The Performance and the Induced Rebar Corrosion of Acrylic Resins for Injection Systems in Concrete Structures

C. S. Paglia, E. Pesenti, A. Krattiger

Abstract**—**Commercially available methacrylate and acrylamide-based acrylic resins for injection in concrete systems have been tested with respect to the sealing performance and the rebar corrosion. Among the different resins, a methacrylate-based type of acrylic resin significantly inhibited the rebar corrosion. This was mainly caused by the relatively high pH of the resin and the resin aqueous solution. This resin also exhibited a relatively high sealing performance, in particular after exposing the resin to durability tests. The corrosion inhibition behaviour and the sealing properties after the exposition to durability tests were maintained up to one year. The other resins either promoted the corrosion of the rebar and/or exhibited relatively low sealing properties.

Keywords**—**Acrylic resin, sealing performance, rebar corrosion, concrete injection.

I. Introduction

THE acrylic resins are often used in the construction field in order to increase the water impermeability of concrete structures. The resins are usually injected within cracks or throughout concrete material, which exhibits segregation or macropores. Concrete structures contain rebars, which are generally protected by the alkalinity of the concrete pore solution [1]. In regions where cracks form, the local corrosion protection, i.e. the alkalinity of the environment and the impermeability of the cementitious material, is not guaranteed. In order to restore the water impermeability of the structures, acrylic resins are injected into the cracks.

The performance of resins to seal cracks was investigated with respect to the capability of sealants to penetrate the cracks and to stick on the crack surfaces [2]. The determination of service live was also carried out for sealers in concrete components. Ultraviolet degradation as well as abrasion and chloride leakage throughout sealed concrete components were studied [3]. Investigations were also carried out on different products in order to evaluate the capability of crack sealer to avoid the ingress of chloride ions to concrete decks (corrosion of the rebar) [4]. Nonetheless, in these latter works, no direct influence of the sealers to the corrosion of the rebar was considered.

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In the recent past, corrosion tests have been performed in order to investigate the interaction of acryl gels with the concrete rebar. In this concern, potentiostatic tests have been carried out according to the DIN EN 480-14 norm [5]. Among other conclusions, it was found that, the pH of the investigated gels was not sufficient to create a passive film on the rebar. Furthermore, the potentiostatic measurements indicated that massive gel enrichments around the rebar promoted their corrosion [6]. On the other hand, further investigations showed that, the rebar corrosion was present for samples not completely embedded in the acryl gel or acryl gel-sand mixtures [7]. A more recent investigation was carried out by monitoring the corrosion potential vs. time of mild steel rods immersed for 15 hours in tap water and in an inhibited solution at room temperature. In this case, it appeared that the free corrosion potential variation of the materials exposed to the inhibited solution and the formation of a black film may be indicative of the formation of a protective passive layer [8].

The development of corrosion inhibitors that can be added within some of the acrylic resins makes the present knowledge of the rebar corrosion induced by the acrylic resins contradictory.

The aim of this work is to further implement the knowledge of the rebar corrosion induced by some recent commercially available resins and to evaluate the performance of the resins, in terms of capability of sealing openings present within cementitious materials. In fact, an appropriate sealing performance cannot be separated by the elimination of the rebar corrosion.

II. Experimental

The acrylic resins either acrylamide or metacrylate-based, consisted of two main components (Table I).

TABLE I
Type of Acrylic Resins

RESIN	TYPE OF RESIN
Resin A	Acrylamide-based resin 1 Components A, B – Producer 1
Resin B	Acrylamide-based resin 2 Components A, B – Producer 1
Resin D	Methacrylate-based resin 3 Components A, B – Producer 2
Resin F	Methacrylate-based resin 4 Component A Component B’ – Producer 3

Fig. 1 Concrete cube of 150 mm length with the central cylindrical cavity filled with the resin

The sealing performance tests were carried out by preparing C 40 concrete cubes with length 150 mm. In the middle of the cube a 30 mm diameter hole was drilled. The depth of the hole was 100 mm. The resins (A, B, D, F/A+BI) were mixed according to the mix proportion of the supplier's data sheet and poured directly into the holes. The same resins were subjected to cyclic exposure at different temperature in air and in water according to the norm EN 13687-3 [9] with the following exposure conditions: 2 hours in water at 21 ^{o}C ± 2 ^{o}C, 4 hours in air at -15 ^{o}C ± 2 ^{o}C, 2 hours in water at 21 ^{o}C ± 2 ^{o}C and 16 hours in air at 60 ^{o}C ± 2 ^{o}C (EN 13687-3). After the cyclic exposure, the resins were inserted into the holes (Fig. 1) and the cubes were tested on the water impermeability according to the norm EN 12390-8 [10]. The water was forced to penetrate through the surface of the cube at a pressure of 500 ± 50 kPa for 72 ± 2 hours. The cubes were then broken in two halves to evaluate the water penetration profiles.

Steel rebars S235 with a diameter of 12 mm were inserted into the resins during the mixing and pouring of the resins into a glass container. The rebars were immersed into the resins and partially exposed for ca. 1 cm in the upper part to the aqueous solution (Fig. 2). The glass containers were then sealed with paraffin foils. The rebars were also immersed in a $Ca(OH)_2$ saturated solution to simulate the concrete pore solution and in tap water as a reference. After 1 year of exposition, the rebar corrosion was investigated with a binocular and with a visual inspection.

