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IMMERSION CORROSION TESTS TO EVALUATE POLYASPARTIC COATINGS ON STEEL

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In this study, a waterproof polyaspartic coating used for concrete structures was modified into an anti-corrosion coating system to prevent steel assets from corroding. A micaceous iron oxide barrier, a zinc phosphate corrosion inhibitor and a novel resin hardener were added to the polyaspartic coating. Its corrosion performance was assessed through immersion corrosion tests in 3.5% NaCl solutions at room temperature (RT) and 35 °C for 30 days. The surface finish of the steel samples was milled and blasted (SA 2.5). The coating was applied directly to the metal substrate. The average thickness of the coating was 220 ±10 μm. The experimental results confirmed the successful enhancement of the control coating on steel that was previously applied to concrete by adding a zinc phosphate corrosion inhibitor and micaceous iron oxide barrier. However, defects in the coating and rust on the substrate of the control coating were hindered by applying the developed coating.

Keywords: polyaspartic coating, immersion corrosion test, steel, zinc phosphate, iron oxide barrier

1. Introduction

The primary purpose of coatings is to provide a barrier to prevent assets from corroding. However, in many applications, coatings are exposed to various environments such as acidic, salty or harsh atmospheres as well as temperature variations and radiation, leading to potential flaws in the coatings, e.g. blistering, cracks as well as localized detachment between the coating and substrate. Over time, these deficiencies will cause the coating to fail and the metal substrate to corrode [1]. Although the adhesive and hydrophobic properties of a coating are two important reasons for applying an effective, functional and corrosion-resistant coating, such characteristics are not always found in one coating system. Therefore, the functionalization of coatings by adding anticorrosive and hydrophobic boosters as well as pigments takes priority in terms of the development of coatings. In this context, the importance of developing hydrophobic, homogeneous and adherent coating materials has grown, particularly in corrosion protection systems. A hydrophobic coating can reduce the degree of contact between water and metal surfaces, delaying the progression of corrosion [2]. The phenomenon of water absorption reduces the protective nature and durability of the coating. Swelling, voids or cracks in the matrix of the coating may occur when the coating is immersed in an aggressive electrolyte solution, affecting its functionality [3]-[4].

Therefore, to develop corrosion protection by applying polymeric coatings, the sorption of water by the coating materials must be reduced as well as the diffusion of water across the interface between the coating and metal hindered [5].

Polyaspartic coatings are still quite novel, originating from polyurethane technology. Polyaspartics are aliphatic polyureas that are formed from a reaction between polyaspartic esters and an aliphatic isocyanate. Polyaspartic coatings boast several advantages, e.g. fast curing with a reasonable pot life; the application of thin or thick coatings; high mechanical and chemical resistance; hydrophobic properties; high solids; and the absence or minimal use of volatile organic compounds in the system. As a result of these properties, polyaspartic coatings are being increasingly used as corrosion protective coatings. The incorporation of a zinc phosphate corrosion inhibitor into the coating to improve its relative level of environmental protection, moreover, its level of corrosion resistance has been considered [6]. In this study, the effect of a zinc phosphate inhibitor, micaceous iron oxide barrier and a novel resin hardener on the corrosion performance of a polyaspartic coating was evaluated by carrying out an immersion corrosion test.

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2. Materials and experiments

The study was carried out on polyaspartic coatings applied to structural steel plates. The control polyaspartic coating was designed to protect concrete structures, whereas the modified polyaspartic coating is intended to prevent steel from corroding. The surface finish of the steel panels was milled and blasted (SA 2.5) as can be seen in *Figures 1a* and *1b*. One layer of the coatings was applied to each steel sample, consisting of a 150 x 80 x 2mm rectangular plate, using the ERICHSEN film applicator model 358 shown in *Figure 2*. The edges of the steel samples were well covered with tape to avoid premature failure of the coating or rusting of the steel plates. The tested samples were placed in a plastic container filled with 3.5% NaCl solution at room temperature (RT) for 30 days, as shown in *Figure 3*. Another group of experiments were carried out by leaving a plastic container in an oven set at 35°C (*Figure 4*). The coating was examined every 10 days and the resistance of the coating to the corrosive environment evaluated by identifying any degree of damage or defects on the coating as well as rust on the steel using visual and macroscopic inspection techniques.

