Enhancing Concrete Early Strength And Durability By Aqueous Carbon Sequestration Approach

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ABSTRACT

Cement clinker is responsible for more than 80% of the embodied carbon of traditional concrete. To tackle the high embodied carbon of concrete, the use of supplementary cementitious materials (SCMs) as clinker replacement is a common practice in the construction industry. Blended cements are typically combinations of clinker with ground granulated blast-furnace slag (GGBS), silica fume (SF), fly ash and limestone, with GGBS having the highest replacement potential of up to 95 wt% of cement as specified in international standards. GGBS is a latent hydraulic cementitious material and at high replacement ratios in blast furnace cement (BFC) possesses high strength development potential but at a rate slower than ordinary Portland cement (OPC).

To address this challenge, the team conducted a series of preliminary studies into the use the aqueous carbonation as an early-stage performance enhancement solution. Aqueous carbonation is a process where carbon dioxide (CO_2) enriched solutions are used to replace plain mixing water during the production of fresh concrete. Previous studies have shown that the aqueous carbonation approach led to an increase in early strength accompanied with a loss in workability [1], [2]. One such study proposed the use of recycled concrete aggregates (RCA) as a partial replacement of coarse natural aggregates to effectively improve the workability of aqueous carbonation concrete [1]. Therefore, the effectiveness of RCA on BFC concrete with aqueous carbonation was also studied.

In this study, GGBS was used to replace 80 wt% of CEM I OPC to produce C32/40 (Grade 40) concrete together with the aqueous carbonation approach. Cleaned and graded RCA was used to replace 10 wt% of the natural coarse aggregates. The workability and strength of BFC concrete was determined

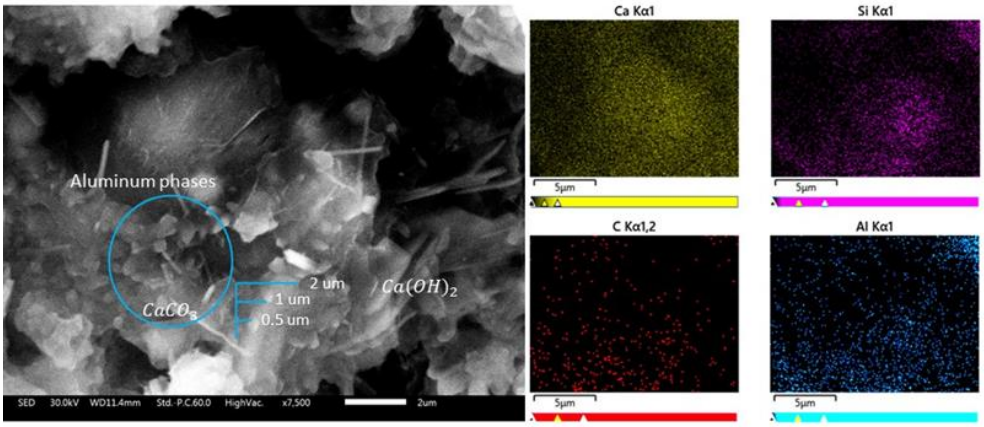
experimentally as per EN12350-2 and EN 12390-3 and evaluated against EN 206-1. To ensure that the effects of early-stage carbonation do not impact the passivation potential and durability of concrete, alkalinity and durability tests were conducted as per EN 12390-12, ASTM C1202 and ASTM C642.

Table 1 shows that aqueous carbonation resulted in a 22.3%, 11.3% and 4.7% increase in compressive strength at 1, 3 and 7 days respectively, and similar 28-day strength, which satisfies the requirements for C32/40 concrete. Nanoparticles of calcite (Figure 1) remineralized within the cement matrix are believed to be responsible for the increase in early strength due to enhanced C-S-H formation and other voluminous phases such as monocarbonate and hemicarbonate [3]

MIX	WORKABILITY	COMPRESSIVE STRENGTH							
	Slump [mm]	1-DAY		3-DAY		7-DAY		28-DAY	
		Strength [MPa]	Std. Dev	Strength [MPa]	Std. Dev	Strength [MPa]	Std. Dev	Strength [MPa]	Std. Dev
G80	140	10.70	2.53	26.79	4.44	37.21	4.43	47.45	4.31
G80 CO_2	115	13.09	3.85	29.83	3.71	38.95	4.28	47.57	5.14
G80 RCA	145	9.31	2.52	22.80	1.09	29.81	0.38	38.34	2.50
G80 CO_2 RCA	210	14.09	2.66	27.60	1.48	41.87	1.26	49.75	0.29

Table 1. Workability and compressive strength properties

Figure 1. Nano-sized $CaCO_3$ (250 to 500 nm) weaved with aluminum phases observed in the blended cement at 3-day age



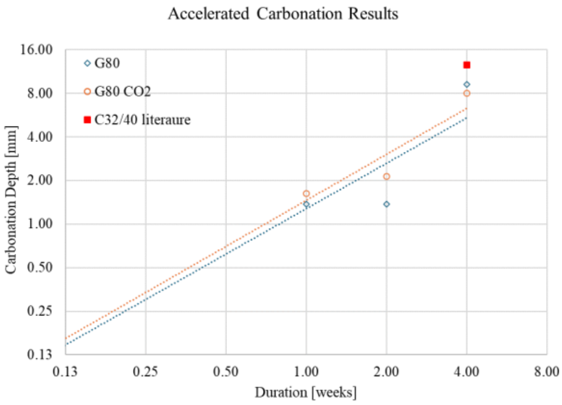
The formation of calcite particles during early-stage carbonation has been reported to occur instantaneously upon exposure of the fresh concrete to CO_2 [4]. It was hypothesized that the high reactivity results in increased particle friction [5] thus resulting in the loss of workability in fresh concrete. Through the provision of an additional source of calcium and alkalinity via RCA, an enhancement in both workability, and 7-day and 28-day strength by 50.0%, 12.5% and 4.9% respectively has been achieved, as shown in Table 1. It is believed that the reaction between CO_2 with the portlandite from the old mortar layer of RCA reduced the porosity and strengthen the interfacial transition zone (ITZ) and that the additional hydroxide ions from RCA neutralized the acidity of carbonated water, thus resulting in improved workability and strength.

Table 2 shows that BFC concrete exhibits excellent resistance to chloride diffusivity, low water absorption (WA) value of less than 5% and less than 13% volume of permeable voids (VPV). It is also observed from Figure 2 that high BFC concrete with aqueous carbonation performed well in the accelerated carbonation test. These preliminary results show that aqueous carbonation significantly improves the early strength without compromising the late strength of concrete. The combined use of aqueous carbonation and 10% RCA replacement improved the workability and strength of concrete, demonstrating a promising approach to produce ultra-low carbon concrete mixtures.

MIX	RCPT [Coulombs]	WA [-]	VPV [-]
G80	537.12	2.93%	6.80%
G80 CO_2	625.35	3.11%	7.21%
Criteria	< 1000 Very Good	< 5% Very Good	< 13% Very Good

Table 2. Transport and chloride diffusivity properties

Figure 2. Accelerated carbonation test results



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