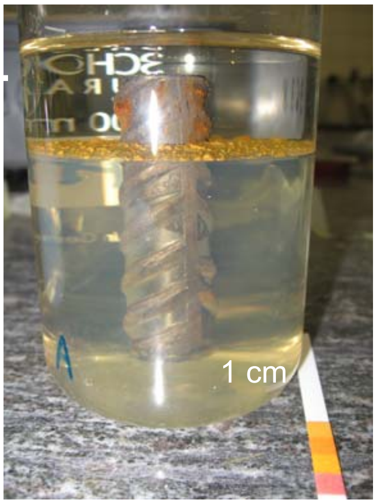

Fig. 2 Steel rebar partially immersed into the resin and into the aqueous solution

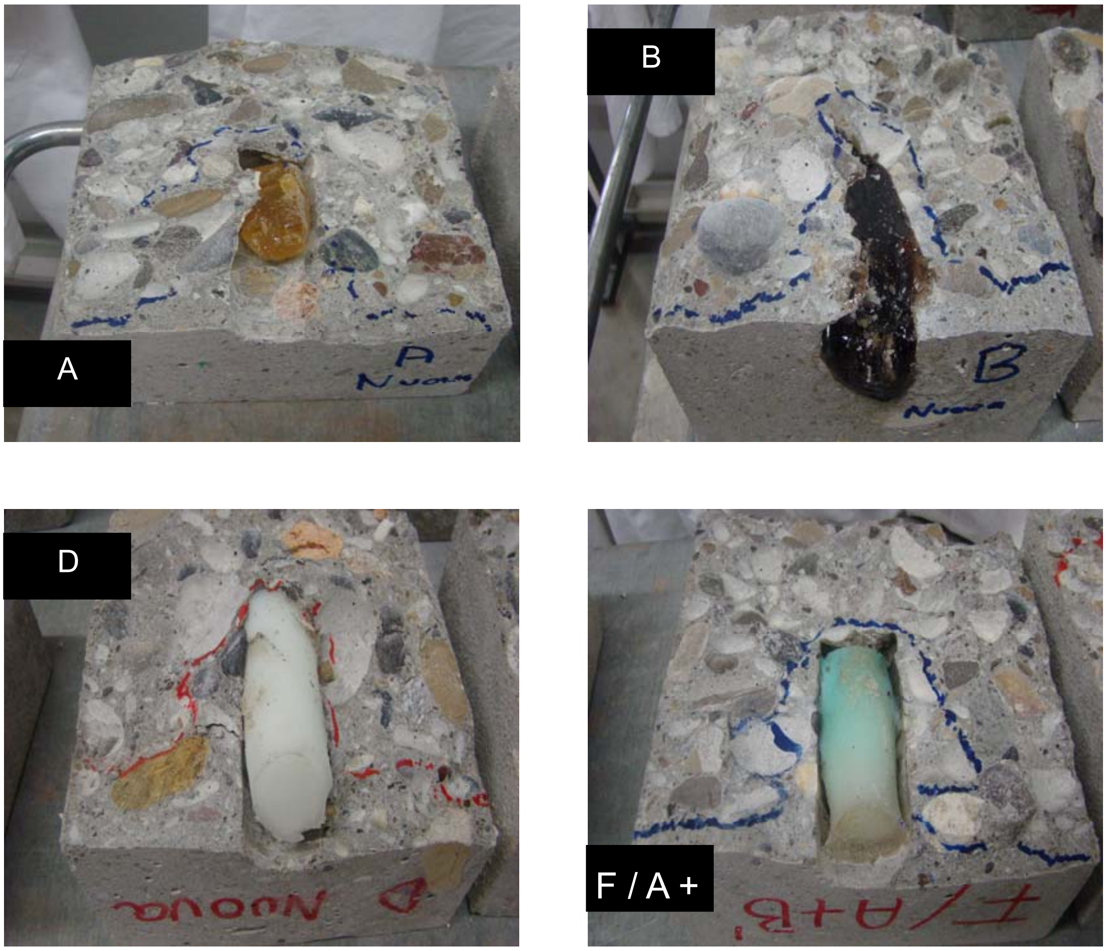

Fig. 3 Water penetration fronts measured according to the norm EN 12390-8 of the halves of concrete cube holes filled with the resins

III. Results and Discussion

The acrylic resins exhibit relatively different hardening times. The acrylamide-based samples (being low added with accelerating components) indicate a relatively long time up to 4.15 minutes, while the methacrylate-based ones indicate a hardening time of maximum 1 minute (Table II). Nevertheless, it can be generally stated that, the acrylamide-based resins exhibit a shorter hardening time as compared to the methacrylate-based resins. Despite the fact that, the hardening times can be correlated with the capability of the resins to penetrate within the cracks, as we will see later, the hardening time appears not to be correlated with the capability of sealing the holes within the concrete cubes.

The water penetration profiles for the cubes filled with the freshly mixed resins and broken in two halves exhibit a wide and deep penetration front along the hole filled with resin A. A relative reduction of the water penetration depth and width is observed for resins B, D and F/A+BI (Fig. 3).

