The effect of hydrophobic treatment on concrete durability characteristics

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Hydrophobic impregnation represents a cost-effective way to increase the durability of concrete structures in cases where insufficient design cover quality and depth have been achieved. The risk of reinforcement corrosion initiation and subsequent deterioration can be reduced as the ingress of water-dissolved aggressive species (chlorides) is minimised or prevented. The purpose of this study was to investigate the effect of silane impregnation on durability indicators, including penetrability tests and chloride ingress (bulk diffusion).

Cover concrete represents the primary barrier against the ingress of aggressive agents towards the reinforcing steel and several design codes define cover depths according to particular environmental classes [1]. The thickness and quality of this zone is largely dependent on on-site quality control and curing conditions respectively [2]. As the modern construction industry is under the perpetual constraints of time and money, quality control is often neglected on site, resulting in sometimes poor execution and outcome of works. Hence, the design cover depth and quality are not achieved due to im-

Table 1: Concrete mix composition

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8
Material (kg/m^3)	CEM I	CEM I	30 % FA	30 % FA	50 % GGCS	50 % GGCS	CEM III/B	CEM III/B
Water to binder ratio (w/b)	0.45	0.60	0.45	0.60	0.45	0.60	0.45	0.60
Cement (CEM III/ B 42.5N)	–	–	–	–	–	–	411	308
Cement (CEM I 52.5N)	411	308	288	216	206	154	–	–
Extender (FA)	–	–	123	93	–	–	–	–
Extender (GGCS)	–	–	–	–	206	154	–	–
Fine aggregate (Crusher sand)	426	472	406	457	419	467	413	463
Fine aggregate (Dune sand)	426	472	406	457	419	467	413	463
Coarse aggregate (19-mm Greywacke)	1040	1040	1040	1040	1040	1040	1040	1040
Water	185	185	185	185	185	185	185	185
Total binder (kg/m^3)	411	308	411	308	411	308	411	308
Fly-ash content (%)	–	–	30	30	–	–	–	–
GGCS content (%)	–	–	–	–	50	50	–	–
Slump (mm)	70	60	90	65	75	60	70	70
fc, 28-d (MPa)	66.7	47.7	55.3	35.6	63.1	49.2	58.5	45.4

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proper placing, compaction and curing of in situ concrete. In this respect, considerable research has been undertaken to identify suitable solutions to avoid premature deterioration and extend the service life of reinforced concrete. Surface treatment represents a preventative measure to protect new and existing structures from environmental attack and reduce the risk of associated reinforcement corrosion. The aim of surface treatment is to reduce the concrete cover's penetrability to aggressive substances. Hydrophobic impregnation (penetrant pore liner) is one type of surface treatment that has the ability to reduce the capillary absorption of water containing dissolved deleterious species (chlorides) and thus delay the initiation of rebar corrosion [1, 3].

Methodology

Two water to binder ratios (w/b 0.45 and w/b 0.60) and four binder types were selected (CEM I, Fly-ash (FA), Ground granulated corex slag (GGCS) and CEM III/B). Hence a total of 8 concrete mixes were used (Table 1). The concrete specimens were demoulded 24 hours after casting, wrapped in plastic sheeting and placed in an environmental room (23 + 2°C temperature and 63 + 2% relative humidity). After 7 days, the plastic sheeting was removed, and the specimens were air cured under the aforementioned controlled environmental conditions until the age of 56 days. Silane treatment was performed at the age of 28 days by applying Sikagard® 706-Thixo [4] (a silane based water repellent impregnation cream) at a consumption rate of 400 g/m^2. The treated specimens were then placed in an environmental room (maintained at a temperature of 23 + 2°C and relative humidity of 63 + 2%) until the age of 56 days.

