

PREVENTION OF INCIPIENT ANODES INDUCED BY PATCH REPAIR BY A NOVEL TYPE OF DISCRETE GALVANIC ZINC ANODES

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ABSTRACT

Corrosion of steel reinforcement as a result of repair of concrete damages induced by reinforcing steel corrosion is a common and well documented result of “stand alone patch repairs”. The corrosion is caused by the transformation of cathodic areas near the corroding steel reinforcement into “incipient anodes”.

Very often, repairs have to be executed on locally limited areas where CP is not economical. Incipient anodes may be prevented by embedding discrete galvanic anodes into the patch repair close to the interface repair/old concrete, shifting the steel potentials of the passive steel towards sufficiently negative potentials to eliminate or at least minimize macro-cells.

Considering the fact that the electrochemical potential of zinc is more negative than even the corrosion potentials of pits on reinforcement, discrete zinc anodes offer a thermodynamically sound possibility to prevent incipient anodes. Reports based on field tests of discrete galvanic anodes yielded mixed results on the durability and reliability of the prevention of corrosion of steel reinforcement adjacent to patch repairs, proving thermodynamics is no guarantee that systems work in reality.

The main issues regarding durability and reliability of galvanic zinc anodes are passivation of the zinc anode and the formation of anodically formed zinc hydroxide forming an ion-transport barrier. A novel type of discrete galvanic zinc anode will be presented that addresses and solves these issues. The novel discrete galvanic zinc anode system is composed of a composite zinc mesh embedded into a proprietary matrix that solidifies into an electrolyte with ion exchange properties. The combination of the novel composite zinc anode and the solid matrix containing additives that prevent passivation of the zinc anode assures high and durable galvanic activity of the discrete galvanic zinc anode.

1. Introduction

Corrosion of the steel reinforcement is one of the mayor causes for increased maintenance and repair costs and subsequently for the reduction of the service life of concrete structures. The mayor causes for the corrosion of the steel reinforcement are ingress of chloride into the concrete overlay due to the application of de-icing salts or due to exposure to sea water [1-3]. Corrosion initiated by de-icing salts or sea salt is due to the formation of macro cells, coupling corroding anodic sites with passive cathodic sites. Due to the macro cell coupling, corroding zones are acting as a galvanic anode providing a degree of cathodic prevention to the surrounding passive steel [1-5]. Consequent and lasting repair involves the removal of the macro cells, requiring the replacement of the chloride contaminated concrete entirely with repair mortar or shotcrete, or to apply cathodic corrosion protection on the affected areas of the concrete member. However, in many cases, local corrosion damages are repaired by patch repairs in which only the concrete in the surrounding of the visible corrosion induced damages is removed and replaced. The durability of such repairs is affected by the "halo effect" [4] wherein the steel within the new repaired area serves as cathode generating accelerated corrosion of the steel in the surrounding of the patch repair [5]. Formerly anodic zones no longer provide protection, and corrosion can initiate in the areas surrounding the repaired zones (these have been called "incipient anodes" [6]) [7]).

For the purpose of forestalling the "halo damage", small galvanic anodes ("point anodes", "discrete galvanic anodes") are available commercially and applied since 1999 [5-6, 8]. The most comprehensive report on the performance of "galvanic point anodes" – two different types of commercially available anodes were tested over a period of 3 years - was made available in 2009 by the Department of Transportation of Florida [5]. The main conclusions of the report were that the activity of the anodes decreased over time significantly and the anodes were estimated to function up to 1/3 to 1/4 of the theoretical consumption limit. Installed in a concrete containing 1,5 % chloride/weight of cement, the point anodes tested over 480 days, showed only modest to negligible polarisation of the reinforcement bars and were not sufficient for the prevention of initiation of corrosion. The efficiency of galvanic corrosion protection depends on the lasting activity of the zinc anode. Deposition and agglomeration of the anodic products or contact with calcium hydroxide in the pore solution may passivate the zinc anode surface [9].

A novel discrete galvanic zinc anode system, composed of a of composite zinc mesh embedded into a proprietary matrix that solidifies into an electrolyte with ion exchange properties and containing additives that prevent passivation of the zinc anode assuring high and durable galvanic activity of the discrete galvanic zinc anode is presented in this paper.