Adhesion tests of the control and modified polyaspartic coatings applied to steel were carried out in accordance with ASTM D3359-17 [7]. A crosshatch tool scratched a grid into the surface of the coating in order to expose the substrate. Then adhesive tape was attached over the grid and pressed firmly for a few seconds before being removed. Finally, the percentage of coating pulled off by the adhesive tape in relation to the surface area of the grid was evaluated and rated according to the ASTM specification whereby 0B and 5B denote low and high levels of adhesion of the coating to the steel substrate, respectively.

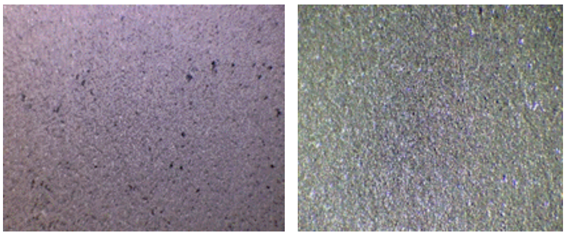
(a) (b)

Figure 1: Photographs of the a) milled and b) blasted steel finish

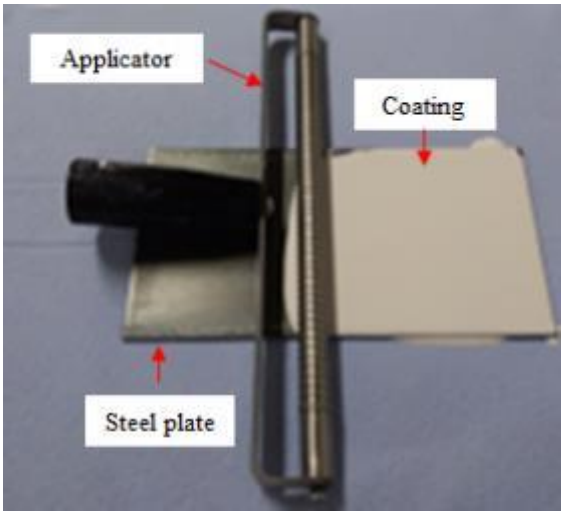

Figure 2: ERICHSEN film applicator model 358

3. Results

3.1. Macroscopic analysis of coatings after immersion corrosion tests

Visual observations of the control and modified (iron oxide barrier + zinc phosphate inhibitor) coatings after 30 days of immersion in a 3.5% NaCl solution at RT and 35 °C are presented in *Figures 5-12*. *Figure 5* shows the surface morphology of the control polyaspartic coating applied to the milled steel surface after the immersion experiment at RT had finished, whereby localized corrosion rust attached to a blister can be seen. *Figure 6* shows the corrosion rust of the control polyaspartic coating that formed on the blasted steel surface after the immersion experiment at RT. Observations of the coatings containing the zinc

