Galvanic Protection for Reinforced Concrete Structures

By David W. Whitmore and J. Christopher Ball

Active corrosion mitigation systems for reinforced concrete structures can be defined as methods that provide a protective electrical current to reinforcing steel embedded with the structure. These types of systems fall into three broad categories:

Fig. 1: Electrochemical realkalization of carbonated concrete façade on airport terminal building

Fig. 2: Impressed current cathodic protection system for copper export terminal

1. Electrochemical treatments;
2. Impressed current cathodic protection; and
3. Galvanic corrosion protection.

Electrochemical treatments such as chloride extraction and realkalization (Fig. 1) provide a high level of current for a short duration to create a passive environment around the concrete/reinforcing steel interface. Impressed current systems (Fig. 2) use permanently installed anodes that distribute electrical current provided by an external power source. These systems provide a high level of control over the amount of current delivered, but the electrical systems must be maintained over time. Galvanic systems (Fig. 3) provide protective current through the installation of dissimilar metals (also known as sacrificial anodes), which corrode preferentially to the metal to be protected. Since galvanic systems operate naturally without the need for an external power source, they provide a low maintenance approach that is economical for many structures.

Galvanic Protection

Galvanic corrosion protection methods were originally developed in the 1820s. Over the years, galvanic corrosion protection systems have been widely used to protect underground steel structures such as pipelines and tanks. Galvanic protection systems were first used on reinforced concrete structures around 1960. Recent technological advancements in the development of galvanic anodes have lead to a significant increase in their use for protecting reinforcing steel in concrete structures.

Sacrificial anodes used for galvanic protection are typically constructed using aluminum, magnesium, or zinc. For reinforced concrete applications, zinc has become the most common sacrificial anode used today. There are several reasons for the popularity of zinc. First, zinc has a high corrosion efficiency. This means that a high percentage of the electrons that are discharged as the zinc corrodes are available to protect the steel. Second, as zinc corrodes, it has a relatively low rate of expansion compared to other metals, including steel. This makes zinc anodes particularly suitable for applications where the anodes are embedded into the concrete structure. Finally, zinc anodes are suitable for use with prestressed and/or post-tensioned concrete because their native potential is generally not sufficient to generate hydrogen atoms or cause hydrogen embrittlement in a concrete environment.

The current output provided from a zinc anode in concrete is dependent on the corrosion by-products that are formed as it corrodes. If the corrosion by-products form a tightly adhering solid layer on the surface of the zinc, the corrosion of the zinc will be significantly reduced, in some cases to nearly zero. If zinc is installed in normal portland cement concrete, the pH around the zinc anode will stabilize in the range between 12.5 and 13. At this level, zinc forms a stable corrosion by-product (passive oxide film) that will correspond to a very low corrosion rate and a low level of protection (Graph 1).

Alkali-Activated Zinc

For concrete applications, there are two primary methods to keep the zinc from passivating over time. The first is to increase the pH around the zinc to be in the pH 14 to pH 14.5+ range. In this environment, the corrosion by-products are soluble and do not form a solid oxide film on the surface of the zinc. These types of system are referred to as "alkali-activated" systems.

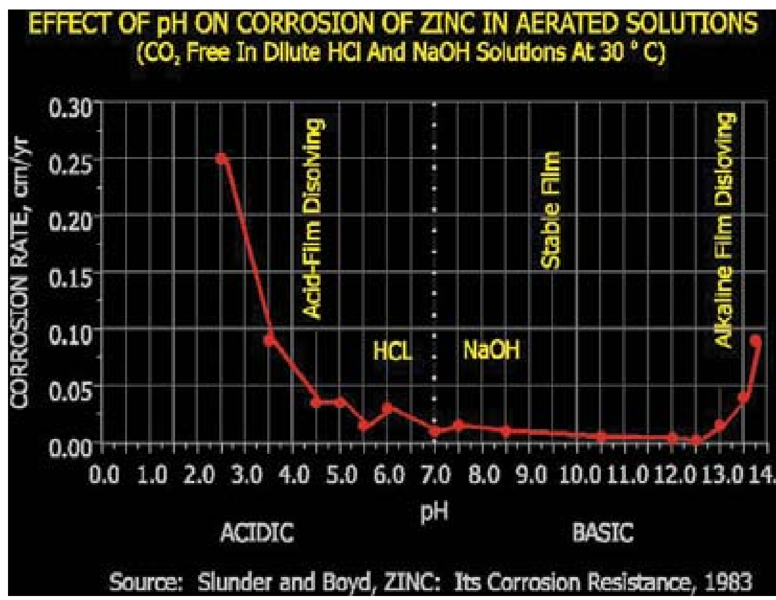
An example of alkali-activated anodes include zinc anodes with a precast mortar matrix saturated with lithium hydroxide (LiOH) (Fig. 4). These anodes are designed to be tied directly to the reinforcing steel to extend the life of concrete patch repairs. In addition to keeping the anode active over time, alkali-activated systems are designed to be corrosive to the sacrificial zinc anode but not to the reinforcing steel in the concrete.