2. Concept

Incipient anodes in patch repairs are generated by the coupling of the passivated steel reinforcement bars in the patch repair with the reinforcement bars embedded into adjacent concrete with modest chloride contamination. The prevention of the formation of incipient anodes by discrete galvanic point anodes is not achieved by shifting the potentials of the corroding reinforcement bars as in cathodic corrosion protection but by shifting the potential of the passivated reinforcement bars towards potentials equal or more negative than the steel potentials of the reinforcement bars in the adjacent chloride contaminated concrete, eliminating the macro cell formed by the patch repair [10] as shown in figure 1.

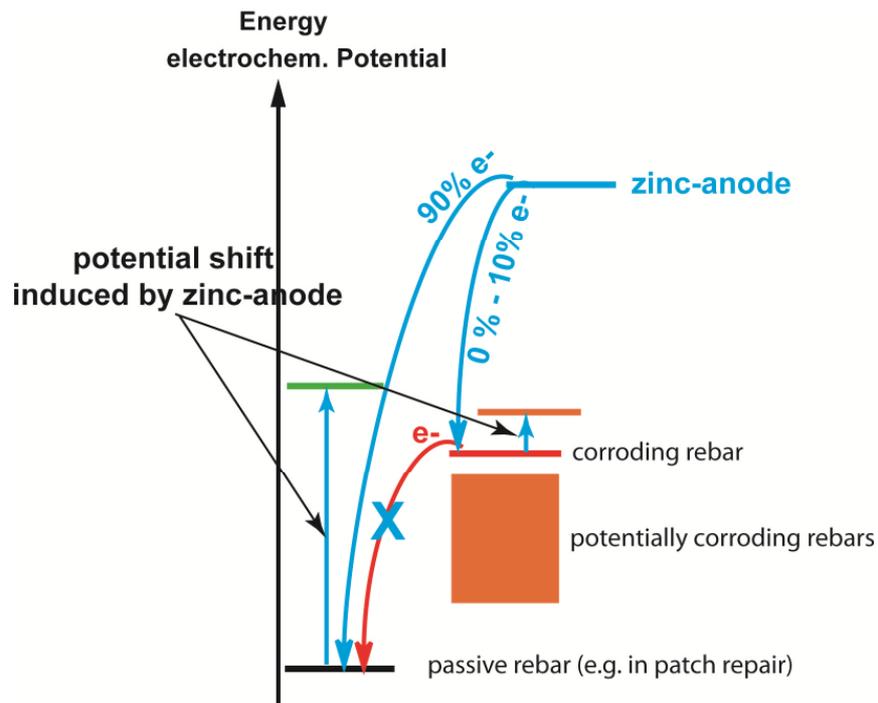


Figure 1: Schematic presentation of the prevention of the formation of incipient anodes by shifting the steel potential of the steel rebar passivated in the patch repair by attached galvanic discrete point anodes

The activity and efficiency of galvanic anodes depend on the lasting activity of the zinc anode. Zinc tends naturally to passivate by formation of an impermeable zinc oxide/hydroxide layer. Depassivation of zinc is achieved either by embedding the zinc in a high pH matrix ($\text{pH} > 13$) or in a low pH matrix ($\text{pH} < 6$). As a result of the galvanic consumption of zinc in a high alkaline matrix OH^- is consumed and has to be provided either by 170 g KOH/100g Zinc or by 73 g LiOH/100g Zinc. If the pH drops below pH 13, the zinc anode will passivate. Depassivation in an acidic environment may lead to further acidification and autocorrosion of the zinc anode.

