Effect of Carbonation on Compressive Strength Development of High-Slag Mortars

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Abstract
This study investigates the effect of carbonation on the compressive strength development of OPC and OPC+slag mortars (50% and 70% slag replacement) exposed to 2%CO_2, 50%RH 23°C as well as the effect of increasing slag replacement level on carbonation resistance. As expected, results showed that OPC has the highest carbonation resistance and that the higher the slag replacement level, the poorer the carbonation resistance. Compressive strength results up to 112 days show that carbonation has no detrimental effect to the compressive strength development of high-slag mortars. It is however notable that the strength of the high-slag mortars was not able to catch up with OPC mortars even after 112 days which may be due to the occurrence of carbonation shrinkage in high-slag binders.

Keywords: carbonation, slag, compressive strength, CO_2 curing, durability

1 Introduction

The CO_2 emissions associated with concrete production can be minimized by replacing a large portion of cement with supplementary cementitious materials (SCMs) like slag and fly ash. Slag, being hydraulic in nature like cement, allows higher substitutions than other SCMs. In a typical concrete mix, slag is used at levels ≥50%. However, although slag notably improves later age strength as well as most concrete durability properties, its use at higher replacement levels results in increased susceptibility of the concrete to carbonation [1, 2].

Carbonation refers to the ingress of CO_2 into the binder system which results in the formation of carbonic acid (H_2CO_3) that further dissociates and reacts with calcium and hydroxide ions in the pore solution resulting in the precipitation of calcium carbonate ($CaCO_3$) and a decrease in the pH of the pore solution. Low concrete pH (~9 or less) is detrimental to steel-reinforced concrete as steel begins to lose its passivation layer at low pH making it susceptible to corrosion. However, whereas the carbonation rates of OPC and OPC+slag binder systems are well investigated, the effect of carbonation on compressive strength development of high-slag binders is not well understood. Although carbonation is generally reported to result in an increase in compressive strength of OPC systems due to the conversion of $Ca(OH)_2$ to $CaCO_3$ [1] which increases the volume of the binder, carbonation has been reported to result in the decrease in the compressive strength of high-slag concrete [2]. Moreover, it has also been reported to be detrimental to strength development of alkali-activated slag binders [3]. Due to the increasing levels of slag being used in concrete production as well as the use of additives to accelerate early age development of high-slag binders, a better understanding of the effect of carbonation on compressive strength is required. This study investigates the effect of carbonation on compressive strength development of high-slag mortars.

2 Materials and Methods

40 x 40 x 160 mm mortars were prepared using Normen sand in combination with OPC and OPC+slag binders (slag at 50% and 70% replacement) at 0.45 w/c ratio. Table 1 shows the mortar mixes investigated. The GP cement used complies with AS 3972 and the slag with AS 3582.2.

The mortars were demoulded after 1 day, cured for 28 days inside a sealed moisture bag and then transferred into the shrinkage room (50%RH, 23 °C) to air cure for 7 days in preparation for the accelerated carbonation test. At age 35 days (28+7 days), the mortars were transferred into the carbonation chamber running at 2%CO_2, 50%RH 23°C for the accelerated carbonation test. Carbonation depth measurements using phenolphthalein (1% solution) and compression tests were carried out after 1 week (7 days), 4 weeks (28 days), 9 weeks (63 days), and 16 weeks (112 days) exposure of the mortars in the carbonation chamber. Reference compressive strengths were also obtained before the mortars were loaded into the carbonation chamber (Day 0).

Table 1. Mortar mixes investigated

Mix Details	Normen Sand (g)	Cement (g)	Slag (g)	Total Binder (g)	Water (g)
OPC	1350	450.0	0.0	450.0	171.0
OPC+50%slag	1350	225.0	225.0	450.0	171.0
OPC+70%slag	1350	135.0	315.0	450.0	171.0

Compression test of the 40 x 40 x 160mm mortar prisms were carried out as per AS/NZ 2350.11 (loading rate is 2.4kN/ sec). In the test method, the two ends of the mortar are subjected to compression test and the compressive strength is reported as an average of two breaks.