TABLE II
Hardening Time of the Acrylic Resins

Sample	Hardening time
Resin A	1.15 min
Resin B	4.15 min
Resin D	15 seconds
Resin F / A + BI	1 min

TABLE III
Maximum Water Penetration Depths after the impermeability Tests According to the EN 12390-8 Norm

Sample	Max. water penetration depth after the test
Resin A	94 mm
Resin B	88 mm
Resin D	75 mm
Resin F/A+BI	90 mm
Resin A after the durability cycles	103 mm
Resin B after the durability cycles	32 mm
Resin D after the durability cycles	24 mm
Resin F/A+BI after the durability cycles	95 mm

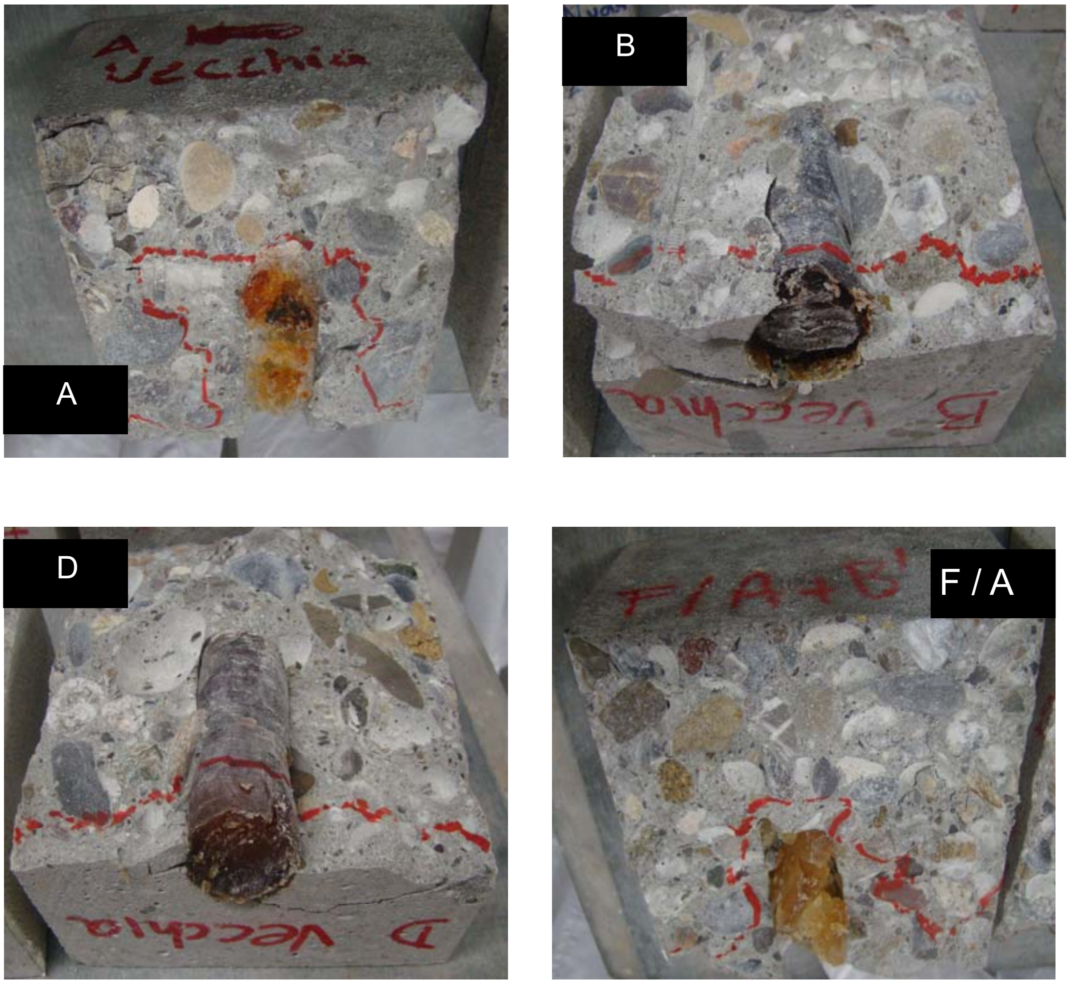

Fig. 4 Water penetration fronts measured according to the norm EN 12390-8 of the halves of concrete cube holes filled with the resins previously exposed to the durability cycles according to the norm EN 13687-3

TABLE IV
VARIATION OF THE PH WITH TIME FOR THE AQUEOUS SOLUTIONS IN CONTACT WITH THE REBARS AND THE RESINS

Rebar	pH 3 days	pH 28 days	pH 8 months	pH 12 months
In the water	7.0	7.5	7.7	---
In the saturated alkaline solution Ca(OH)2	12.0	12.0	10.9	---
In resin A	3.0	5.0	5.8	4.85
In resin B	3.0	6.5	6.9	7.01
In resin D	6.0	8.0	8.2	7.81
In resin F/A+B'	5.0	-	6.5	6.85

TABLE V
VALUES OF THE PH FOR THE SINGLE COMPONENTS OF THE RESINS

Sample	pH
Resin A	
Component A	8.36
Component B	2.2
Resin B	
Component A	7.54
Resin D	
Component B	2.39
Component A	8.10
Resin F / A + BI	
Component B	9.26

The water generally penetrates under pressure along the interface resin-concrete. The weaker is the sealing along this latter interface, the wider is the penetration front line, as for instance for resin A. Interestingly, the depth and width of the water penetration front of the resin A and F/A+ BI, previously exposed to the durability cycles, increases or remain almost the same as compared to the holes filled with the same resins, but not subjected to the durability cycles (Figs. 3, 4 B, F/A+BI). On the contrary, resin B (acrylamide-based) and resin D (methacrylate-based) exhibit, after the exposure to the durability cycles and placing in the concrete holes, a significant reduction in the water penetration front lines. In fact, for these latter resins, a maximum water penetration depth of 32 mm and 24 mm, respectively, is observed (Table

III). In these latter cases, the interface resins-concrete appears to be almost completely sealed by the resins.

