

Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 73/1/73/2 (1995)

Artikel: Surface treatments for concrete quantifying the improvement
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DOI: <https://doi.org/10.5169/seals-55194>

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Surface Treatments for Concrete Quantifying the Improvement

Traitement de surface du béton et mesure de l'amélioration

Oberflächenbehandlung von Beton mit messbaren Verbesserungen

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SUMMARY

An experimental programme to investigate the influence of pore-lining surface treatments on new concrete is described. The focus is on the effect on chloride ingress and time to corrosion of embedded reinforcement. The results show that the characteristics of any concrete treated with a pore liner are considerably better than for a good quality concrete with no surface treatment and are almost independent of the concrete itself.

RÉSUMÉ

L'article décrit un programme de recherche sur l'influence d'un traitement de surface par remplissage et lissage des pores de bétons neufs. Il fait le point sur les effets du temps et de la diffusion des chlorides sur les armatures enrobées. Les résultats montrent que les caractéristiques de n'importe quel béton subissant un tel traitement sont considérablement meilleures que celles d'un béton de bonne qualité non-traité. Elles sont également quasiment indépendantes du béton lui-même.

ZUSAMMENFASSUNG

Es wird ein Versuchsprogramm beschrieben, um den Einfluss einer porenauskleidenden Oberflächenbehandlung auf neuen Beton zu untersuchen. Im Mittelpunkt steht die Auswirkung auf die Chloriddiffusion und die Zeitspanne bis zur Korrosion der eingebetteten Bewehrung. Nach den Ergebnissen zu urteilen, ist das Verhalten eines jeden Betons, wenn er mit Porenauskleidung behandelt wurde, bedeutend besser als für einen hochwertigen Beton ohne Oberflächenbehandlung, und zwar ziemlich unabhängig vom eigentlichen Beton.



1. INTRODUCTION

Under ideal conditions concrete will improve in quality with time due to the longer term reactions which produce the cement hydrates. However, the interaction with the environment can cause deterioration of concrete. A low ratio of water to cement and good curing are important factors in reducing future deterioration but in some circumstances even these cannot guarantee long service life. One such case is highway structures where the action of chlorides in deicing salts and, to a lesser extent, the action of freezing and thawing create an extremely aggressive environment. It is increasingly accepted that current design code recommendations for minimum concrete quality and cover to the reinforcement are inadequate and that for chloride ingress no combination of normal concrete and cover will provide a service life normally expected of bridges [1]. This has led to increased use of surface treatments to provide an effective barrier to the ingress of water and chloride ions.

The most commonly used surface treatments for this application are pore liners; in particular silanes and siloxanes. They can be sprayed on the surface and the liquid which enters the pores reacts with the cement matrix, in the presence of moisture, to form a lining to the capillary pores [2, 3]. The major advantage over other treatments is that, while they reduce the penetration of water and water-borne ions, the passage of air and water vapour is not prevented. Consequently, the concrete is still able to "breathe". While the fact that pore liners reduce chloride ingress has been reported elsewhere [4, 5, 6] the variation in their effectiveness for different concrete qualities is less well documented. This paper reports a test programme to study the increase in resistance to chloride ingress and the delay in corrosion initiation due to the application of surface treatments.

2. EXPERIMENTAL PROGRAMME

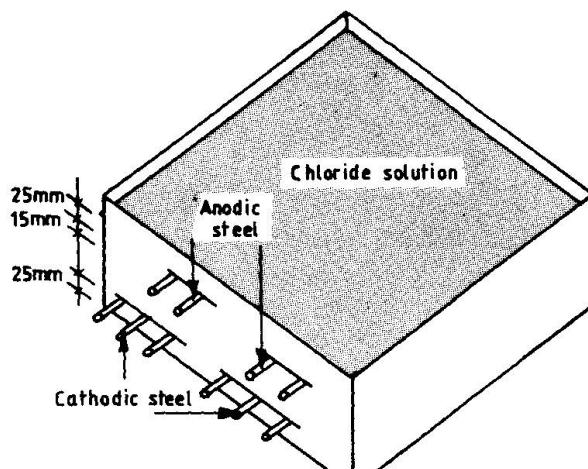
2.1 Test Regime

The ingress of chloride into concrete varies depending on the mechanism by which it is transported [7, 8]. If concrete is subjected to cyclic exposure rather than continuous exposure, the chloride ingress is greater. This is because absorption dominates in the former case whereas in the latter the mechanism is diffusion. In this study, cyclic exposure was adopted because the amount of chloride penetration would be greater within the time scale of the tests and because it is more representative of the conditions which prevail when sodium chloride is used as a deicing salt. The exact ponding cycle chosen was similar to that used by Pfeifer [4]; three days ponding with a 15% sodium chloride solution and four days drying (in this case all at 20°C and 55±5 °C relative humidity).