Oxygen Permeability Index (OPI), Water Sorptivity Index (WSI) and Chloride Conductivity Index (CCI) tests were carried out in accordance with SANS 3001-CO3-2 (2015) [5], the UCT DI test manual (2017) [6] and SANS 3001-CO3-3 (2015) [7] respectively.
The hydrophobic (silane) impregnation depth was measured 4 weeks after treatment. The indirect tensile splitting test was performed on two silane treated concrete cubes (100 mm) and water was sprayed on the internal surface. The hydrophobised part of concrete repelled any water while the untreated part showed darker coloration, due to water absorption.
Bulk diffusion tests were carried out in accordance with ASTM C1556 (2004) [8], starting at a sample age of 56 days. Six test specimens (3 treated / 3 untreated) were used per mix. After the chloride exposure period, specimens were removed from the salt solution and cut into slices at suitable increments. These slices were pulverized and milled into approximately 10 g powder samples. A potentiometric titrator was used to determine the acid soluble chloride ion content, in accordance with ASTM C1152 (2012) [9].

Results and discussions

Durability Indexes

According to the results, silane treated concrete recorded lower WSI (Fig. 1) and CCI values (Fig. 2) relative to untreated concrete. Hydrophobic (silane) impregnation chemically modifies the near surface zone of the concrete and reduces the capillary uptake of water. As the silane molecules bond and cover the capillary walls, the latter become devoid of ionic electrical charges and polar molecules such as water/chlorides are no longer attracted to the concrete surface [10]. The overall interaction between ions and concrete is reduced and subsequent capillary absorption of liquids or migration of ions is minimised.

Silane penetration depth

As expected, the silane penetration depth increased with a higher w/b ratio (Fig. 3). This was attributed to the higher capillary porosity of the cement paste microstructure which allowed deeper penetration of the water repellent product. The effect of binder type for the w/b 0.60 mixes was unclear due to the overlapping of error bars but for the w/b 0.45 mixes, the inclusion of FA and GGBS (CEM III/B) increased and reduced the penetration depth respectively. The silane penetration depth (mm) was also found to be highly related to the Oxygen Permeability Index (OPI/log-scale), as shown in Figure 4. Note that measured OPI values ranged from about 9.2

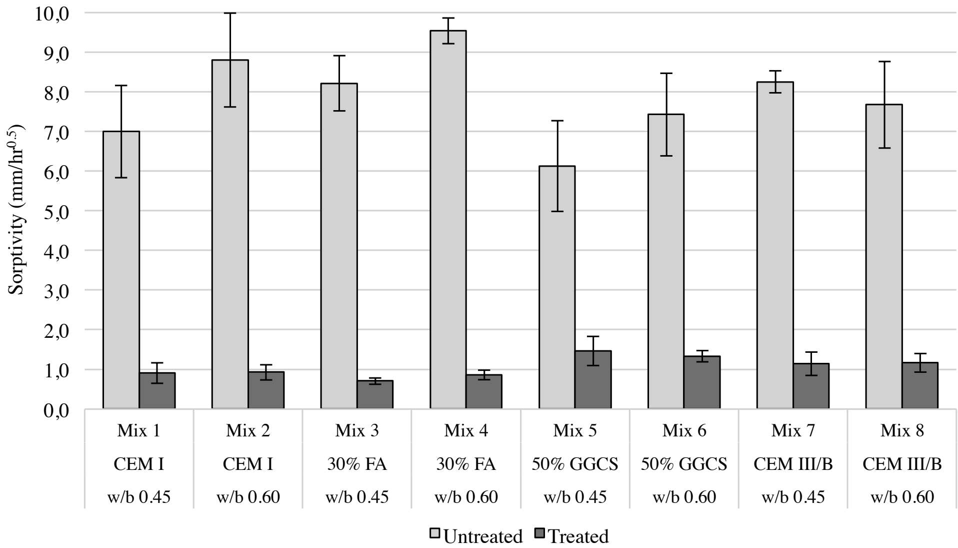

Fig. 1: Durability Index test results (WSI)