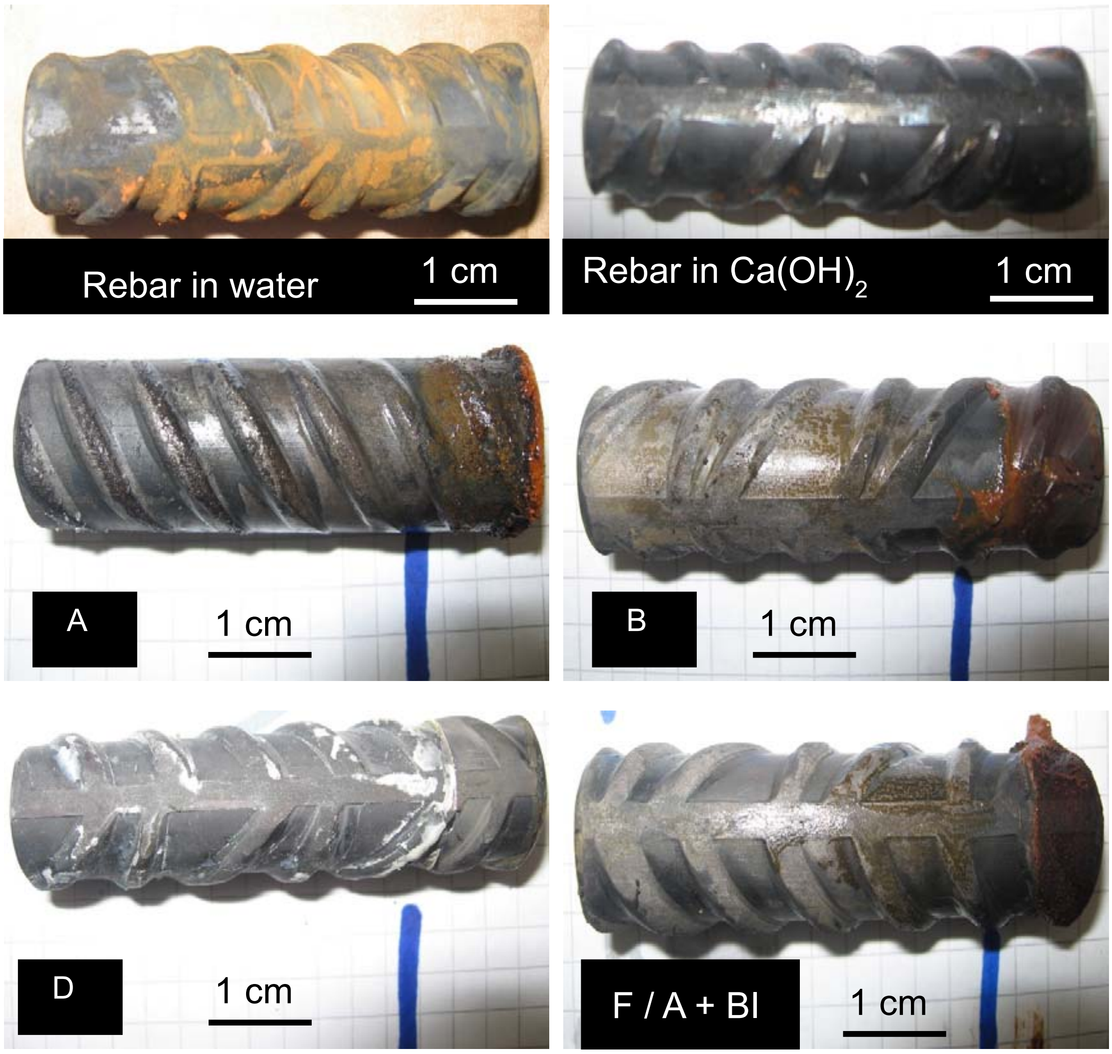

Fig. 5 General overview of the rebars corrosion partially immersed in the aqueous solution and partially in the resins (line = boundary aqueous solution - resin)

The penetration fronts are almost horizontal and are generally controlled by the concrete permeability itself and not by a lack of sealing along the interface resin-concrete. Thus, for these latter resins, ageing processes taking place over time do not significantly modify the relatively good water sealing performance.

The monitoring of the aqueous solution pHs in contact with the different resins and the rebars exhibits relatively neutral values around 7.5 for the rebar immersed in tap water and values above 10.9 for the rebar immersed in the alkaline solution (Table IV).

The only other aqueous solution to exhibit pH around 8.0, a little above the pH of a neutral aqueous solution, is the resin in contact with the rebar and the methacrylate-based resin D. The other aqueous solutions (resin B, F/A+BI) exhibit pH values below 7.0 (Table IV).

