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Review

Contribution of Sacrificial Anode in reinforced concrete patch repair: Results of numerical simulations

Eric Lozinguez [a,*], Jean-François Barthélémy [a], Véronique Bouteiller [b], Tiffany Desbois [c]

[a] Cerema, Project-team DIMA, 110 rue de Paris, BP 214, 77487 Provins Cedex, France
[b] Université Paris-Est, MAST, EMGCU, IFSTTAR, 77447 Marne-la-vallée, France
[c] Cerema, Direction Ouest, 5 rue Jules Vallès, 22015 Saint-Brieuc Cedex, France

HIGHLIGHTS

- Patch repair always leads to corrosion increase of the active steel within the remaining substrate concrete.
- SACP should be preferentially placed within the substrate concrete (and not within the new concrete of patch repair).
- Contaminated concrete should be removed all around the steel for a sustainable repair.
- The ratio between macrocell current and overall current of SACP in reinforced concrete is far from that in maritime field: taking into account the electrical resistivity of concrete allows to better estimate the SACP lifetime.

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ABSTRACT

This paper deals with the numerical determination of potential and current distribution along the reinforcement when using patch repair applied to reinforced concrete elements. Numerical finite element models of the electrochemical phenomena demonstrate the useful contribution of Sacrificial Anode in improving the Cathodic Protection of the reinforcement by testing several configurations. The main result is that the Sacrificial Anode should be embedded in the substrate concrete area rather than in the patch area. Moreover, the influence of the resistivity of the repairing concrete is evaluated.

Contents

* Corresponding author.
E-mail addresses: eric.lozinguez@cerema.fr (E. Lozinguez), jean-françois.barthelemy@cerema.fr (J.-F. Barthélémy), veronique.bouteiller@ifsttar.fr (V. Bouteiller), tiffany.desbois@cerema.fr (T. Desbois).

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1. Introduction

Corrosion of the reinforcement is recognised as the main degradation of reinforced concrete structures [1]. From the point of view of service life, Tuutti, proposed a schematic sketch of steel corrosion sequence in concrete subdivided into an initiation stage and a propagation stage [2]. In the initiation stage, the aggressive species penetrate the concrete cover (carbonation reaction or chloride ion ingress) and once the rebar level is affected corrosion occurs and the propagation stage begins. Due to the diffusion/precipitation of the corrosion products and because the volume of iron corrosion products are higher than the volume of iron metal (2–6), disorders such as rust stains, cracks or spallings can be encountered.

According to the analysis of the questionnaires of the European CONREPNET Project [3], from the 230 case histories (main types of structures were buildings, bridges, dams, power stations and car parks), corrosion was the most common process of deterioration, being responsible for 55% of the problems. Patching was the most applied repair type (60% of the case histories) and after removing the defective concrete, the material used for the patching was "cementitious" type for 60%. Concerning the performance of repair, cementitious patches were 45% successful due to insufficient defective concrete having been removed and incipient anodes becoming dominant.

Therefore, recurring corrosion after patch repair could initiate in one of the three following areas: the patch area, the substrate (adjacent unrepaired area) or the interface between them [4–7]. On the one hand, total or partial removal of contaminated concrete around the steel reinforcement will lead to two different situations: if the contaminated concrete is totally removed, corrosion damage will appear most likely within the substrate in the vicinity of the patch [8,9] whereas if the contaminated concrete is only partially removed, the patch repair will more likely be deteriorated because of the creation of a macrocell between the top and the bottom of the steel and the subsequent development of rust below the rebar as schematized in Fig. 1 (3D view visible in the foreground of Fig. 22). On the other hand, incipient anode will consist in macrocell corrosion [10–19] resulting from treated and not treated areas.

At the scale of the structure, it is worth recalling that the main difference between microcell and macrocell corrosion lies in the fact that the anodic and cathodic reactions take place at the same location for the former and at different locations for the latter, creating thus a ionic current within concrete.

Even if the removal of the contaminated concrete is complete and the alkalinity of the new concrete is supposed to protect the reinforcement from corrosion, experience shows that patch repair rarely exceeds the 10-year guarantee [20].

In order to reduce this recurring corrosion, the use of Sacrificial Anode for Cathodic Protection (SACP) embedded into the concrete seems an attractive solution. Indeed this technique takes advantage of the electrochemical properties of zinc which, as a less noble metal than iron, corrodes preferably and consequently protects the neighbouring rebars. This protection technique has been used for decades in civil engineering as well as in the maritime field and some feedbacks on protected structures can be found [21–25]. In literature, few articles tackle the issue of the efficiency of SACP in patch repair and the feedbacks on structures do generally not give much details about the precise locations of the anodes. Christodoulou's study focused on the arrangement of galvanic anodes for the repair of reinforced concrete structures and highlighted that anodes had a dominant effect on potentials to a distance between 250 and 600 mm [26]. Soleimani modelled the kinetics of corrosion and found that resistivities of the patch repair and that of substrate concretes were the most significant factors affecting the corrosion that occurred mainly in the 2–5 cm portion of interface between them [9]. Cheung modelled the electrochemical corrosion process with SACP by means of 2D numerical simulations and found that the location of the anode in the substrate rather than in the patch area lead to significant reduction of the macrocell corrosion [27]. For patch repair of RC structures, Qian studied both components (microcell and macrocell) of corrosion from theoretical and experimental work [10]. Ribeiro proposed a criterion, based on experimentals results, to prevent the macrocell corrosion inside patch repairs based on the least electrochemical incompatibility between

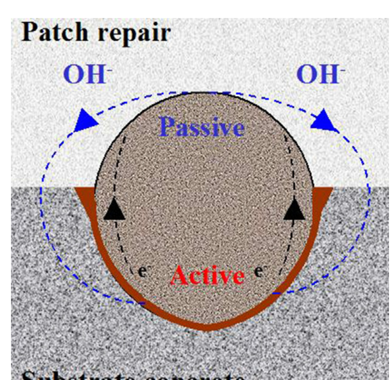

Fig. 1. Illustration of macrocell corrosion around the steel.