3 Results and Discussion

Fig. 1 shows the carbonation depths at 16 weeks (112 days). Phenolphthalein is pink at pH higher than ~8.5 and colourless at pH lower than ~8.5 indicating drop in pore solution pH due to carbonation. As may be expected, the plain OPC mortar exhibits the best resistance to carbonation (highest amount of pink region) while mortars with slag exhibit poorer resistance to carbonation. The higher the slag replacement, the poorer the carbonation performance. The mortar with 70% slag is fully carbonated (i.e. no colour change) at 112 days.

Fig. 2 shows the compressive strength results of the mortars before loading into the carbonation chamber and after 7, 28, 63 and 112 days exposure to 2%CO_2 50%RH 23 °C. The strength development was observed to continue over time and carbonation was found to have no detrimental effect on the strength of high-slag mortars. The compressive strengths of the high-slag mortars were however consistently low and were not able to catch up with the strength of the OPC mortars even after 112 days which is not as expected. The later age strength of high-slag binders is known to be better than plain OPC [4]. The observed trend may be due to the susceptibility of high-slag binders to carbonation shrinkage. It has been reported that open porosity increases in high-slag concrete as carbonation proceeds [5].

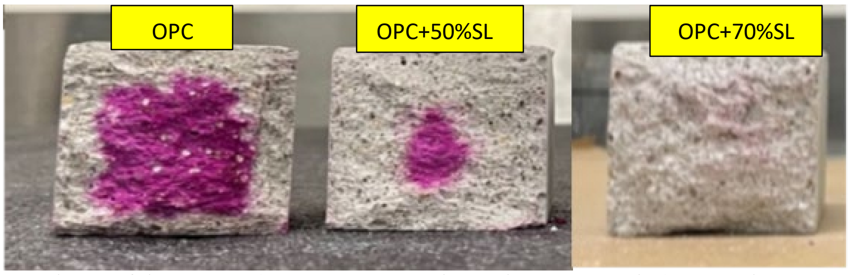

Fig. 1. Photos of the mortars (OPC, OPC+50% slag and OPC+70% slag) at 112 days exposure in the carbonation chamber showing the carbonation depth determined using phenolphthalein

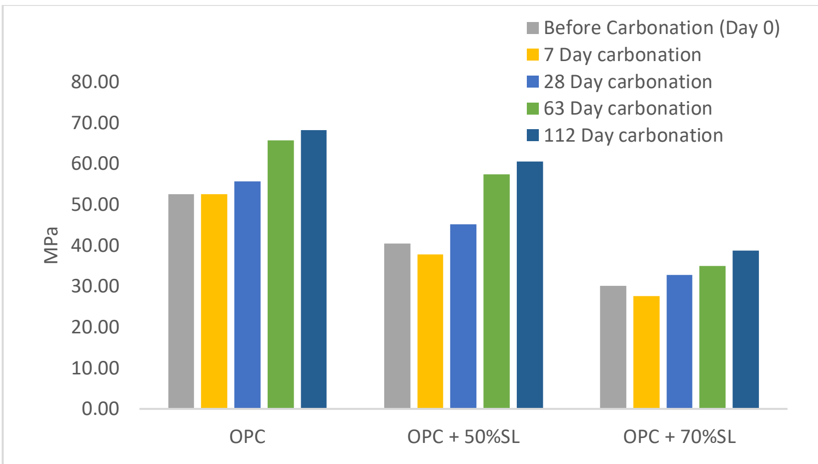

Fig. 2. Compressive strength of the mortars before carbonation (Day 0) and after 7 days, 28 days, 64 days, and 112 days exposure to 2%CO2, 50%RH 23°C

Conclusions

This study confirms the higher carbonation rate of high-slag binder systems and that the higher the slag content, the faster the rate of carbonation. The compressive strength was observed to continuously develop over time under accelerated carbonation conditions (2%CO_2, 50%RH 23 °C) and therefore, carbonation has no detrimental effect to compressive strength development. The strength of the high-slag mortars was however consistently lower than the OPC mortars even up to 112 days which suggests possible occurrence of carbonation shrinkage resulting in increased porosity.

The effect of carbonation on phase and microstructure development is an ongoing work of the authors and should help support the conclusions of this paper.

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