Generally, the components "B" of the resins exhibit lower values (acid region) as compared to the components "A". (Table V). Resin D contains an inhibitor.

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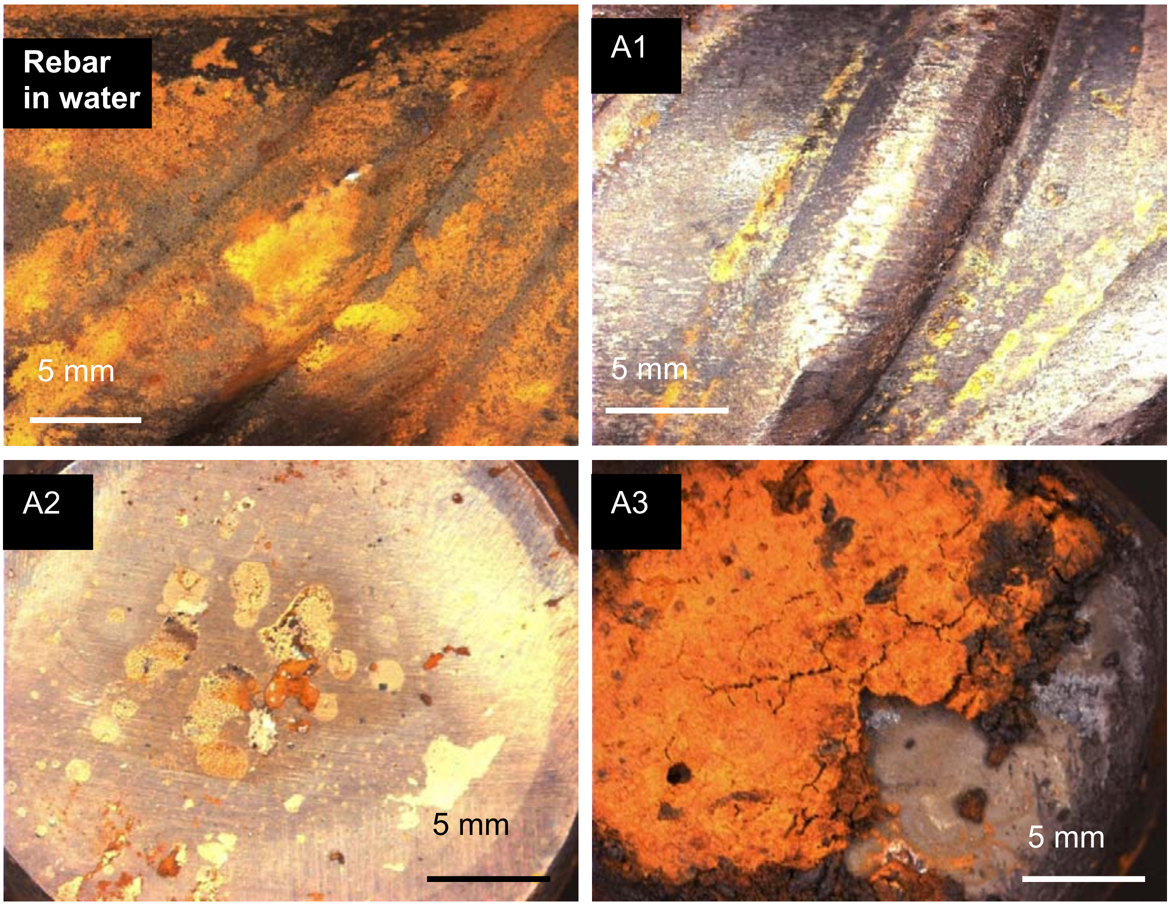

Fig. 6 Detailed view of the rebar in contact with tap water and with the resin A. A1: Slight formation of corrosion products for the rebar immersed in the resin. A2: Slight formation of corrosion products and resin debris on the lower surface of the rebar immersed in the resin. A3: Layer of corrosion products on the upper rebar surface in contact with the aqueous solution A

A general overview of the rebars partially immersed in the resins and in the aqueous solutions indicates the presence of corrosion products on the rebar surface for resins A, B and F/A+BI. The parts of the rebar immersed in the aqueous solutions generally exhibit an increased formation of corrosion products as compared to the parts immersed in the acrylic resins (Fig. 5). On the contrary, the rebar immersed in the aqueous solution and in resin D does not exhibit corrosion products. As comparison, the rebar immersed in tap water exhibits a uniform corrosion along the entire rebar surface, while the rebar immersed in the saturated $Ca(OH)_2$ is generally protected from corrosion (Fig. 5).

A detailed view of the corrosion of the rebar immersed in the resin A indicates a slight formation of corrosion products on the rebar surface immersed directly into the resin, while the rebar immersed into the aqueous solution exhibits an increased formation of corrosion products (Fig. 6). A general increased presence of corrosion products for the part of the rebar immersed in the aqueous solution as compared to the rebar immersed in the resin is also observed for resin B (Fig. 7).

For resin D (methacrylate-based), the corrosion is generally absent for the rebar region immersed in the resin as well as for the rebar region immersed in the aqueous solution D (Fig. 8). On the other hand, the methacrylate-based resin F/A+ BI exhibits similar corrosion features as resin A and resin B (Fig. 9).

