The influence of carbonation and age on salt frost scaling of concrete with mineral additions

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ABSTRACT
Resistance to salt frost scaling is tested by accelerated methods such as CEN/TS 12390-9. However, it has been shown that ageing and coupled deterioration mechanisms, like carbonation or leaching, can alter the frost resistance e.g. for concrete with high amount of slag (GGBS). This paper presents results from a laboratory study of concrete which have been exposed to accelerated carbonation at 1% CO2-concentration at different ages. The results show that exposing the specimens to accelerated carbonation at a young age result in an increased scaling and a carbonation depth corresponding to 10 year natural exposure. By increasing the age before the accelerated carbonation exposure the scaling is significantly reduced and the salt frost scaling resistance correlates better with field observations.

Key words: Frost action, Carbonation, Supplementary Cementitious Materials (SCM), Testing.

1. INTRODUCTION

The resistance of concrete to salt frost scaling is tested by accelerated methods such as CEN/TS 12390-9 [1] and SS 137244 [2], which originally were developed based on the experience of Portland cement concrete [3] [4]. The testing regime is being under review, partly due to that it does not consider ageing effects, such as changes to pore structure, micro cracking, leaching and the effect of carbonation [3] [4] [5]. With increasing use of mineral additions, such as slag (GGBS) and fly ash (FA), for reducing the environmental footprint and improve resistance to reinforcement corrosion this type of test methods need to be modified so that it can safely and adequately be used for concrete with mineral additions. Moreover, the test results also need to be correlated with the performance in field conditions [6] [7] [8].

2. EXPERIMENTAL PROGRAMME

The concrete mixture proportions are listed in Table 1. The aggregate was of granitic type, the superplasticizer (SP) was polycarboxylate-based (PCE), and the air entraining agent was a synthetic surfactant. The concrete had w/b ratio of 0.45 or 0.40 and had GGBS additions from 20 to 60 % of the total binder content. For additional mixes and results see [9].

Table 1 - Investigated concrete mixes.

Mix ID	Cement	GGBS	*w/b*	Air content
CEM I 0% 0.45	CEM I 42,5 N SR3 MH LA	0 %	0.45	5.2 %
CEM I 20% 0.45	CEM I 42,5 N SR3 MH LA	20 %	0.45	4.9 %
CEM I 30% 0.45	CEM I 42,5 N SR3 MH LA	30 %	0.45	5.1 %
CEM I 40% 0.45	CEM I 42,5 N SR3 MH LA	40 %	0.45	5.0 %
CEM I 60% 0.45	CEM I 42,5 N SR3 MH LA	60 %	0.45	5.8 %
CEM I 0% 0.40	CEM I 42,5 N SR3 MH LA	0 %	0.40	5.5 %
CEM I 20% 0.40	CEM I +20%S	20 %	0.40	6.0 %
CEM I 30% 0.40	CEM I +30%S	30 %	0.40	6.2 %
CEM I 40% 0.40	CEM I +40%S	40 %	0.40	6.2 %

The standard slab test procedure for freeze-thaw testing as described in CEN TS 12390-9 [1] and SS 137244 [2] were used to assess the salt-frost scaling resistance on a cut surface. Four different preconditioning regimes have been studied:

- **Standard procedure - 31d Std:** From demoulding (24±2 h) the cube is stored in water until the age of 7 days, and then stored in climate chamber (20±2°C and RH 65±5%) until a 50 mm thick specimen is cut at an age of 21 days. The slab is placed in a climate chamber (20±2°C and RH 65±5%) until it is 28 d old. At 28 d, 3 mm de-ionized water is poured on the top surface and the specimen is saturated for 72±2 h. At the age 31 d the freeze thaw cycles are started.
- **Modified standard procedure – 31d C:** As standard procedure, but from the age 21 d until 28 d the cut specimen is placed in a climate chamber with 1.0 % CO_2-concentration (20±2°C and RH 65±5%). At 28 d, 3 mm de-ionized water is poured on the top surface and the specimen is saturated for 72±2 h. At the age 31 d the freeze thaw cycles are started.
- **45 d curing regime – 45d C:** From demoulding (24±2 h) the cube is stored in water until the age of 21 days. Then the cube is stored in a climate chamber (20±2°C and RH 65±5%) until specimen is cut at an age of 35 days. At the age 35 d the cut specimen is placed in a climate chamber with 1.0 % CO_2-concentration (20±2°C and RH 65±5%) until it is 42 d old. At 42 d, 3 mm de-ionized water is poured on the top surface and the specimen is saturated for 72±2 h. At the age 45 d the freeze thaw cycles are started.
- **87 d curing regime – 87d C:** From demoulding (24±2 h) the cube is stored in water until the age of 63 days. Then the cube is stored in a climate chamber (20±2°C and RH 65±5%) until specimen is cut at an age of 77 days. From the age 77 d until 84 d the cut specimen is placed in a climate chamber with 1.0 % CO_2-concentration (20±2°C and RH 65±5%). At 84 d, 3 mm de-ionized water is poured on the top surface and the specimen is saturated for 72±2 h. At the age 87 d the freeze thaw cycles are started.

For all specimens, the weights were recorded immediately before and after the saturation with de-ionized water to determine the water uptake. Moreover, on accompanying specimens, cured in the same manner as the specimens for freeze-thaw testing, the carbonation depth was determined after 7, 14 and 28 d exposure to 1.0% CO_2 by spraying a phenolphthalein solution on a freshly split concrete surface. In addition, the compressive strength of the concretes were determined at 28, 56, and 180 days, see [9].