Deposition and agglomeration of the anodic products at the anode surface or contact with calcium hydroxide in the pore solution may also passivate the zinc anode surface. The anodic products formed need more space than the zinc-metal, e.g. zinc hydroxide consumes 2,34 times more space than zinc metal. Therefore, the anodic products may clog pores and hinder or even block ionic transport to and from the anode surface consequently passivating the zinc anode. The main factors controlling long time activity and durability of discrete galvanic point anodes are: a) prevention of passivation of the zinc anode surface, b) providing enough space for the anodic products formed and c) prevention of auto-corrosion of the zinc anode. The novel discrete galvanic zinc anode system relies on the following basic concepts:

- (1) The activity and depassivation of the zinc anode surface is assured by embedding the zinc anode in a proprietary binder matrix described elsewhere in detail [9]. The binder solidifies into a matrix with ion exchange properties containing additives that prevent passivation of the zinc anode assuring high and durable galvanic activity of the discrete galvanic zinc anode.
- (2) The zinc anode itself is composed of a zinc-mesh matrix providing a high galvanic available surface from which only part is galvanically active and therefor assuring a nearly constant galvanic active surface over about of 90% of the theoretical service time.
- (3) The surface/volume and zinc metal volume/anode volume ratio is such that there is enough space for anodic products formed to be accommodated without impeding ion transport and therefore galvanic activity. Besides the geometric volume ratio this is assured by a volumetric porosity of the binder matrix of at least 35 Vol.%.

- (4) The electrochemical environment of the solidified binder matrix contains additives that reduce autocorrosion to negligible values.
- (5) Two galvanized wired brackets are integrated into the anode allowing and assuring optimum and quick electrical connection to the steel reinforcement bars (figure 2).

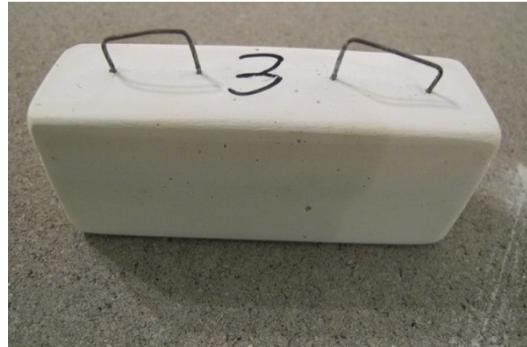


Figure 2: Sika® FerroGard® ICM discrete galvanic zinc anode (SFG-anode) for the prevention of the formation of incipient anodes induced by patch repairs.

3. Preliminary results of laboratory galvanic cell measurements

To evaluate the performance of galvanic anodes, measurements were performed in galvanic cells that simulate the conditions in a real concrete environment and allow accelerated testing. The set-up of the galvanic cell is shown in figure 3.