In order to further clarify the presence of corrosion products, the resins were cut in two halves and examined with respect to the colour change along the regions where the rebars were placed. In this concern, it is clear that the resin D did not generally exhibit corrosion products along the rebar region, while the other resins indicate a presence of corrosion products, which contributed to the colouring of the resin along the rebar regions (Fig. 10).

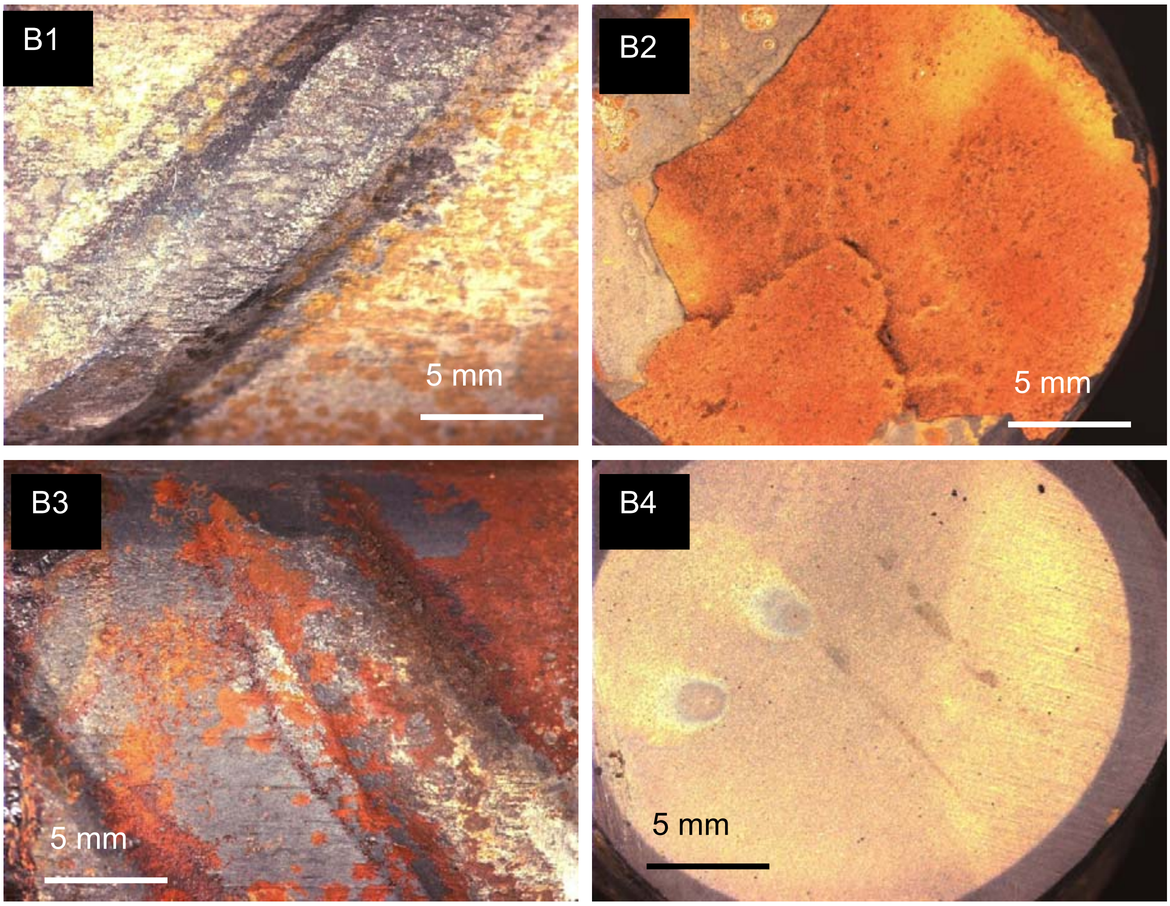

Fig. 7 Detailed view of the rebar in contact with resin B. B1: Formation of corrosion products on the rebar surface immersed in resin B. B2: Layer of corrosion products on the upper rebar surface in contact with the aqueous solution B. B3: rebar corrosion in contact with the aqueous solution B. B4: Slight formation of corrosion products on the lower surface of the rebar immersed in the resin B

The methacrylate-based resin D significantly inhibits the rebar corrosion. This is mainly caused by the relative high pHs of the resin and by the relatively high pHs of the aqueous solutions. The aqueous solution of the rebar in contact with resin D maintains a relatively high pH over time for up to 12 months. The pH up to 12 months remains slightly below 8 and this appears to be sufficient to prevent the corrosion. In the case where the pH of the aqueous solutions reaches values around 7, and the resins do not contain corrosion inhibitors, rebar corrosion initiates. Among the resins investigated, the methacrylate-based resin D is the only resin which does not exhibit corrosion of the rebar. This interesting corrosion resistance property can also be correlated with the good sealing performance of the resin. In fact, after the durability tests in particular, resin D is also able to seal the cavity of the concrete cube. A similar sealing capability after the durability tests is also exhibited by resin B, but its corrosion protection properties are generally low. In this concern, and considering the corrosion and sealing properties, resin D appears to be the most appropriate injection material among the resins investigated.

IV. Conclusions

A major issue concerning the acrylic resins has always been the capability of the gels to protect the concrete rebar. In most cases the corrosion caused by the resins on the rebar greatly limited their use in the construction field. In this concern, another issue that must be addressed was the maintenance of the sealing properties with time and with changing the exposure conditions.

