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A new arrangement of galvanic anodes for the repair of reinforced concrete structures

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HIGHLIGHTS

- A new arrangement for galvanic anodes in the repair of reinforced concrete.
- Galvanic anodes installed in the parent concrete surrounding the patch repair.
- Galvanic anodes performance not affected by the properties of repair material.
- Close interval potential mapping is advantageous for performance monitoring.
- An alternative criterion, to that of 100 mV depolarisation, is proposed.

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ABSTRACT

Discrete galvanic anodes are traditionally embedded in the patch repairs of steel reinforced concrete (RC) structures to offer corrosion prevention. This research investigated the performance of galvanic anodes installed in the parent concrete surrounding the patch repair, in order to explore the performance of such a new arrangement and identify its potential for wide-scale application.

This arrangement was tested on a RC multi-storey car park and a RC bridge, both suffering from chloride-induced corrosion of the reinforcement. The performance of the anodes was assessed using close-interval potential mapping for 215 days after installation. The results indicate that the anodes polarised the steel at a significant distance away from the patch repair interface, up to 600 mm in some cases. It illustrates that such an arrangement may be advantageous when repairing RC structures as the corrosion prevention can be targeted at the steel in the surrounding parent concrete, which is traditionally considered to be at higher risk due to incipient anode development.

1. Introduction

Patch repairs of deteriorating concrete is a common approach to rehabilitate defective concrete structures. Bridge Advice Note 35 [1] suggests that areas which show chloride concentrations greater than 0.3% by weight of cement and half-cell potential measurements higher than −350 mV should be removed. Concrete replacement to this extent on chloride-contaminated structures can be very onerous and expensive [2].

Galvanic anodes have been used to limit the extent of concrete replacement and extend the service life of patch repairs to RC structures [3–5]. They respond to changes in the environmental conditions they are exposed to [3,6,7]. Such an effect will be more dominant in parent concrete that has a residual level of chloride contamination as opposed to non-contaminated repair concrete or mortar and this has been employed to extend the use of galvanic anodes [8,9].

This work measured the performance of galvanic anodes installed within the parent concrete around the perimeter of the repair as opposed to the traditional approach of placing the anodes within the patch repair area itself. The anodes were monitored in order to assess their performance and the results provide an improved understanding of the corrosion protection mechanism [5].

2. Theoretical background

Galvanic anodes operate on the principle of differential potentials of metals [3,4]. A schematic illustration of a galvanic cathodic protection (CP) system is provided in Fig. 1. For the protection of steel reinforcement in concrete, such electrochemically more active metals include zinc, aluminium and magnesium.

Contemporary galvanic anode systems can be categorised as (Fig. 2) [10]:

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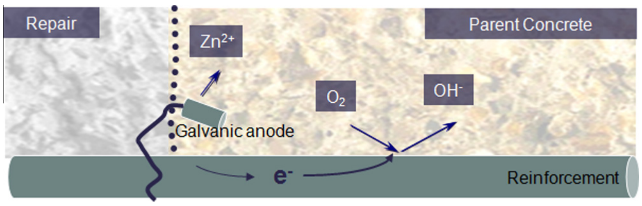

Fig. 1. A compact discrete galvanic anode connected to the steel reinforcement which becomes the cathode of the galvanic cell that is formed [10].

Fig. 2. Galvanic anode examples (i) a thermally applied metal coating (top left), (ii) adhesive zinc sheets (top right) [4], discrete anodes in drilled holes (bottom left) [15], discrete anodes installed in patch repair (bottom right).

i. Metal coatings applied directly to the concrete surface.
ii. Sheet anodes attached to the concrete surface.
iii. Distributed anodes embedded in a cementitious overlay.
iv. Discrete anodes embedded in cavities in the concrete.

For galvanic anode systems, current output tends to fall with time as the anode is consumed. As a result galvanic protection is not generally achieved by sustaining an adequate level of steel polarisation, as is the case for other electrochemical treatments [9,11].

For this reason, traditional galvanic anode systems are only installed for corrosion prevention and take the form of discrete anodes embedded within concrete patch repairs [3,12]. The concrete repair process will restore steel passivity [4,13]. Thus, embedded galvanic anodes are only required to provide a small cathodic polarisation to the steel reinforcement in the parent concrete adjacent to the repair area, which is considered to be an area of high risk [14–16]. This is also commonly known as “cathodic prevention” [17].

The traditional 100 mV depolarisation performance criterion for Impressed Current Cathodic Protection (ICCP) systems has also been routinely applied to galvanic anode systems [18,19]. However, several publications note that this is not suitable for galvanic CP systems which are primarily designed to offer cathodic prevention only [9,19–21]. The new international standard for CP of steel in concrete [17] has taken this into account and performance assessment of galvanic CP is preferably focused on corrosion risk assessment. In practice this is based on monitoring of changes in the condition of the reinforcement that arise as the result of the protective effects afforded by galvanic CP [11]. Examples include corrosion potential as a function of time and/or distance from an anode or edge of the repaired area and/or corrosion rate [5,22].

There are a number of factors affecting the performance of galvanic anode systems. These are summarised in Table 1.

3. Methodology

This section describes the structures and the testing regime employed to evaluate the performance of the galvanic anodes.

3.1. Structures

The structures comprised a multi-storey car park (MSCP) with 11 stories in the East Midlands, UK and an 18 span bridge approximately 180 m long in Scotland, UK. MSCP was built in the early 1970s and it has a concrete one-way spanning ribbed type deck arrangement with 80 mm thick slab in-between the ribs (Fig. 3). Due to the nature of the structure it was lightly reinforced with steel mesh. The bridge was also built in the early 1970s and comprised prestressed concrete beams supported on RC crossbeams with steel Rendhex pile supports (Fig. 4). Due to the nature of dealing with full-scale structures at an age of at least 40 years, full details of the concrete composition were not available.

Both structures suffered from chloride-induced corrosion [5] (Fig. 5). The MSCP exhibited structural damage on the decks and soffits with exposed reinforcement and extensive concrete spalling. Chloride analysis, at more than 50 test locations on the concrete slabs and soffits of various floors, conducted in accordance with BS 1881–124 [24], indicated that the chloride levels were up to 2.92% by weight of cement at a depth of 30–55 mm. This is high and presents a corrosion risk that should be addressed [1].

The bridge also exhibited widespread areas of chloride-induced deterioration, being located in an aggressive marine environment.

Table 1
Factors affecting the performance of galvanic anode systems applied to RC structures [10].

Factor	Effect
Concrete resistivity	An increase in concrete resistivity reduces the protection current output of a galvanic anode which limits the protection delivered [3,4,17]
Current distribution	Discrete anodes distribute current poorly compared to surface applied anodes but protection can be targeted to the area of need [3,4,17]
Continuing corrosion	Products designed for use in a preventative role may fail when trying to arrest an active corrosion process [23]
Charge capacity/current output	The maximum theoretical life cannot exceed a period determined by the anode charge capacity and anode current output
Anode activity/surface area	Determines protection current output and discrete anodes in particular need a method of anode activation. For alkali activated systems, anode activation is dependent on the quantity of alkali in the assembly
Anode delamination/adhesion to concrete	Galvanic anode systems applied to concrete surfaces in particular are at risk of suffering from delamination and loss of contact with the concrete