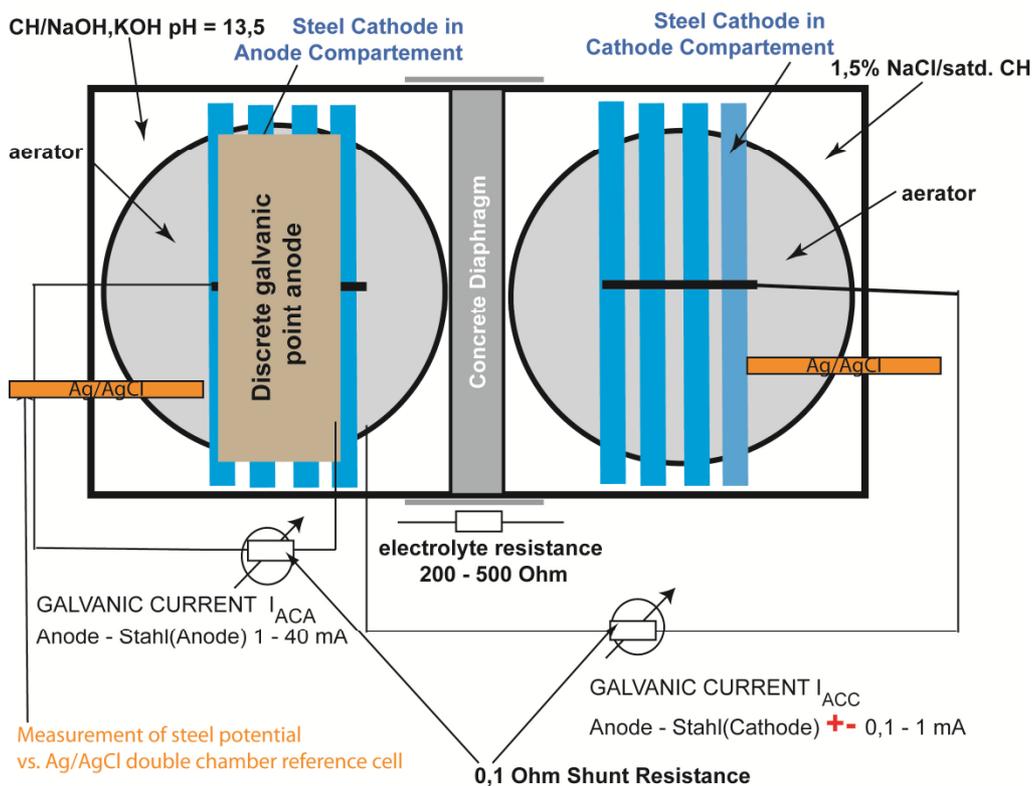


Figure 3: Scheme of the set-up of the galvanic cell simulating a real concrete environment for discrete galvanic point anodes embedded into patch repairs. The concrete diaphragm is prepared from Sika MonoTop®-412 N [11].

The steel electrodes consisted of 4 steel reinforcement bars (\varnothing 10 mm) connected by welding to a steel rod (\varnothing 6 mm) with a total steel surface of 200 cm². The concrete cell separator was casted with a repair mortar, 1-component CC mortar complying to EN 1504-3 as R4 mortar and having a resistivity similar to host concrete. The electrolyte in the anode compartment consisted of a simulated concrete pore solution (pH 12,8 – 13,5), the catholyte consisted of a 1,5 – 2,0 % NaCl solution, initially saturated with calcium hydroxide (CH). The current and steel potentials were measured and recorded online with the CAS MO-DAC monitoring and control system. Data were recorded every 30 min.

The galvanic performance of the anodes for corrosion protection of steel reinforcement bars in chloride environment (3 % NaCl) was evaluated in a electrolytic cell consisting of a 3 liter bucket in which an aerator, steel reinforcement bars and reference cell as shown in figure 3 were immersed in 1,5 Liters of 3 % NaCl.

The galvanic cell shown schematically in figure 3 simulates the set-up of a patch repair in a concrete member: The SFG anode is connected to the rebar in the passivating environment of the patch repair simulated by the artificial pore solution with a pH of 12, 8 – 13,5, separated by a 3 cm thick mortar slab (made from repair mortar) from the adjacent rebar immersed into a moderately corroding salt solution (1,5 % NaCl, satd. CH, pH kept > pH 9) – simulating the “old” concrete. The steel reinforcement bars are intensely aerated in both compartments. This set-up creates an environment that is very harsh in comparison to the real situation with respect to oxygen transport to the steel rebar surface and with respect to ion transport which is fast in solution but slow in concrete. Data received so far compared with published data [5] indicate that the time scale in the galvanic cell set-up is about ten times faster than in a concrete environment.