3. RESULTS AND DISCUSSION

The surface scaling after 56 cycles are presented in Figure 1. The acceptance criteria for "good" frost resistance according to SS 137244 [2] is shown in the figure. As can be seen in the figures, in all cases the scaling compared with the standard procedure increased for the carbonated specimens independent of curing condition, with the exception of mix C+20%S 0.40 for 45d C and 87d C curing. The increase in scaling is generally highest for 31d C, i.e. when carbonation starts on specimens at an age of 21 d. In Figure 2 the carbonation depth for the different concrete mixes and curing conditions are presented. The carbonation depths are, as expected, influenced by the curing conditions and age at exposure and are lower for more mature specimens. Moreover, with increasing GGBS content the carbonation depth increase and with decreased *w/b* ratio it decreases and is considerably lower, especially for the more mature specimens (curing condition 87d C). With respect to the measured carbonation depths for the accelerated carbonation (7 days in 1% CO_2) the measured depths should be compared to what is expected in field conditions (exposure conditions corresponding to XF4). Data from specimens exposed to atmospheric CO_2 during 11 year exposure at a field stations [8] showed a carbonation depth of about 1.1 mm with 30% GGBS at *w/b* 0.50 and 3.8 mm for a CEM III/B at *w/b* 0.50. At *w/b* 0.40 the carbonation depths were approximately 0.7 mm respectively 2.1 mm.

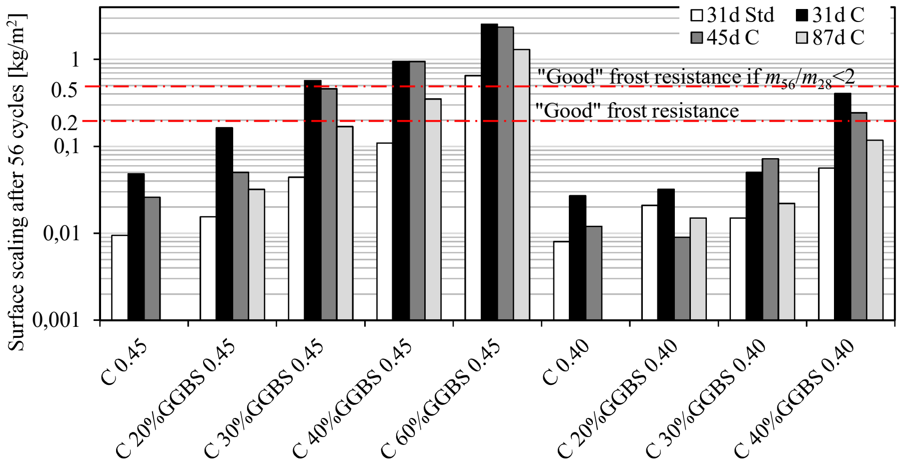

Figure 1 -. Comparison of the surface scaling (log scale) after 56 cycles.

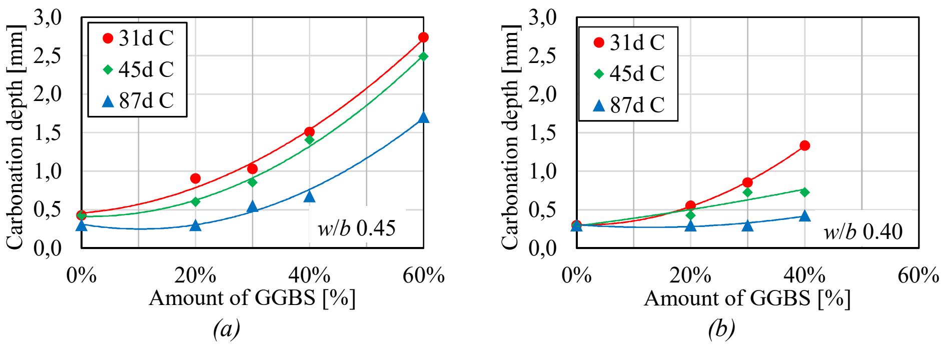

Figure 2 - Comparison of carbonation depth after 1 week in 1% CO2 for the different curing conditions for w/b 0,45 (a) and w/b 0.40 (b).

4. CONCLUSIONS

The effect of accelerated carbonation, 1 week with 1% CO2-concentration, on salt-frost scaling and the influence of different curing conditions has been studied. With the materials used and *w/b* ratios investigated it is clear that at 20% GGBS of total binder there is very little effect of carbonation on the frost resistance. Even with early accelerated carbonation at age of 21 days (31d C) all the tested concretes meet "good" scaling resistance or better after 56 cycles. For higher amounts of GGBS the early accelerated carbonation lead to increased scaling and especially at high amounts of GGBS (>40%). For the longest curing time 87d C (77 days when starting carbonation) the scaling was lower and GGBS contents of 30% achieved good frost resistance, this was also the case for some of the mixes with 40% GGBS); however, the scaling was still higher than for standard testing procedure. It should be pointed out that for the mixes with a higher slag content the compressive strength was much lower as an efficiency factor (k-value) of 1.0 was used, see [9]. The following conclusions can be made:

- With 20% GGBS of the total binder it was found that carbonation did not have a significant effect on the salt-frost scaling, even at early age carbonation.
- A GGBS content of about 30 to 40% is reasonable with respect to the salt-frost scaling resistance, but the testing and carbonation should not be done to early as this will produce a carbonation depth corresponding to more than 10 years natural carbonation.
- A prolonged curing regime before commencement of carbonation is needed if the test results should be realistic. In this study an age of 77 days when starting carbonation and 87 for start of frost cycles seems to have given reasonable results.

ACKNOWLEDGEMENT
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