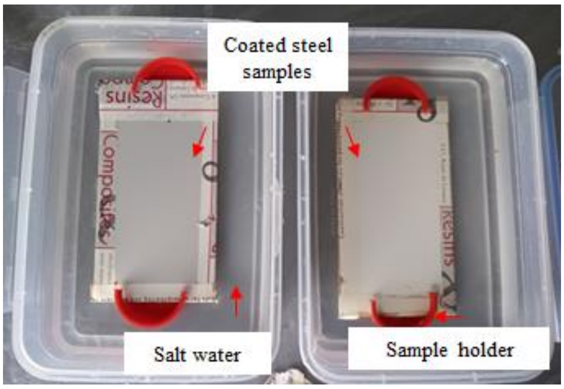

Figure 3: Immersion tests at RT

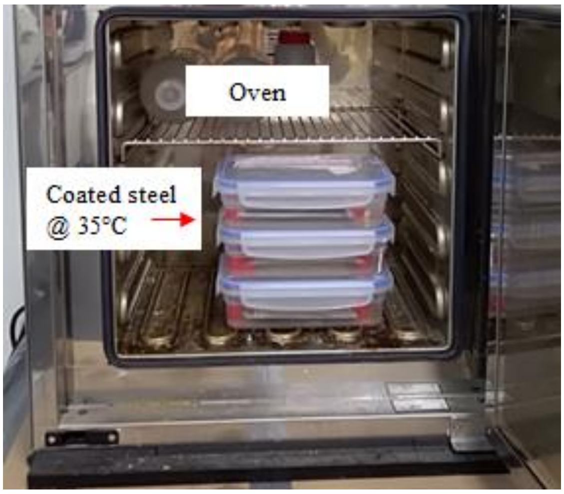

Figure 4: Immersion tests at 35 °C

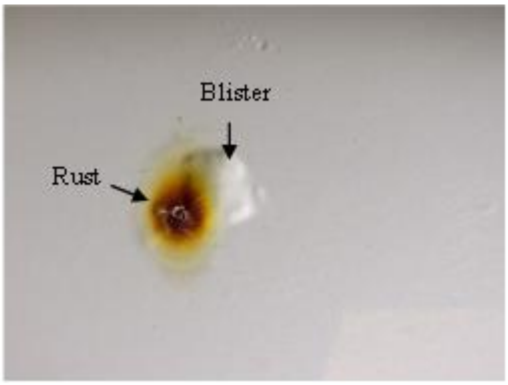

Figure 5: 1X macro photograph of the control coating applied to the surface of the milled steel after the 30-day-long immersion test at RT

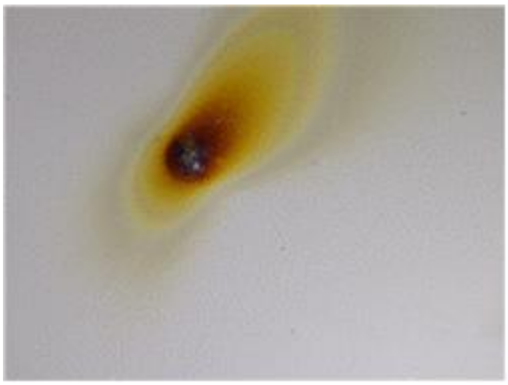

Figure 6: 0.67X macro photograph of the control coating applied to the blasted (SA 2.5) steel surface after the 30-day-long immersion test at RT

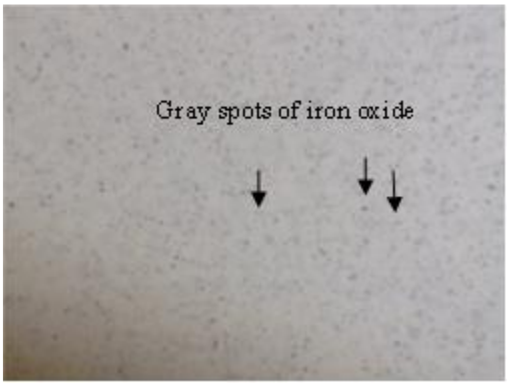

Figure 7: 1X macro photograph of the modified coating (iron oxide barrier + zinc phosphate inhibitor) applied to the milled steel surface after the 30-day-long immersion test at RT

Figure 8: 1X macro photograph of the modified coating (iron oxide barrier + zinc phosphate inhibitor) applied to the blasted (SA 2.5) steel surface after the 30-day-long immersion test at RT

phosphate inhibitor and micaceous iron oxide barrier on milled and blasted steel surfaces following the immersion experiments at RT are illustrated in *Figures 7* and *8*. It should be noted that no defects in the coating or rust can be seen on these modified coating systems. Flakes of the lamellar iron oxide barrier are clearly visible. The absence of blisters and corrosion rust on the steel is attributed to the protection afforded by these coatings containing zinc phosphate and an iron oxide barrier.

