Durability of low-clinker concrete with water-repelling admixtures

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ABSTRACT

The study under auspices of the BE-sTrONG project examined concretes with low cement content (higher w/b) with hydrophobic admixtures from Polyhedral Oligomeric Silsesquioxanes (POSS) and Rapeseed Oils (RO), containing 50% of clinker and 50% of either ground granulated blast furnace slag or natural volcanic pozzolan, against market's references in marine environment. The investigated admixtures showed reduction of chloride intrusion and permeability, especially RO, against the references (w/b 0.40) corresponding to almost 30% less w/b. RO, however, causes reduction in compressive strength, which yet may be confronted adjusting its composition.

Key words: Admixtures, Binders, Testing, Chlorides, Durability.

1. INTRODUCTION

The BE-sTrONG project [1] aims to make concrete for marine environments more sustainable by exploring advanced admixtures with low clinker cements for optimized sustainable material composition. The goal is to reduce the CO_2 footprint by at least 30% compared to current best practices by 2025, focusing on reducing water absorption in concretes. For this purpose, numerous studies on mortar and concrete were performed, testing high water-to-binder ratio mixes with either hydrophobic functionalized Polyhedral Oligomeric Silsesquioxanes (POSS) or vegetable/Rapeseed Oils (RO) against realistic references. The binder choice utilized two low-clinker binders where 50% of clinker was replaced respectively by: 1) slag - S50, 2) natural volcanic pozzolan from Iceland – P50. POSS, developed as a water-repellent additive, showed good results in the LORCENIS EU project, reducing permeability and chloride resistance when added to the concrete mix in form of finely ground powder [2,3]. Despite some strength reduction, it was shown earlier that RO can provide exceptional watertightness [4]. Our paper presents a share of concrete studies with an emphasis on compressive strength and durability criteria.

2. MIX DESIGN

Table 1 shows concrete mix designs used in the selection of projects results:

Table 1 – Mix design.

Mix ID / Materials	*P50*	*S50*	*free water*	*Abs. water*	*Årdal 0/8mm*	*Årdal 8/16mm*	*Dynamon SX-23*	*RO*	*POSS*	*AEA*
P50 REF 0.40	418,3		167,3	6,3	1027,8	806,7	2,26			
P50 0.55 RO	341,1		187,6	6,2	1022,5	802,6	0,76	3,42		
P50 0.55 POSS	343,7		189,0	6,2	1002,5	786,9	0,53		12,50	
S50 REF 0.40		416,5	166,6	6,3	1030,8	809,1	2,28			
S50 0.55 RO		337	185,4	6,2	1016,0	797,5	0,67	3,39		
S50 0.55 POSS		343,6	189,0	6,2	1007,8	791,1	0,49		12,49	
P50 REF 0.40 A	410,8		164,3	5,9	965,3	757,7	2,11			1,08
P50 REF 0.55 A	348,9		191,9	6,0	982,8	771,5	0,43			0,42
P50 0.55 RO A	345,9		190,3	6,1	986,6	774,4	0,58	3,46		1,99
S50 REF 0.40 A		414,0	165,6	6,0	973,0	763,7	2,24			0,83
S50 REF 0.55 A		350,6	192,6	6,1	991,5	778,3	0,38			0,45
S50 0.55 RO A		344,8	189,7	6,1	987,8	775,3	1,06	3,45		1,49

Mix ID includes the water-to-binder ratio and specific admixture, while REF indicates a reference without special admixtures. The tested POSS was an emulsion-based dispersion with 33 % dry matter. Workability ranged from 190 to 225 mm. For concretes with an air-entraining agent (AEA), denoted with an A suffix, the target air content was 4-6 %. Notably, the RO-mixes required about triple the AEA dosage compared to respective reference mixes.

Mixing procedure: 1 min with dry components, then 2 min with water and admixtures, 2 min rest and 2 min of remix, with adjustments of SP. **Addition of POSS / RO**: 1 L water + 10g SP, mixed for 30 sec on average speed (magnetic mixer IKA C-MAG HS7), then POSS or RO added and mixed for 3 min before added to the cement mix with the rest of mixing water.

3. CAPILLARY ABSORPTION TEST

Capillary absorption test was done on samples with different hardening procedures (**x** – for early e**x**posure to drying and **m** – for better **m**aturity):

- **x**-samples: 1d+6d in water, sawing 20 mm discs, 21d in 50% RH.
- **m**-samples: 1d+27d in water, sawing 20 mm discs (which is standard procedure).

For the same mix, each core contained both m- and x- samples. Drying commenced at 28d. **Two drying temperatures** were used: 1) 14d to 16d at 50°C (until constant mass) – safe for the microstructure; 2) 7d at 105°C – gives clearer saturation / «knee» - point, yet destructive for the microstructure**. Exposure to water**: on water surface (with 3 mm over material contact zone) – 4d with weighing after 10 min, 30 min, 1h, 2h, 3h, 4h, 6h, 1d, 2d, 3d, 4d.

