

EMBEDDED GALVANIC ANODES FOR TARGETED PROTECTION IN REINFORCED CONCRETE STRUCTURES

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Corrosion of reinforcing steel in concrete is a major cause of structure maintenance and repair. Oxidation at the anodic sites on the steel reinforcement causes expansive forces that leads to visible concrete distress such as rust stains, cracks, spalling, or delaminations. Corrosion can also cause delaminations in the concrete cover (which may not be visually apparent), potentially with large sections of concrete dislodging from the structure. Additionally, loss of section due to reinforcement corrosion can cause structural issues.

Advancements in concrete repair methods and corrosion mitigation systems have given structural engineers many options to repair and extend the service life of actively corroding structures. Today, most structures suffering from corrosion can benefit from some level of electrochemical corrosion protection.

ELECTROCHEMICAL CORROSION PROTECTION

Electrochemical corrosion mitigation systems for reinforced concrete structures provide direct current to embedded reinforcing steel to mitigate corrosion; they fall into three general categories: electrochemical treatments, impressed current cathodic protection, and galvanic protection.

Electrochemical treatments are processes that are intended to modify the environment around the reinforcing steel such as to provide long-term corrosion mitigation. Examples of electrochemical treatments include electrochemical chloride extraction and electrochemical realkalization. Electrochemical chloride extraction passivates corrosion by using a high level of direct current for a relatively short duration to transport chloride ions away from the reinforcing while generating a substantial increase in alkalinity around the reinforcing steel. Electrochemical realkalization uses direct current to transport an alkaline solution into the concrete cover to mitigate corrosion caused by carbonation.

Impressed current cathodic protection systems are designed to provide direct current to the structure via permanently installed anodes and an external power supply. These systems commonly use inert anodes to distribute the electrical current to the reinforcing steel. Through the external power supply, impressed current systems provide the user with a high level of control over the level of protection, but the electrical systems must be monitored and maintained and periodically replaced.

Galvanic protection systems provide direct current through the use of dissimilar metals. Like



Discrete galvanic anodes installed around concrete repair to provide protection from halo effect corrosion



Discrete galvanic anodes are installed along the edge of the concrete patch repair

OVERVIEW OF ELECTROCHEMICAL CORROSION MITIGATION SYSTEMS

Generic system	Type of protection	Level of protection	Typical use
Electrochemical treatment	Active protection (short treatment duration)	Corrosion passivation	Global protection
Impressed current cathodic protection	Active protection (permanently in-place)	Cathodic protection	Global protection
Galvanic corrosion protection	Passive protection (sacrificial)	Corrosion prevention Corrosion control Cathodic protection	Global or targeted protection of specific areas

a battery, the more anodic metal naturally corrodes relative to the more noble metal. In reinforced concrete, galvanic anodes provide sacrificial protection to the reinforcing steel, do not require external power, and generally are not adjusted in the field. Galvanic systems are used to provide low-maintenance protection that can be economically tailored to protect large and small sections of the structure.

Anodes used in a galvanic protection system can be surface applied or embedded into the concrete structure or a new overlay. For embedded systems, zinc is the most common sacrificial anode used today. When compared with metals such as aluminum and magnesium, zinc exhibits a relatively small corrosion expansion that can be easily managed through mortar shell formulation or by providing sufficient porosity and reinforcement within the anode unit. Embedded zinc anodes are suitable for use with conventionally reinforced, prestressed, and post-tensioned concrete.

When galvanic anodes are embedded into concrete, it is important to prevent a buildup of oxides on the anode surface that will significantly restrict the performance of the anode. To combat this, an embedded anode unit will contain a chemical activator that generates a soluble corrosion by-product. Embedded anodes will either be alkali-activated in the pH 14 to pH 14.5+ range, or halide-activated, whereby salts such as chloride or bromide are used. Because halides are corrosive to zinc and steel, halide-activated anodes should be installed such that the halide activator is a minimum of 2 in. (50 mm) away from any reinforcement to minimize the risk of future corrosion.

FACTORS THAT AFFECT SYSTEM SELECTION

The type of corrosion mitigation system employed will depend greatly on a number of factors. To develop a corrosion management strategy that meets the needs of the client, answering a series of initial questions such as those that follow can help to gather the necessary information and understanding.

- What is the expected life of the structure?
- What service life is expected of the protection system?

- What is the severity of corrosion?
 - Is the corrosion localized or widespread?
 - How much concrete damage exists?
- How accessible is the structure now and in the future?
- What level of monitoring and maintenance is acceptable and likely to be completed?
- Will the structure be strengthened externally or have external coatings or membranes applied?
- What is the cost of future repairs and/or structure replacement including indirect costs such as traffic disruption and user costs?
- Is the budget available for a comprehensive approach?

GLOBAL VERSUS TARGETED PROTECTION

In some cases, a global protection strategy using electrochemical chloride extraction, impressed current cathodic protection, or galvanic protection is a preferred solution. Global protection should be considered if: 1) a long service life is desired; 2) corrosion activity is widespread; 3) the structure is considered to be critical in nature; 4) access is difficult and/or cost of future repairs are high; or 5) a high level of protection is required over large areas.