Halide-Activated Zinc

The other method of activation is for the zinc to be in a corrosive salt environment where the salt is in direct contact with the surface of the zinc anode. The most common type of salt used to activate zinc anodes embedded in or applied to concrete structures are halide salts. Halide salts contain anions such as fluoride (F^-), chloride (Cl^-), bromide (Br^-), and iodide (I^-) which prevent the formation of a stable oxide film on metals. As the zinc corrodes, it reacts with the available halides in the environment to form soluble corrosion by-products (such as zinc chlorides) that are able to diffuse away from the interface before oxidizing further. Examples of this type of activation include bulk zinc anodes placed on concrete piles in a saltwater environment (Fig. 5).

The principle benefit of this type of activation is that a high level of protective current can be produced depending on the level of halide that is available. A potential drawback of halide activation is that the halide ion is corrosive to both the zinc and the reinforcing steel. To minimize this risk, halide-activated systems should be installed such that the halide activator is

Fig. 3: Galvanic anodes used in bridge deck overlay system



Graph 1: Corrosion rate of zinc at various pH levels

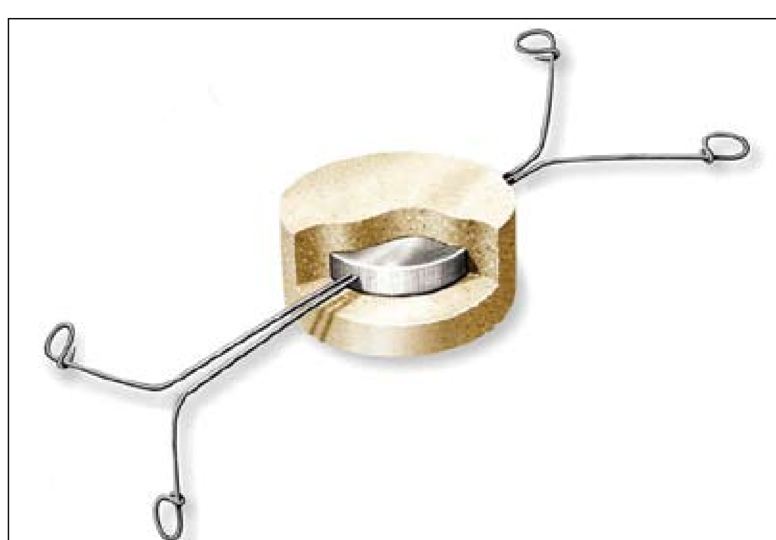


Fig. 4: Cutaway of alkali-activated zinc anode for concrete repair

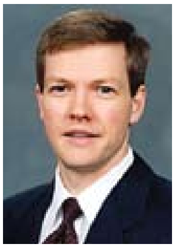
Fig. 5: Bulk zinc anodes used to protect concrete piles in seawater

typically kept a minimum of 2 in. (50 mm) away from any reinforcing steel. Keeping a distance from the reinforcing steel helps to prevent the halide activator from directly contacting the reinforcing bar or diffusing to the reinforcing bar over time. This can be successfully accomplished with surface-mounted systems such as galvanic overlays or metalized coatings (Fig. 6).

Fig. 6: Activated arc-sprayed zinc metalizing providing cathodic protection on bridge substructure

Summary

Galvanic anodes are used to provide convenient, cost-effective corrosion control for reinforced concrete structures. Applications for galvanic protection systems include localized corrosion protection around patch repairs, and joints between new and existing concrete. Galvanic anodes are also used in distributed corrosion protection systems designed to provide blanket corrosion protection to entire structures exposed to corrosive environments. In all cases, it is important to understand and select an appropriate system that ensures the zinc anode provides the level of corrosion protection desired without creating additional corrosion concerns for the structure.



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