Photographs of the coatings after the immersion experiments at 35 °C are shown in *Figures 9-12*. A cluster of blisters and localized rust on the milled steel surface to which the control coating was applied can be seen in *Figure 9*. The control coating applied to the blasted steel surface is presented in *Figure 10* where a large blister of the coating and rust through a crack in the coating can be observed. The modified coatings on the milled and blasted steel surfaces after the immersion tests at 35 °C are illustrated in *Figures 11* and *12*. Some rust can be observed in the photograph of the coating applied to the milled steel surface, while the iron oxide barrier of the coating on both steel surfaces and the absence of blisters can be seen in the macroscopic images.

3.2. Adhesion test of the coatings to the substrate after the immersion corrosion tests

Figures 13-16 show the results of the adhesion tests carried out after the immersion corrosion tests for each surface finish. In *Figure 13*, a loss of grid can be seen on the control coating attached to the milled steel surface. On the other hand, no crosscut squares detached when the control coating was applied to the blasted steel surface, however, the coating expanded along the cut lines of each grid as illustrated in *Figures 14*. Nevertheless, no grid loss in the case of the modified coating applied to the milled and blasted steel panels were visible in *Figures 15* and *16*.

Anti-corrosive pigments in the coating formula enhanced adhesion of the coating and reduced the extent to which the grid coating was removed, thereby increasing the degree of adhesion between the coating and the steel substrate. The adhesion classification of the coatings with regard to the ASTM D3359 classification is described according to the following categories: 5B – 0% adhesion failure, 4B – 5% adhesion failure, 3B – 5-15% adhesion failure, 2B – 15-35% adhesion failure, 1B – 35-65% adhesion failure.

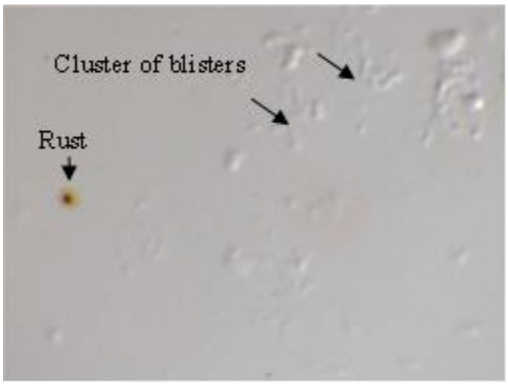

Figure 9: 1X macro photograph of the control coating applied to the milled steel surface after the 30-day-long immersion test at 35 °C

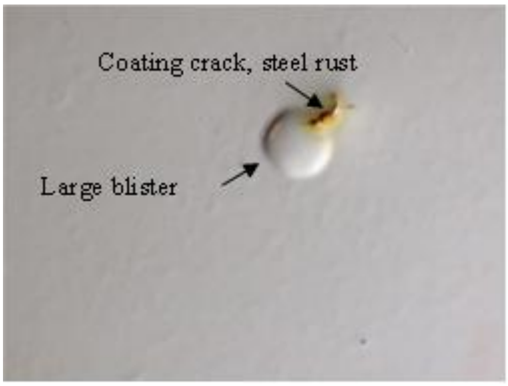

Figure 10: 2X macro photograph of the control coating applied to the blasted (SA 2.5) steel surface after the 30-day-long immersion test at 35 °C

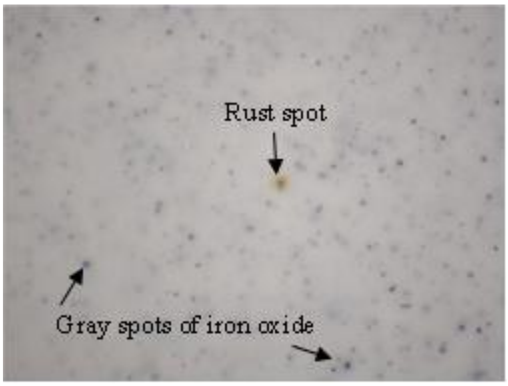

Figure 11: 3X macro photograph of the modified coating (iron oxide barrier + zinc phosphate inhibitor) applied to the milled steel surface after the 30-day-long immersion test at 35 °C