In other cases, corrosion is not widespread or budget limitations prevent a more comprehensive approach from being implemented. In these cases, implementing a targeted corrosion mitigation approach is generally preferred rather than not providing any protection whatsoever. Targeted corrosion protection can be economically implemented to provide an extension of service life at a moderate incremental cost and reduce the risk of serious corrosion damage.

TARGETED CORROSION PROTECTION USING EMBEDDED GALVANIC PROTECTION CONCRETE REPAIRS AND STRUCTURAL MODIFICATIONS

Due to differing levels of chloride contamination, carbonation, concrete cover, exposure conditions, and other factors, corrosion activity is not uniform throughout the structure. For example, leaking joints may lead to localized corrosion at the end of a beam while the remaining areas of the beam are corrosion free. Using a targeted protection strategy,



Distributed galvanic anodes used in galvanic encasement repair of bridge abutment



Distributed galvanic anodes used in conjunction with bridge deck overlay

the engineer mitigates the most active areas, at the beam end in the example mentioned previously.

The targeted corrosion mitigation approach begins with repairs completed via industry standards, particularly using ICRI Technical Guideline No. 03730, “Guideline for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion.” In areas where concrete damage exists due to corrosion, this guideline calls for concrete removal to extend outside of the areas of active corrosion and concrete to be removed from the full circumference of all reinforcing steel in the repair area. This repair procedure will deal with the areas of most active corrosion.

Unless all chloride-contaminated concrete is removed, chlorides will be present in the concrete adjacent to the repairs. This will create abrupt differences in corrosion potential in localized areas and creates a risk that corrosion activity will be initiated or aggravated in the existing concrete adjacent to the repair, commonly referred to as the halo effect. This condition can also be created when modifications are made to existing structures such as expansion joint repairs, slab replacements, and additions such as bridge widening, which creates an interface between new and existing concrete.

For almost a decade, embedded galvanic anodes in a discrete or “point” form have been used to provide localized corrosion prevention around concrete repairs. Embedded discrete anodes are installed around the perimeter of the concrete repair as close as practical to the patch edge. The anode units are prewet and tied directly to the reinforcing steel. The anode spacing is dependent on the amount of steel protected, but is generally in the range of 12 to 24 in. (305 to 610 mm).

Repair materials that are used with galvanic anodes should have normal resistivity, typically less than 15,000 ohm-cm. Most normal portland cement mortars and concrete meet this criterion. If higher resistance materials are to be used, then the anodes can be embedded in a normal resistance grout prior to application of the repair material to provide a conductive path between the anode and the reinforcing steel in the concrete adjacent to the patch. For additional information on embedded anode installation, refer to Repair Application Procedure “RAP8—Installation of Embedded Galvanic Anodes” available from the American Concrete Institute at www.concrete.org.

CONCRETE JACKETING AND OVERLAYS

For over 5 years, galvanic anodes in a ribbon or strip form have been used to provide protection in reinforced concrete. As opposed to discrete or point anodes, these anodes are referred to as distributed anodes and are provided in various shapes and lengths up to 7.5 ft (2.3 m).

Distributed anodes are placed across the surface of the concrete to be protected then embedded in a reinforced concrete jacket or overlay. The distributed anode systems are used to provide galvanic protection over a larger area but can be easily used to protect small structural elements such as a single pile, column, or wall. This type of system can also be referred to as a galvanic encasement.

With a galvanic encasement, the deteriorated concrete is removed and the reinforcing steel is cleaned of corrosion by-products. The galvanic anode strips are distributed across the surface and attached to the existing reinforcing steel. Additional



Distributed galvanic anode installed along expansion joint repair

reinforcement is provided by placing reinforcing steel or noncorrosive fiberglass reinforcement over the anodes, then the concrete is placed such that the repairs and jacket or overlay are completed in a single step.

More recently, embedded galvanic anodes in ribbon form have been used to provide targeted protection to expansion joint repairs, deck widening projects, and concrete repairs. Using distributed anodes in these types of applications allow the engineer to provide a consistent line of protection along the new/old concrete interface using anodes with greater surface area and zinc mass. With heavily reinforced structures, distributed anodes may be more economical than discrete anodes at a tight spacing.

SUMMARY

A range of systems are available for electrochemical corrosion mitigation, including electrochemical treatments, impressed current cathodic protection, and galvanic protection. Galvanic systems provide protection using dissimilar metals and operate naturally without the need for an external power source. Embedded zinc anodes are activated to enhance their performance and are provided in a range of shapes and sizes that provide flexibility in design and application.

Galvanic systems can be used for global or targeted corrosion protection. Many structures can benefit from a corrosion management strategy that uses galvanic anodes to provide targeted protection

and extended service life. Examples of these applications are concrete repairs, expansion joint repairs, bridge widening, and galvanic encasement using concrete jackets and overlays.



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