2.2 Test Samples

Concrete samples were 400 x 400 x 150mm with a 12mm deep reservoir formed on one face to contain the sodium chloride solution. Anodic reinforcing bars were positioned at 25mm and 40mm from the ponded face and cathodic bars near the bottom face (Figure 1). Where the bars projected from the concrete, they were protected with a rich mortar and a tar based corrosion protection coating. A 10Ω resistor was connected across each pair of bars. The sides of the samples were coated with epoxy resin to prevent any contamination via the sides.

The variables investigated in this study were the ratio of water to cement of the concrete and the type of surface treatment. Three concretes with different water to cement ratio (0.45, 0.55 and 0.65) were selected to represent the normal range used in practice. A 20mm maximum size crushed rock was used as coarse aggregate and a natural sand as fine aggregate. In addition to the control



Specimen size -300x300x150 mm
Details of bars -10mm diameter, M.S.
Cover -25mm & 40mm

Figure 1. Details of specimens used for the chloride ponding test

samples (ie. those with no surface treatment) four treatments were investigated; 100% silane, 40% silane, silane-siloxane and silane-acrylic. An earlier study had shown that the variation in the sorptivity of concretes treated with silanes of differing concentration was low and so it was decided to include only the extreme values in this study. After curing for 14 days in water and 14 days in air, the specimens were saturated and then conditioned for 3 days at 20 °C and 55±5 rh before application of the surface treatments. This was considered to represent typical conditions under which surface treatments might be applied in the British Isles.

2.3 Test Methods

2.3.1 Chloride content

Samples were drilled from the sides of the specimens at the same depths as the reinforcing bars ie. 25mm and 40mm. The water soluble chloride ion content of the samples was analysed in accordance with BS1881 : Part 124 [9] and expressed as a percentage of the cement content. A set of samples was collected from all samples when the bars at 25mm cover in the control (untreated) samples first showed some indication of corrosion. A second set of samples was obtained after about 30 weeks of ponding and a final set at the end of the 44 week test period.

2.3.2 Half-cell potential

Half-cell potential readings were taken every three weeks throughout the 44 week period using a copper-copper sulphate half-cell. Three points were selected along each of the anodic bars to see if there was any variation in corrosion activity along the length of the bars.

2.3.3 Macrocell corrosion

The voltage across the anodic and cathodic bars was monitored throughout the test period. From this, the macrocell corrosion current was calculated using Ohm's Law. No attempt was made to measure microcell corrosion activity.

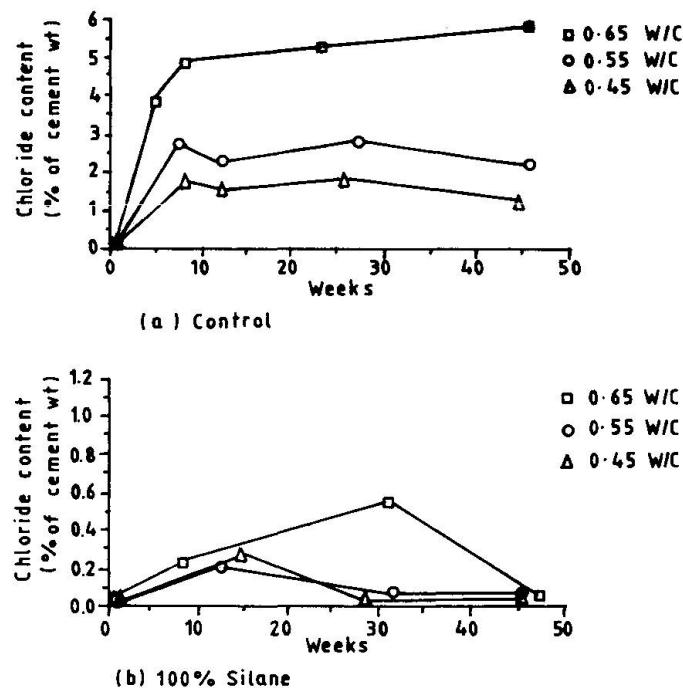


Figure 2. Chloride ingress at 25 m depth in cyclic ponding test.

3. CHLORIDE PENETRATION

Figure 2 shows the variation with time of the measured chloride concentrations at 25mm from the surface subjected to ponding. For clarity, only the untreated samples and 100% silane have been included and it should be noted that different scales have been used. It is clear that the chloride concentration seems to level off after about ten cycles. At the end of the test, the ion concentration in the untreated samples was between 1.0% and 5.5%; increasing with increasing water-cement ratio. With 100% silane applied to the surface, the ion contents were considerably reduced. While there is some variability in the results, mainly due to the level of accuracy possible at such low values, the final ion concentration for each of the three concretes was about 0.2%. Similar results were obtained for the concretes treated with 40% silane, silane-siloxane and silane-acrylic.