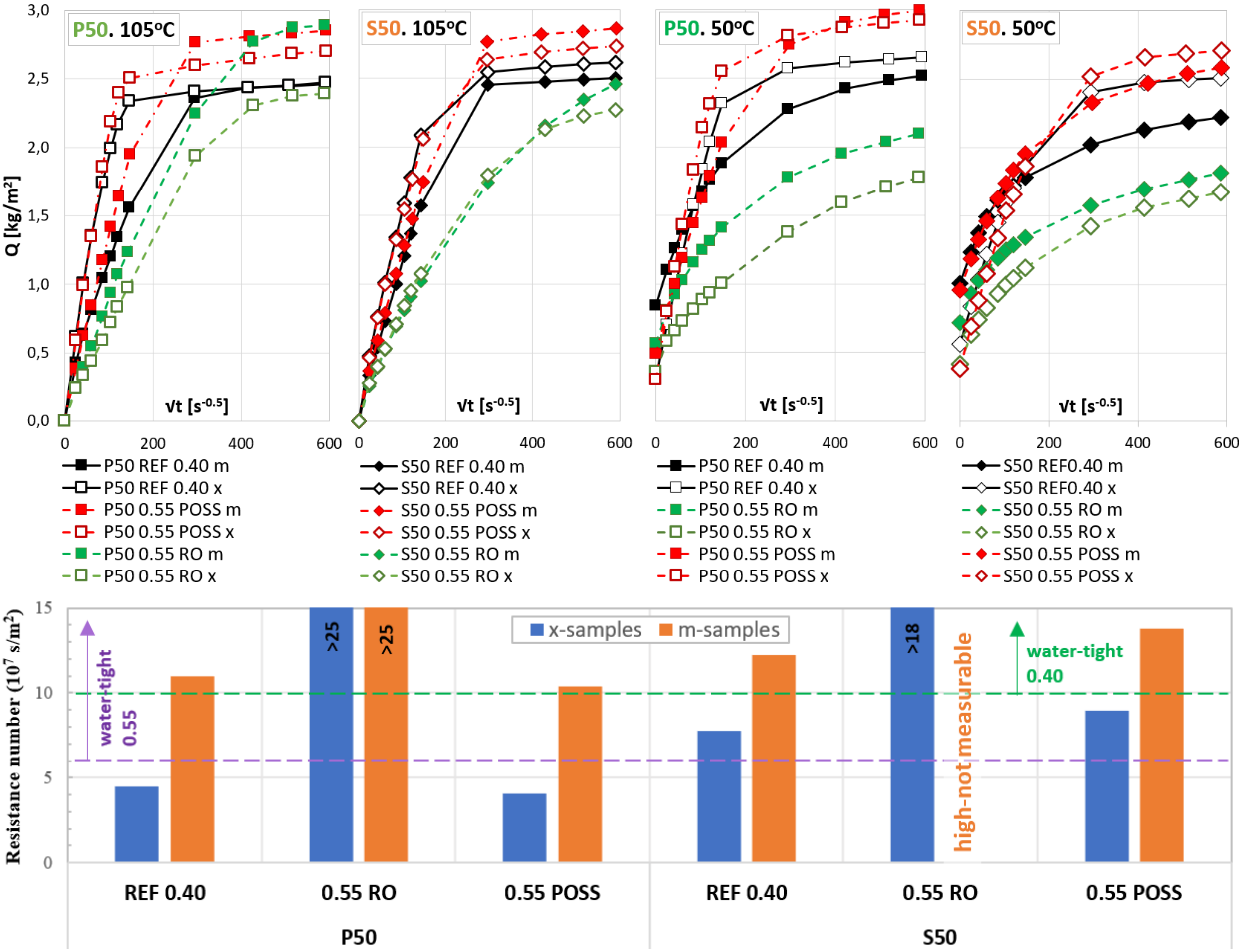

Figure 1 – Capillary suction results. Top: curves for different pre-conditioning and drying procedures. Bottom: Resistance number for 105°C drying.

Note: Every point is an average of 3 samples. The starting point for 50°C curves was corrected for initial water content, defined after drying at 105 °C post-test, assuming no water/weight loss from the hydration products.

Figure 1 (top) shows that the POSS curves are slightly higher than REF curves, while RO curves are lower, with considerably reduced water absorption velocity. Drying temperature has the most impact on concretes with a higher w/b-ratio: at 50 °C, absorption is slowed, and most curves do not show a clear saturation (no plateau). The resistance numbers (Figure 1 bottom) indicate that (a) P50 requires prolonged curing, (b) both admixtures reduce permeability, and (c) RO provides superior watertightness compared to REF 0.40, regardless of the preconditioning procedures.

