

Fig. 3: Ferrocement Secondary Roofing Slabs



Fig. 4: Interlocking Ferrocement Secondary Roofing Slabs

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Fig. 5:Sectional elevation of Precast Water Tank



Fig. 6: Spinning of Ferrocement Tank Water Tank Wall during casting



Fig. 7: Strengthening of beams using Ferrocement Laminates



Fig. 8: Ferrocement laminate reinforcement for Flexural Strengthening

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Fig. 9: Ferrocement laminate reinforcement for Shear Strengthening



Fig. 10 - Building before Upgrading



Fig. 11 - Upgraded with Ferrocement Cladding System

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Interactions between Surface Coatings and Their Concrete Substrate

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Synopsis: Protective coatings are often used to waterproof their substrate, to increase the durability of concrete, or simply to improve the aesthetics of a structure. However, there are side effects. For example, coatings that shed water would inhibit the curing effect that could be derived from subsequent wetting due to outdoor exposure. A protective coating could also increase the carbonation of its substrate since it provides a favourable dry environment for carbonation to proceed. This paper presents long-term results to illustrate these two 'side effects' on the use of protective coatings.

Keywords: carbonation; coating; concrete; curing

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INTRODUCTION

Protective coatings are often used to treat concrete surfaces in order to enhance the aesthetics of structural elements, to act as anti-graffiti coatings, or to increase the service life of structures. They are generally solvent or water-based materials and are marketed for their water-repellent properties with claimed service life of around 10 years. In terms of concrete durability relating to reinforcement corrosion, discussions^{1,2,3} mainly focused on the coating material, and were generally based on their ability to resist the penetration of aggressive ions into the concrete substrate. It is generally assumed that the application of coatings increases the service life of concrete structures. However, Ho, *et al*⁴ has pointed it out, that under certain conditions, the application of coatings could reduce rather than increase the durability of concrete.

A research program was initiated some 10 years ago at CSIRO in order to have a better understanding of the interactions between protective coatings and the quality of their concrete substrate. Commercial coatings with various application rates were used on surfaces having different surface texture and quality. Some specimens were subjected to accelerated tests in the laboratory while others have been exposed outdoors since 1988. Some laboratory results have already been reported^{5, 12}. The long-term exposure tests were terminated in 1995 due to the deterioration of some of the coatings. This paper reports the findings from this exposure test.

Three coatings were used in this study. The first one (Coating 1) was a penetrating sealant commonly used to maintain a dry substrate. It has also been applied to buildings exposed to a coastal environment to restrict the ingress of chloride ions into concrete. The second one was marketed as an anti-carbonation coating while the third was an acrylic paint commonly used to improve the external appearance of above-ground structures. Note that this research concentrated on the concrete substrate and the aim was to find out how the time-dependent quality of concrete can be influenced by various

treatments. No attempt is made to rank the performance of coating materials and thus, the three coatings discussed in this paper will be referred to only as Coatings 1, 2, and 3. Clark ⁶ warns of the danger of presenting the performance of materials by generic names based on the binder, when such materials with different formulations can have a wide range of performance characteristics.

PROPERTIES OF CONCRETE

In the study of concrete quality, the properties of interest depend on the service and exposure environment. For building exteriors and the reinforcement corrosion aspect dealt with in this paper, the penetrability of substances such as carbon dioxide, chloride ions, oxygen and water are of prime importance. Consequently, the permeability and alkalinity of the cover concrete are important properties relating to corrosion protection, and these two properties have been expressed ⁷ in terms of water sorptivity and carbonation. The former is related to the rate of water penetration due to capillary suction and is generally accepted as one form of permeability ⁸. In an earlier paper ⁹, the quality of concrete was expressed as the inverse of carbonation or water sorptivity. Accordingly, good quality concrete is represented by low values of these properties.

Water sorptivity $(mm/h^{0.5})$ of concrete was determined by measuring the depth of water penetration (mm) at various times up to 24 hours (h). Test procedures have been documented in detail in earlier papers ^{11,15}. As for carbonation tests, a phenolphthalein indicator was used to reveal the depth of carbonation (mm).

Note that carbonation relates only to the initiation phase of reinforcement corrosion. Water sorptivity, on the other hand, relates to both the initiation phase, by affecting the ingress of aggressive materials (such as chlorides from sea sprays and sulfur dioxide from polluted atmosphere), and the propagation phase, by providing moisture and lowering the resistivity of the concrete. Performance specifications for durable structures¹⁰ based on these properties have been recommended and used in the design of bridges.