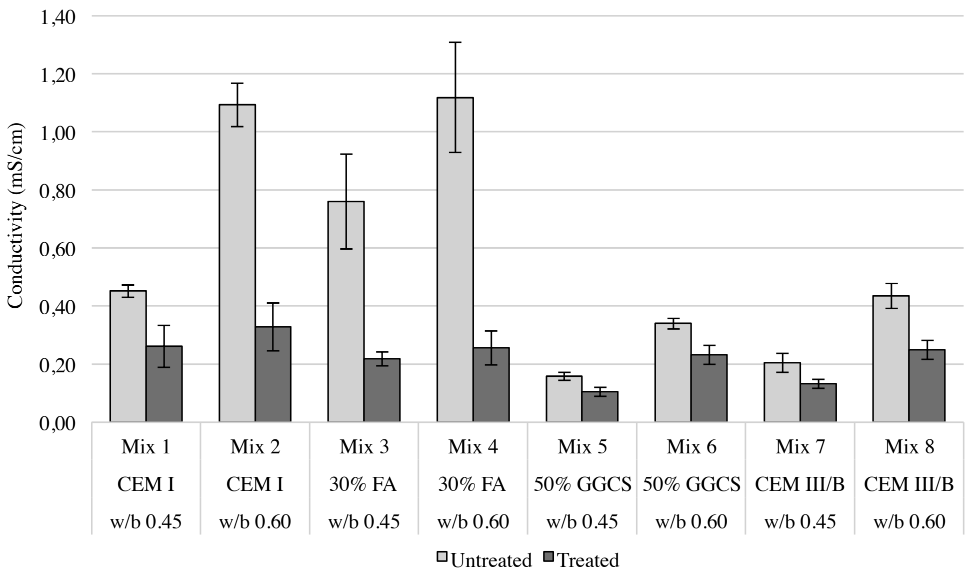

Fig. 2: Durability Index test results (CCI)

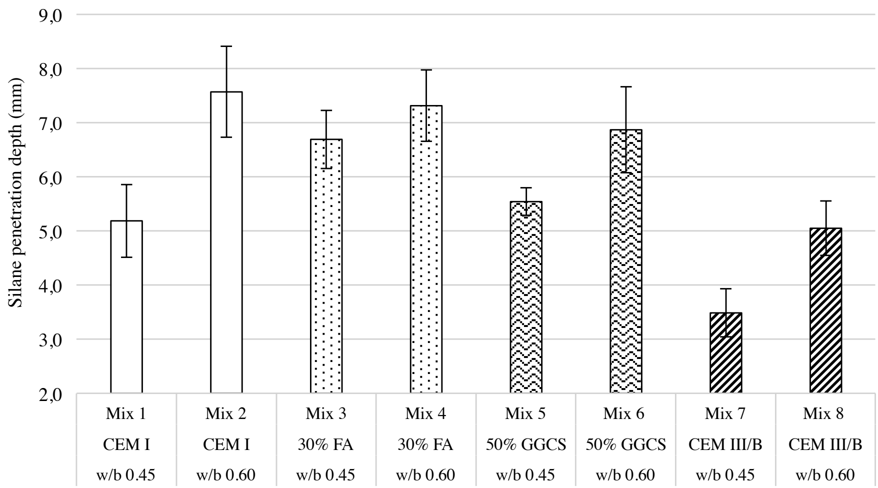

Fig. 3: Silane penetration depth

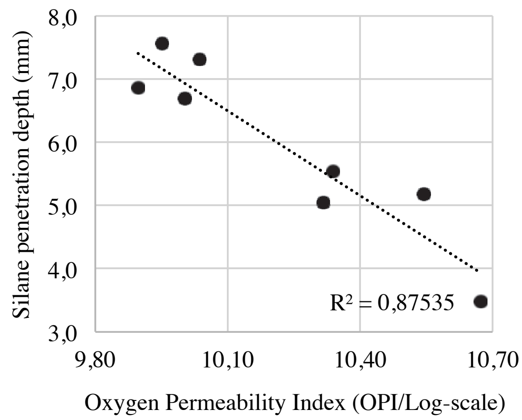

Fig. 4: Correlation between silane penetration depth and OPI

to 10.6, representing the negative log of the coefficient of permeability. Due to the logarithmic scale, a concrete with an OPI value of 9.2 is about 25 times more permeable, compared to a concrete with an OPI value of 10.6. The good correlation between OPI and silane penetration depth was explained by the fact that the penetration depth of the product is a function of the overall quality (interconnectedness, tortuosity of the capillary pore structure) of the near surface concrete and the OPI test evaluates these properties.