4. STRENGTH DEVELOPMENT AND CHLORIDE INTRUSION

Figure 2 shows **compressive strength development** from 28 to 180 days and the total air content. Strength development from 28 to 180 days is higher for P50 than for S50, as expected. RO reduces strength by 10-20 %, consistent with [5]. For mixes with w/b 0.55, with and without AEA, RO mixes have similar strength development to the reference, while POSS increases development by 40 %. **The chloride profiles** were determined by powder grinding and potentiometric titration of acid-soluble chlorides. The powder was ground from well-hardened cores (90 d of water storage) with the test surface exposed to 90d of 6 % NaCl solution. Figure 3 shows that all tested concretes have low apparent diffusion coefficients, meeting marine exposure requirements by NS-EN 206 ($<2{,}5\cdot10^{-12}m^2/sec$).

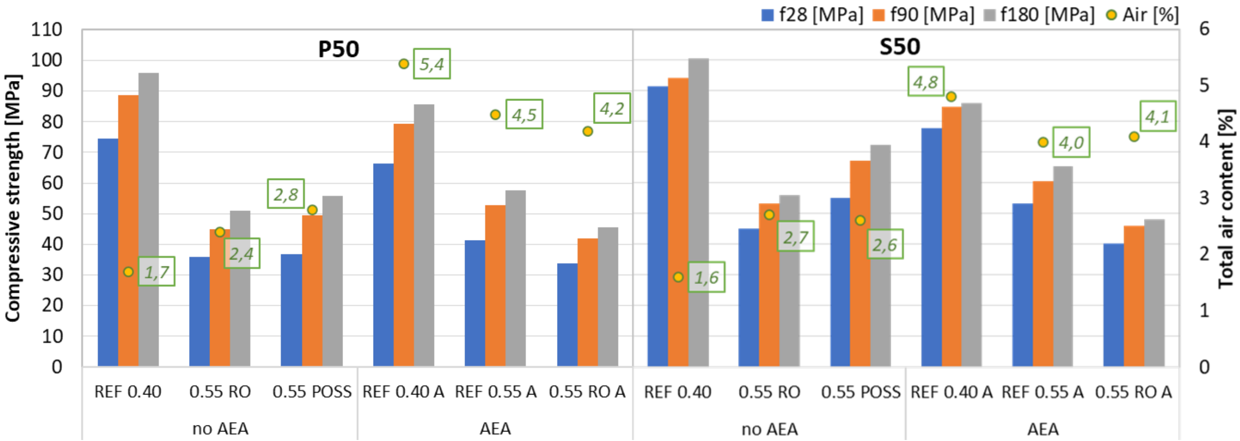

Figure 2 – Strength development with and without AEA and air content. Left: P50. Right: S50.

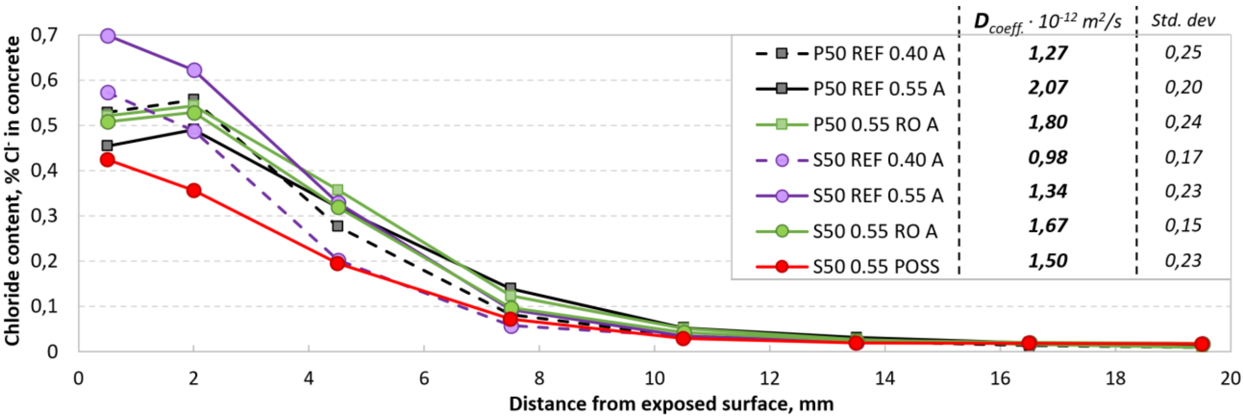

Figure 3 – Bulk diffusion after 90 d in 6 % NaCl. Chloride profile and diffusion coefficient.

5. CONCLUSIVE REMARKS AND FUTURE WORKS

Water repelling admixtures reduce permeability and increase chloride resistance of concrete, which gives the opportunity to significantly reduce cement content and improve the environmental impact by increasing w/b ratio while still satisfying marine exposure according to EN 206. Further improvements in these concrete recipes are on the way to meet requirements set for carbonation and frost resistance.

6. ACKNOWLEDGEMENT

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