as the binder system. The addition of CO_2 as an admixture into the fresh concrete enhanced the 28-day compressive strength by 5% while providing a similar slump. 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.