Bulk diffusion

An example for typical chloride ingress profiles is given in Figure 5. In general, silane treatment reduced the surface chloride concentration and the effect was most pronounced in the FA, GGCS, and CEM III/B mixes. Similarly, the silane treated concrete had lower apparent chloride diffusion coefficients relative to the untreated concrete. As the chloride penetration and content is reduced within the near surface zone, the supply of chloride ions that can diffuse deeper into the concrete is smaller. Thus, the diffusion gradient is less steep in silane treated concrete. Diffusion of chlorides is also significantly slowed down within the silane impregnated (treated) layer due to reduced ionic interactions with the concrete.

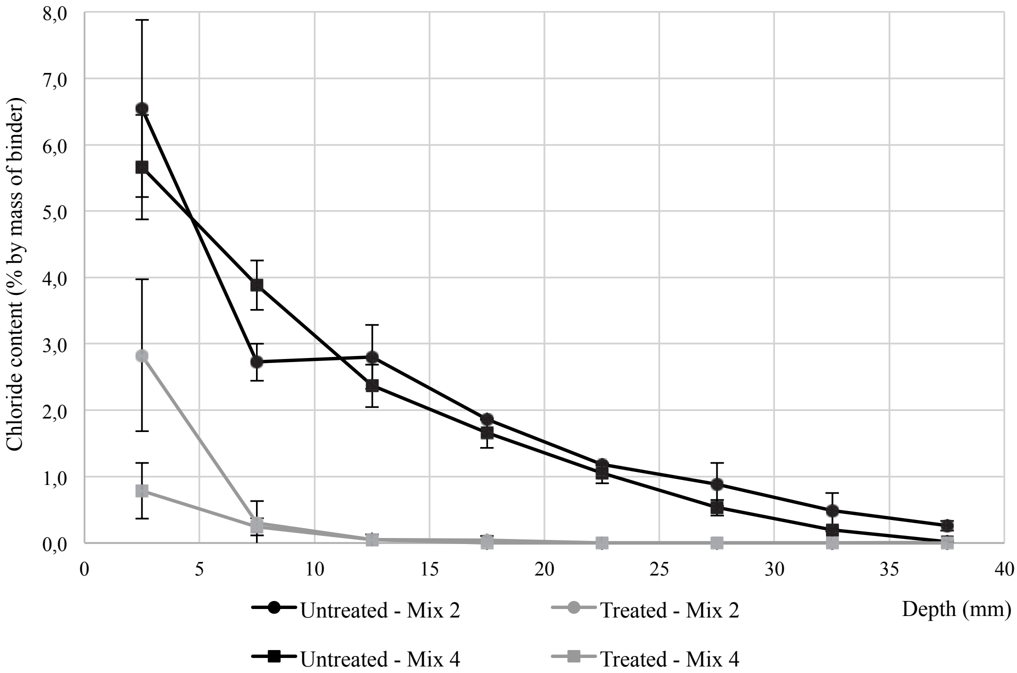

Fig. 5: Diffusion test results: CEM I and FA mixes, w/b = 0.60

Conclusions

The silane penetration depth was strongly dependent on the quality (porosity) of the near surface zone as deeper penetration was observed in the higher w/b concrete mixes. A near linear correlation between Oxygen Permeability Index values and silane penetration was recorded, indicating that the OPI test is an excellent method to assess likely penetration depth of the product.

Silane impregnation significantly improved the transport properties (lowered sorptivity and conductivity) of the concrete mixes, indicating a significant decrease in penetrability. Similarly, in relation to chloride ingress, chloride surface concentrations and chloride ingress in general were significantly reduced for all treated concrete mixes; chloride ingress in treated concrete was significantly lower, compared to untreated concrete.

For practical applications, the results indicate that the durability of reinforced concrete structures in marine environments (splash/spray zone, airborne exposure), regardless of the binder type, can effectively be extended using silane impregnation, assuming proper surface preparation and application methods.

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