A methacrylate-based resin (D) investigated in this work exhibited a significant rebar corrosion resistance caused by the relatively high pH of the resin and resin aqueous solution. Furthermore, a relatively good sealing property, in particular after the resin was exposed to durability tests, was observed. That means acrylic resins might be used, with the appropriate technical assessments, to seal reinforced concrete structures, thus avoiding the corrosion of the rebars.

The other acrylamide-methacrylate based resins investigated in this work promoted the formation of corrosion products on the rebar surface and/or exhibited relatively low sealing properties.

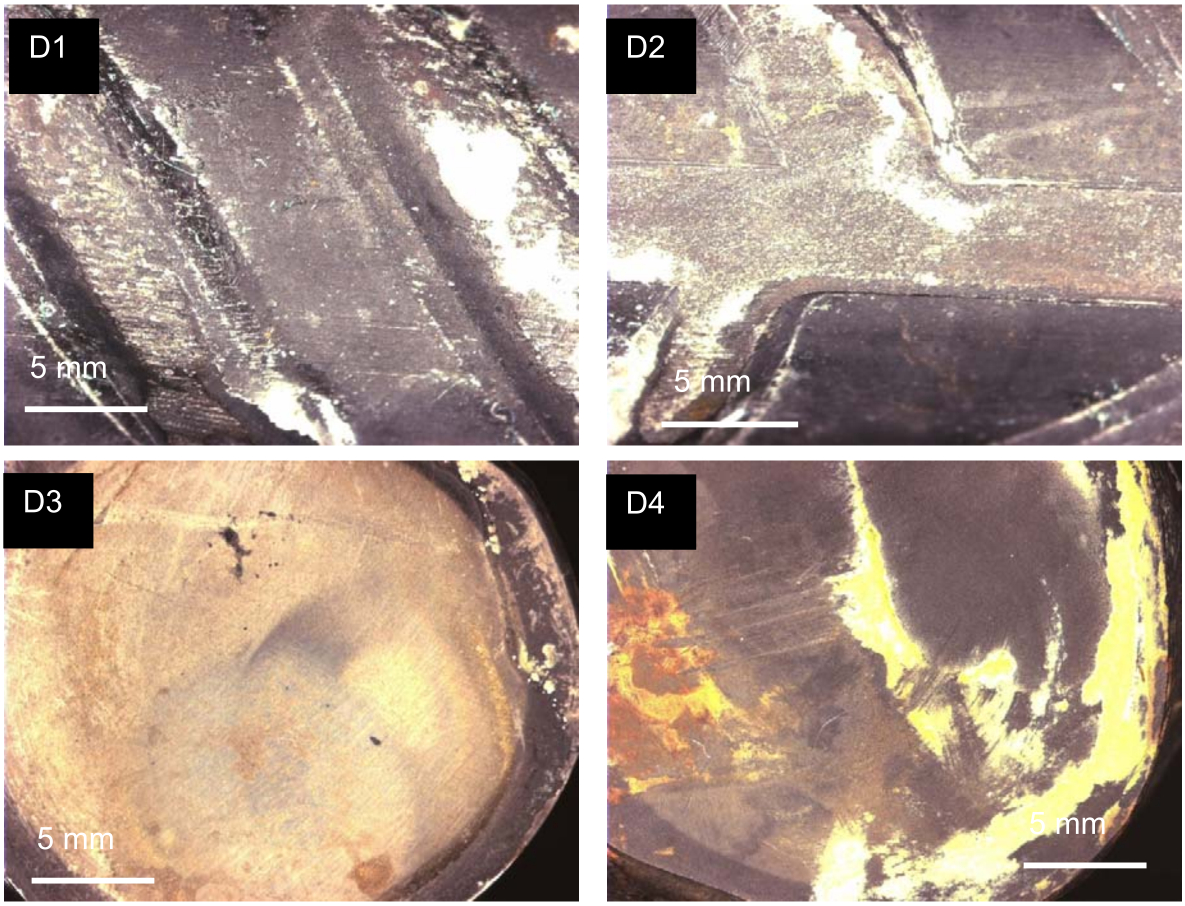

Fig. 8 Detailed view of the rebar in contact with resin D. The corrosion of the rebar immersed in the resin (D1, D3) or in the aqueous solution D (D2, D4) is basically absent