In this investigation and by following manufacturers' instructions, three different types of coatings 1, 2 and 3 were applied to a grade 25 concrete, one month after they were demoulded. Replicate specimens ($400 \times 170 \times 60 \text{ mm}$) were placed

- a) indoors maintained at 23°C and 50% RH;
- b) outdoors but under shelter from rain;

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- c) outdoors and vertically facing north (NV) to achieve a relatively dry environment;
- d) outdoors and inclined at 45° facing south (SI) to achieve a relatively wet environment.

The exposure site was at Highett, about 23 km Southeast of Melbourne $(38^{\circ}S)$. A directional rain gauge was used to record the amount of rain received on these surfaces. Specimens were initially cured for 1 day having a sorptivity value of 17 mm/h^{0.5} prior to exposure. Control specimens with standard moist curing (fog room) of 7 and 28 days had sorptivity values of 7 and 4 mm/h^{0.5}, respectively.

Note that during application, coatings 1 and 2 were absorbed into concrete to a depth of 5 mm and 1 mm, respectively, whereas coating 3 acted as a surface layer.

INFLUENCE ON CURING

Recent research on modern binders ¹¹ confirms the general belief that there is negligible hydration at humidity levels below 80% relative humidity, and shows that the rates of improvement for concrete exposed to environments less than 100% RH are very slow. For example, at 94% RH, the duration of curing has to be extended to one year in order to achieve a quality equivalent to that obtained with seven days at 100% RH. For effective curing, this finding reiterates that importance of keeping concrete saturated.

Due to the speed of construction, concrete in aboveground structures is rarely cured beyond one day. Thus, further curing has to rely on the weather, with wetting by rain on concrete surfaces. Research ¹³ found that the quality of concrete improved slowly with time when exposed to the weather in Melbourne. Thus, the application of coatings soon after construction for whatever reasons, would interrupt this curing process because these coatings have the ability to shed water from the concrete surface.

The influence of coatings on the curing quality of concrete is shown in Table 1. As indicated, under NV conditions, the quality of the untreated concrete improved from its initial sorptivity value of $17 \text{ mm/h}^{0.5}$ to a value of 6.0 mm/h^{0.5}. The improvement was even better for specimens placed under the SI conditions, reaching a quality (2.5 mm/h^{0.5}) better than that obtained with 28 days of standard curing. The difference in results can be explained by the amount of rain received on these surfaces. Over this 7-year period, the NV specimens received 154 mm of rain, while the SI specimens received 4510 mm. Thus in any study relating to the long-term performance of

concrete, it is important to take into account both the macro- and microclimatic conditions.

As expected, under the indoor environment where the humidity was maintained at 50% RH, the quality of concrete remained practically unchanged regardless of the surface treatment. Even under shelter, the variations in RH in an outdoor environment had only a minor effect on the quality of concretes with the sorptivity values of both the treated and untreated specimens remaining high. Note that one general requirement of coatings is their high permeability to water vapour to allow "breathing" of the substrate. This "breathing" caused variations in the RH of the substrate allowing some minor curing process to take place, with a subsequent slight drop in their sorptivity values.

Under NV and SI exposures, specimens with either coating 1 or 2 improved further. However, their improvement was much less compared with that obtained from the untreated concrete. As for concrete with coating 3, extensive chalking was noticed after 5 years. For the subsequent 2 years, it was believed that this coating has lost its effectiveness as a water barrier and the migration of water under NV and SI conditions provide some form of curing, thus a reduction in water sorptivity to 12.5 and 8.0 mm/h^{0.5}, respectively. Visual inspection indicated that coating 2 was still in good condition while coating 1 began to show signs of deterioration after 7 years of exposure.

INFLUENCE ON CARBONATION

The principles of applying anti-carbonation coatings to concrete are generally well understood. Klopler ¹ discussed the effectiveness of protective coatings in terms of an equivalent air layer thickness. This work has been extended and a practical approach has been developed ¹² to assist industry in assessing coatings as carbon dioxide barriers. This approach is based on a γ factor, which relates the depths of carbonation of treated (X_T) and untreated (X_U) surfaces. Coating effectiveness, γ , is defined as

and the depth of carbonation (X) at time (t) is given by

where C is the carbonation rate.

As mentioned earlier ⁴, protective coatings may increase rather than decrease the carbonation of concrete substrate unless the coating has a high