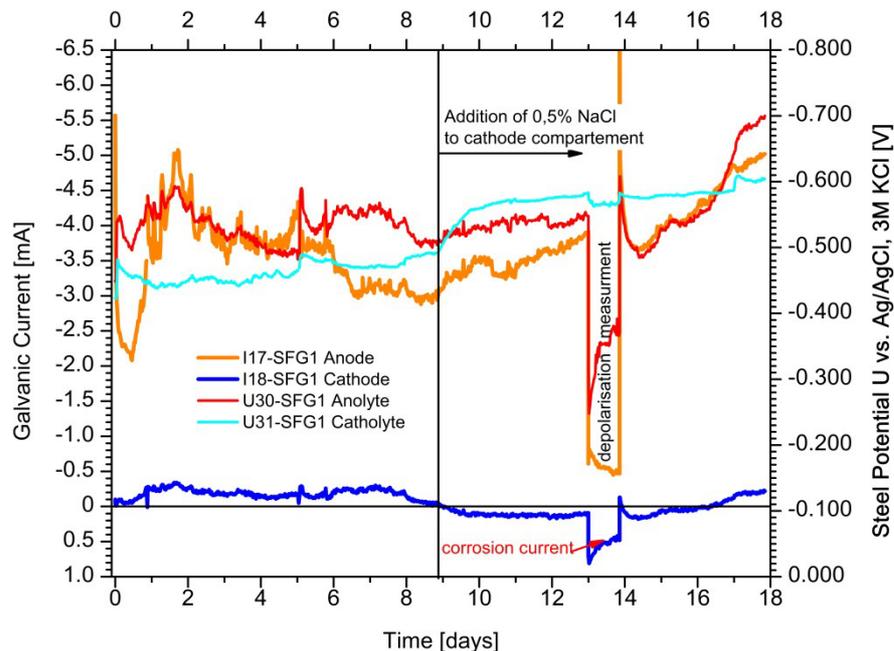


Figure 4: Galvanic performance of Sika® FerroGard® ICM discrete galvanic zinc anode (SFG-anode)

The galvanic performance of an SFG anode (approx. 150 g zinc/anode, 650 cm² galvanically available surface, 127 cm² galvanically active surface, open circuit potential (OCP) -1160 mV vs. Ag/AgCl) was evaluated in the galvanic cell set-up described above and shown in figure 3. Results are shown in figure 4. The high initial current output (about 6 mA) that temporarily decreases to about 2 mA and stabilizes at currents in the range from 3,5 – 4,5 mA is characteristic for the SFG anodes. The galvanic current is consumed by about 95 % by the rebar in the passive environment of the anode compartment, only 5 % is consumed by the reinforcement bars in the moderately corroding environment in the cathode compartment.

The galvanic current shifts the potential of the reinforcement bars in the “patch repair” environment from -240 mV vs. Ag/AgCl by about 300 mV to the level of the potential of the reinforcement bars in the corrosive environment (about – 550 mV vs. Ag/AgCl), efficiently eliminating the “corrosion cell”, even slightly cathodically protecting the reinforcement bars by currents of about 1 – 3 mA/m² steel surface. The cathodic protection ceases temporarily by increasing the “corrosivity” of the environment in the cathodic compartment increasing the NaCl concentration from 1,5 % to 2,0 % and the steel potentials of the reinforcement bars in the patch repair environment shift temporarily slightly positive of the potentials of the reinforcement bars in the corrosive environment. The performance of the SFG anode in preventing incipient anodes is illustratively shown by the depolarisation measurements executed by disconnecting the SFG anode from the system: Complete depolarisation in solution is obtained within 3 hours (refer to Fig. 4 above), different from concrete where it takes at least 24 hours. The potential of the steel rebar in the patch repair environment shifts by about 300 mV rapidly towards the potential of a steel rebar in a passive environment (- 260 mV). The steel reinforcement bars in the corrosive environment shift by about 20 mV towards positive values, showing that the main effect of the discrete galvanic point anodes is the elimination of the macro cell by shifting the potentials of the passivated reinforcement bars rather than by protecting the reinforcement bars in the adjacent old concrete by cathodic polarisation.

Depolarisation establishes a macro-cell with a throwing power of about 300 mV and a corrosion current (about 3,5 µA/cm² steel surface) flows between the steel reinforcement bars in the corrosive and passivating environment. As a consequence a classic macro-cell is established. The corrosion current shifts the potential of the steel rebar in the patch repair environment towards more negative values as observed in real patch repairs [11]. The corrosion current decreases due to that shift stabilizing at values of about 0,5 mA corresponding to 2,5 µA/cm² steel surface.

The macro cell and consequently the corrosion current are immediately eliminated by reconnecting the SFG anode to the steel rebar electrode. The data shown in figure 4 demonstrate illustratively the mode of operation of the SFG discrete galvanic point anodes: Macro cells are eliminated and therefore the formation of incipient anodes is prevented by polarizing the reinforcement bars in the patch repair areas to levels nearly equal to the potentials of the steel reinforcement bars embedded into to the patch repair adjacent concrete.

The evaluation of the performance of the SFG discrete galvanic anode for corrosion protection in the galvanic cell described above yielded galvanic currents of about 12 mA, corresponding to 600 mA/m² steel rebar surface, with a cell resistance of 4,5 Ohm. The steel-reinforcement bars were polarized to about – 900 mV vs. Ag/AgCl yielding 4 hours depolarization values of 400 mV. However, in concrete environment, cell resistances between point anodes and steel reinforcement bars in distances up to 30 cm are in the range of several hundred Ohms while the galvanic corrosion protection is effective until about 50 Ohms.