Figure 12: 1X macro photograph of the modified coating (iron oxide barrier + zinc phosphate inhibitor) applied to the blasted (SA 2.5) steel surface after the 30-day-long immersion test at 35 °C

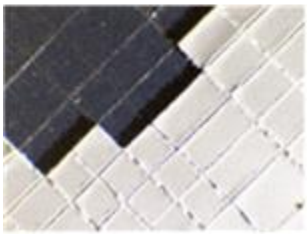

Figure 13: ASTM class 1B adhesion of the control coating to the milled steel surface

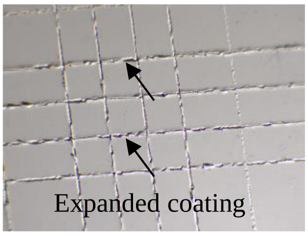

Figure 14: ASTM class 5B adhesion of the control coating to the blasted (SA 2.5) steel surface

Figure 15: ASTM class 5B adhesion of the modified coating to the milled steel surface

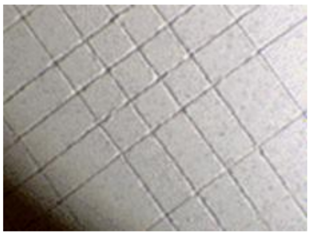

Figure 16: ASTM class 5B adhesion of the modified coating to the blasted steel surface

4. Discussion

Protective coatings are usually applied as barriers in various environments where degradation is more likely, for instance, when continuously immersed in water, under marine and atmospheric conditions as well as in the presence of salts and acids, while the coatings of structures buried in soil are subjected to microbial degradation and humid conditions [1]. Although other corrosion investigation techniques, e.g. salt sprays and electrochemical corrosion, are well-established to predict the corrosion characteristics of coatings on a metal substrate, the resistance of a coating to the penetration of water as well as the adhesion of a coating to a substrate remain significant challenges, moreover, other techniques could possibly be implemented [8]. In the present study, immersion corrosion tests were conducted and the results confirmed the applicability of this technique to estimate the corrosion performance and adhesion of the control and modified polyaspartic coatings. The corrosion and corrosion protection mechanisms in this new anti-corrosion coating system can briefly be explained according to the scenario below:

4.1. Corrosion behavior of the control coating

The control coating, in the absence of both zinc phosphate as a corrosion inhibitor and an iron oxide barrier, applied to the milled surface finish of the steel panels exhibited blisters and rust after the immersion corrosion tests had been conducted at RT. The tendency of this coating to blister increased when the coating was immersed at 35 °C, which can be attributed to the reduction in adhesion between the coating system and the steel substrate. This interpretation is in agreement with the adhesion measurements for the same coating after the immersion corrosion tests. Even though the surface finish slightly affects the performance of the control coating, the coating applied on the blasted steel panels exhibited rusting after the immersion corrosion tests at RT, while an isolated large blister was observed on the coating after the tests at 35 °C.

4.2. Corrosion behavior of the modified coating

The modified coating yielded significantly different results in all the corrosion and adhesion tests compared with the control coating. The flaws that had been observed in the control coating were fully resolved after the formula of the coating was modified by adding the zinc phosphate corrosion inhibitor and the micaceous iron oxide barrier, enhancing adhesion and preventing the coating from forming blisters, cracks or rust on the steel.