For the 40mm depth, the trend is similar except that even at the end of the 44 weeks, the chloride ion content in the 0.45 water-cement ratio concrete was no higher for untreated concrete than for treated concrete. These results indicate that while surface treatments are effective on all concretes, the improvement gained is much greater on high water-cement ratio concretes. In fact, there is evidence that after treatment all concretes perform almost equally.

4. CORROSION ACTIVITY

For the control slabs, there was evidence of corrosion activity within the first 10 weeks. Figure 3(a) shows the half-cell and corrosion current readings for 0.55 water/cement ratio concrete. At the end of the test period, half-cell potentials were between -450mV and -600mV for all three concretes. The corresponding corrosion currents were -0.02mA to 0.20mA. At the end of the test, the samples

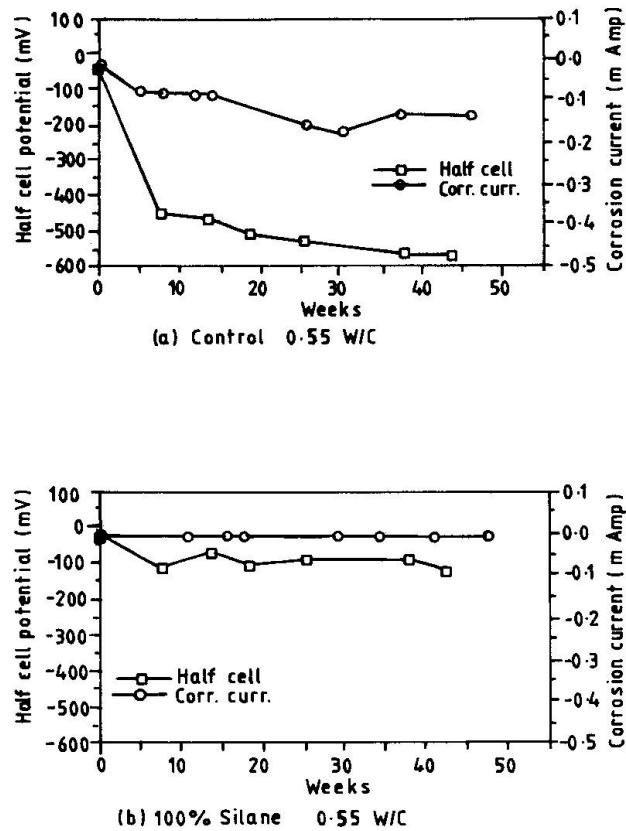


Figure 3. Corrosion at 25 mm cover in cyclic ponding test

were broken and the bars inspected for rusting. This confirmed the above result with rusting evident on all the bars at 25mm cover in the untreated specimens. In fact, except in the case of the 0.45 water-cement ratio concrete, the bars at 40mm cover had some rust on the top surface; also confirming the potential and corrosion current readings.

The results for the 0.55 water/cement ratio concrete treated with 100% silane are shown in Figure 3(b). A similar trend was obtained for the 0.45 water/cement ratio concrete, but for the 0.65 water/cement ratio, there was a significant jump in the half cell potential to -500mV after 30 weeks [10]. The potentials and currents were borne out by the visual inspection at the end of the test with corrosion visible only on the reinforcing bars in the 0.65 water-cement ratio specimen. Two other surface treated specimens exhibited corrosion; the 0.65 water-cement ratio concrete with silane-acrylic and the 0.45 water-cement ratio with silane-siloxane. There is no clear explanation for why corrosion occurred in these particular specimens, but from the overall picture it can be seen that with surface treatments, the instances of corrosion within the test period were reduced; from 100% for untreated specimens to 25% among the treated specimens. However, even when corrosion activity occurred with surface treatments, the time lapse until it took place was greater; 20-30 weeks for the treated specimens compared to 10 weeks for those untreated.



For bars at 40mm cover, there was corrosion in the untreated specimens using 0.55 and 0.65 water-cement ratio concrete after about 20 weeks. In none of the treated specimens was there evidence of corrosion of the bars at this cover within the 44 week period.

5. CONCLUSIONS

From this study, it is possible to draw the following conclusions :

- (1) Chloride ingress is reduced considerably by the application of surface treatments to new concrete. For the surface treatments investigated, there was no significant difference in their performance in relation to chloride ingress.
- (2) The resulting resistance to chloride penetration is generally independent of the quality of the concrete.
- (3) Corrosion of reinforcement due to chloride ingress is delayed due to the application of a surface treatment though no one treatment performed better than the others. For the ponding cycle used and reinforcement at 25mm cover the time to the start of corrosion was more than doubled.

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ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the material suppliers and the funding from the Engineering and Physical Sciences Research Council (formerly SERC).