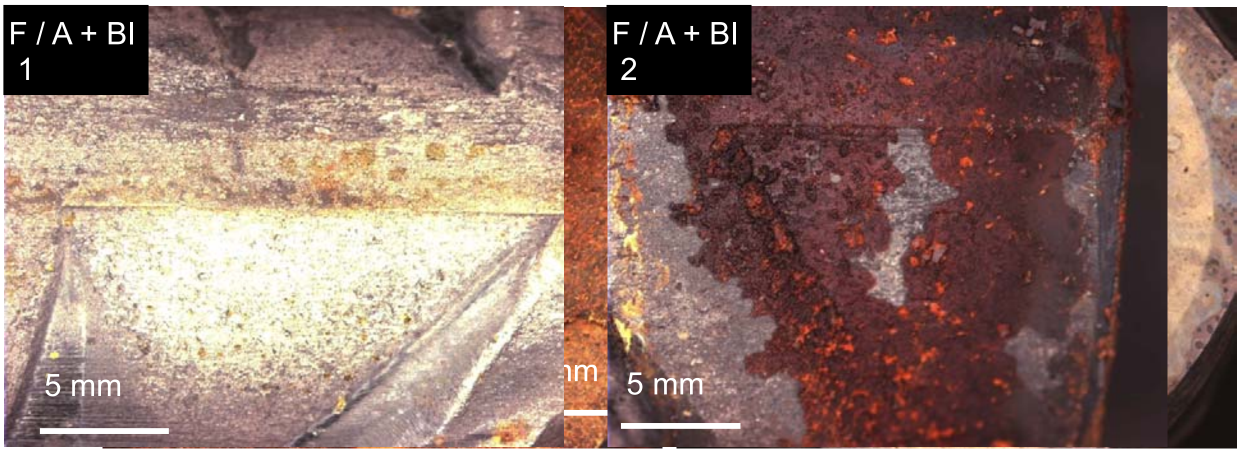

Fig. 9 Detailed view of the rebar in contact with resin F/A+ BI. F/A+ BI 1: slight presence of corrosion products for the rebar immersed in the resin. F/A+ BI 2: corrosion of the rebar immersed in the aqueous solution F /A+BI. F/A+ BI 3 Slight formation of corrosion products on the lower surface of the rebar immersed in resin F/A+ BI. F/A+ BI 4 Layers of corrosion products on the upper rebar surface in contact with the aqueous solution F/A+ BI

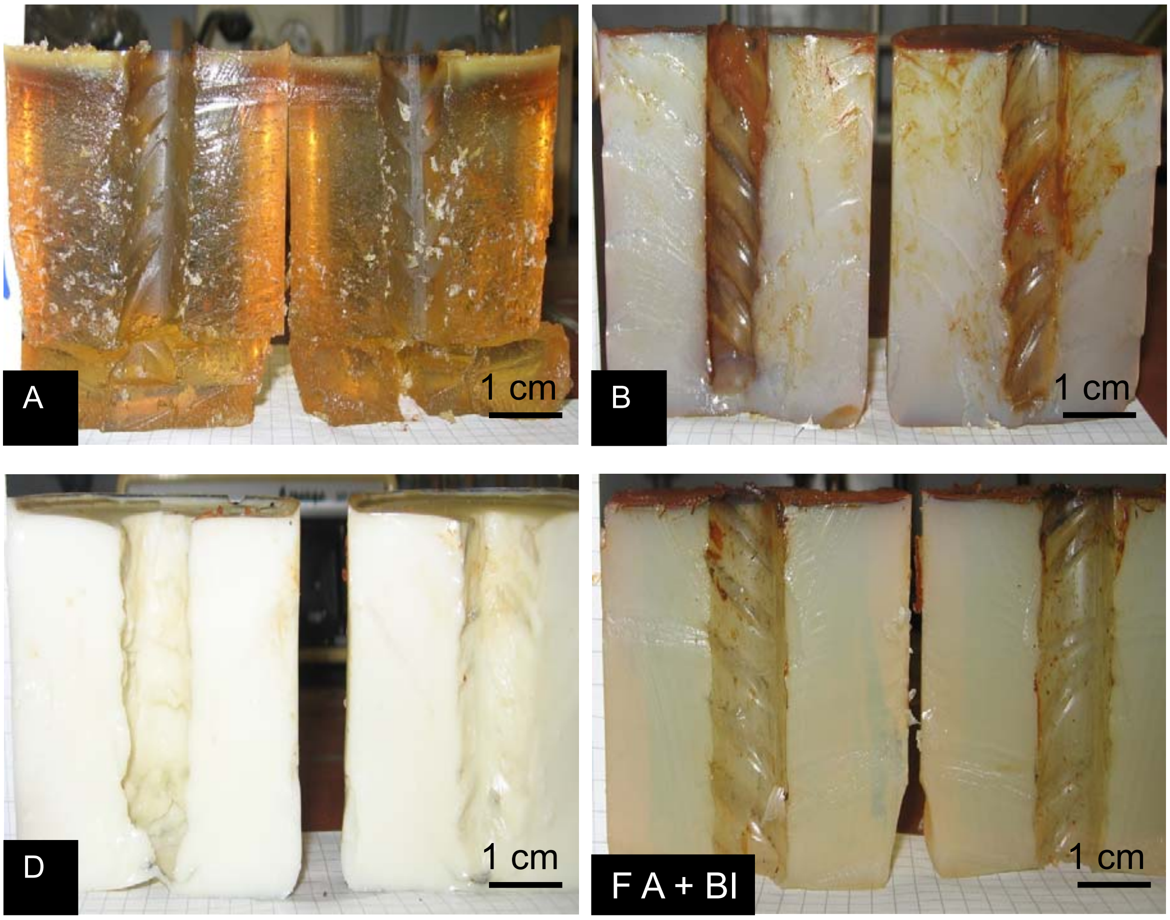

Fig. 10 Resin A: slight presence of corrosion products, in particular in the upper part of the resin (red-black colour) close to the aqueous solution. Resin B: uniform presence of corrosion products along the rebar region. Resin D: almost total absence of colouring effects due to the formation of corrosion products. Resin F/A+BI: uniform presence of corrosion products along the rebar region, in particular in the upper region close to the aqueous solution

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