Corrosion resistance was achieved by using an effective hardener, an anticorrosion pigment composed from the corrosion inhibitor zinc phosphate and a lamellar micaceous iron oxide barrier, which in turn resulted in strong bonding and inhibitive characteristics. Thereafter, coating defects such as blisters of the modified coating could not be observed after immersion corrosion experiments were conducted in a 3.5% NaCl solution over a 30-day period. This can be attributed to strong bonds between the coating and the substrate caused by the new hardener as well as enhanced by the zinc phosphate, which resulted in a defensive film on the steel surface, while the iron oxide barrier prevented the penetration of corrosive elements.

The zinc phosphate inhibitor in the modified coating formed a thin film on the substrate, preventing corrosion and supporting adhesion between the coating and the steel. The iron oxide barrier provided protection by controlling the penetration of moisture or water and extending the bath of the corrosive elements to saturate the coating and make contact with the substrate. This can be explained by the insignificant amount of moisture or water that could pass through the coating. However, no blisters were observed in the modified coating compared to the one without a micaceous iron oxide barrier. As a consequence, preferable coating characteristics of the new coating formula such as stability as well as corrosion resistance and inhibition were achieved.

Combining the zinc phosphate with the iron oxide barrier in the evaluated coating is a promising inhibitive technique to reduce the degradation of the coating and provide a good level of corrosion resistance. The corrosion resistance of the pigmented coating as well as its adhesion to milled and blasted steel substrates in a direct-to-metal system and without surface preparation of the milled steel are attributed to functionalization of the coating after adding the iron oxide barrier and zinc phosphate corrosion inhibitor. Furthermore, the new hardener applied to the resin enhanced the adhesion of the film, thereby reducing the tendency of the coating to blister, crack, etc.

The role of zinc phosphate in developing the investigated coatings is in agreement with results from other studies, namely that the addition of zinc phosphate to the organic coating improved its adhesion to the steel substrate and prevented the diffusion of the corrosive medium through the coating or onto the interface between the metal and coating [6]. On the other hand, the iron barrier and zinc phosphate inhibitor hindered the penetration of water as well as prevented the steel substrate from blistering and corroding.

The hypotheses of the coating-degradation and protection mechanisms have been investigated [9] and are presented schematically in *Figures 17* and *18*. It can

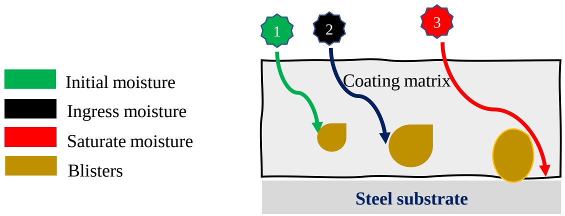

Figure 17: A schematic diagram of the control coatings [9]

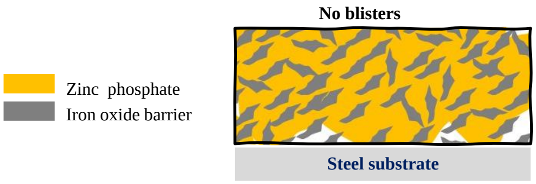

Figure 18: A schematic diagram of the modified coatings [9]

be seen that penetration of the corrosive environment through the unmodified polyaspartic coating is quicker as well as leads to the formation of blisters and rust on the steel surface. The ,odified polyaspartic systems exhibited a good degree of protection as a direct-to-metal system on milled and blasted surface finished steel substrates, which is very beneficial in terms of site application by reducing the cost of the cleaning operation before coating that is normally recommended prior to applying a coating protection system.

5. Conclusions

The addition of a zinc phosphate corrosion inhibitor and a micaceous iron oxide barrier resulted in highly protective coatings for direct-to-metal systems. Resistance to corrosion and blistering as well as the loss of adhesion of the coating to the substrate are immensely improved by the modified polyaspartic coating, which did not corrode in artificial seawater containing 3.5% NaCl at RT nor at 35 °C throughout the 30-day-long assessment. To date, the upgraded coating can be readily applied to protect steel structures as a direct-to-metal protection system of milled and blasted surfaces without the need for pre-cleaning or surface preparation before coating.

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