4. Conclusions and Outlook

Patch repairs of steel rebar corrosion induced damages to concrete members are a common solution despite the fact that these technique leads not to a sustainable solution. Therefore there is a general need to eliminate the incipient anodes generated by the patch repairs. The formation of incipient anodes may be prevented by embedding suitable discrete galvanic point anodes into the mortar of

the patch repairs adjacent to the concrete. Numerous galvanic anodes are on the market. However, to offer these galvanic anodes as an essential part of a sustainable concrete repair technique, these anodes have to be reliable in long term performance and durable in current output over a time period of at least 12 – 15 years.

The novel discrete galvanic zinc anode presented here was developed based on a concept accepted to assure the above defined requirements. The results of the physico-chemical and preliminary accelerated laboratory tests in galvanic cells indicate strongly that the novel galvanic point anodes fulfill the defined requirements. However, the obtained results have to be corroborated and complimented by tests in the field and in pilot test set-ups. These tests are underway covering different environmental conditions and concrete qualities and exposures.

Furthermore, a scientific based criterion may be formulated: Discrete galvanic point anodes should shift the steel potentials of the steel reinforcement bars in the patch repair mortar to potentials nearly equal to the steel potentials of the steel reinforcement bars in the adjacent concrete. Usually, the required potential shifts are in range of 150 – 250 mV.

5. Literature Cited

1. L. Bertolini, B. Elsener, P. Pedferri, E. Redaelli, R. Polder, "Corrosion of Steel in Concrete", 2nd Edition, Wiley-VCH, Weinheim (2013)
2. "Corrosion of reinforcement in concrete, Mechanisms, monitoring, inhibitors and rehabilitation techniques", Edited by M. Raupach, B. Elsener, R. Polder and J. Mietz, *European Federation of Corrosion Series EFC 38*, Woodhead Publishing Limited, Cambridge, UK (2006), 336pp
3. "Corrosion of steel in reinforced concrete structures – Final report", edited by R. Cigna, C. Andrade, U. Nürnberger, R. Polder, R. Weydert, E. Seitz, *Cost Action 521, European Communities* (2003), pp 238
4. J. P. Broomfield, "Corrosion of Steel in Concrete, Understanding, Investigation and Repair, Taylor & Francis, London (1997)
5. M. Dugarte, A. Sagües, "Galvanic Point Anodes for Extending Service Life of Patched Areas Upon Reinforce Concrete Bridge Members", Contract No BD 544-09, Final Report to the Florida Department of Transportation, 30 September 2009, NTIS Springfield, VA 22161 (2009)
6. G. Sergi, C.L. Page, "Sacrificial anodes for the cathodic prevention of reinforcing steel around patch repairs applied do chloride-contaminated concrete" in *Corrosion of Reinforcement in Concrete, Mechanisms and Corrosion Protection*, The European Federation of Corrosion Publication number 31, Eds. J. Mietz, R. Polder, B. Elsener, The Institute of Materials, London, (2001), pp. 93 – 100
7. [1], pp130
8. J. Bennet, W. Mc Cord, "Performance of Zinc Anodes Used to Extend the Life of Concrete Patch Repairs", Paper No 06331, *Corrosion/2006*, NACE International Houston (2006)
9. W. Schwarz , F. Müllner, A. van den Hondel, "Maintenance and Repair of Steel Reinforced Concrete Structures by Simultaneous Galvanic Corrosion Protection and Chloride Extraction" in *Concrete Solutions*, Eds. M. Grantham, P.A. Muhammed Basheer, B. Magee, M. Soutsos, CRC Press, London (2014), pp 223 -228
10. M. Bruns, Ingenieurbüro Raupach, Bruns, Wolff GmbH & Co. KG, private communication August 2015
11. F. Wenk, "Sika MonoTop-412 N, Measurements of specific electrical resistivity", Report Version 01, 16 October 2013, IBU Institut für Bau und Umwelt, CH 8640 Rapperswil