Embedded Galvanic Anodes Increase Sustainability of Reinforced Concrete Structures

David Whitmore, PEng; Vector Corrosion Technologies
Sean Abbott, PEng; Vector Corrosion Technologies

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Abstract

The benefits of galvanic techniques for corrosion protection have been known for more than 150 years. In the previous decade this technology has been studied, and adapted for use in reinforced concrete structures, consider the use of galvanized reinforcing steel as an example. By sacrificially corroding, galvanic anodes prevent corrosion of the steel reinforcement. While thin coatings are well suited to providing uniform protection over the surface of reinforcing steel in new construction, they can be consumed quickly in localized areas and may not be suitable for rehabilitation scenarios. Discrete sacrificial anodes can be concealed within the concrete, and enable designers to focus long-lasting protection at specific corrosion “hot spots”.

In the transportation sector, embedded galvanic anodes are being used in applications ranging from bridge deck widenings to patch repairs in wharf structures. Different anode configurations are available, allowing the specifier to tailor how much protection is provided, and to where. The systems are self-powered, and most are simple to install and require no maintenance making them cost-effective, even for small or isolated projects.

The essential function of galvanic protection systems is to extend the life of aging and deficient concrete structures by addressing the corrosion of reinforcing steel. The condition of our transportation infrastructure is rapidly deteriorating, and galvanic anodes can provide a practical method of enhancing its useful life.

Introduction

Corrosion of reinforcing steel within concrete is recognized as a significant problem facing present day owners and engineers. Some estimates indicate that it would cost $78 billion to restore all structurally and functionally deficient bridges in the U.S. alone (1). Corrosion is cited as being a significant cause of this deterioration. In many concrete structures, exposure to de-icing chemicals and marine sourced chloride is a significant cause of corrosion, playing a more detrimental role than originally anticipated. Long-term exposure to carbon dioxide in the atmosphere is also recognized as a frequent cause of corrosion of reinforced concrete.

Many electrochemical methods of corrosion protection have been devised in recent years to combat corrosion at its source. These systems include a number of ingenious methods of providing galvanic protection or galvanic cathodic protection to a structure. By supplying a small electrical current to the reinforcing steel one can make the reinforcing steel more cathodic, and reduce or eliminate its corrosion. Galvanic technologies operate by connecting a “sacrificial anode” to the reinforcing steel of a structure. This anode must be made electrically and ionically continuous with the reinforcing steel. Galvanic systems are considered desirable because they create their protective current internally, through a natural reaction wherein the anode corrodes to protect the reinforcing steel. They do not rely on the use of an external power supply, which necessitates routine maintenance and monitoring. Galvanic systems can be designed to provide a significant level of corrosion protection, and yet satisfy owners looking for a low-maintenance option.

Galvanic protection systems can be fabricated in a wide array of shapes and styles. Most systems used for protection of concrete structures incorporate zinc anodes, or some alloy of zinc. The most visible feature that differentiates these systems is the way in which they are applied or installed on the concrete. Most designs are fastened to the outside of the concrete by either being placed in a cementitious overlay or a conductive adhesive gel, in some cases the anode material is even melted and sprayed onto the surface of the concrete in a molten state.

Embedded Galvanic Anodes

Some recent designs have also focused on the benefits of incorporating the anode into the concrete structure. By being placed inside the concrete there is a minimal change to the external appearance of the structure and no decrease in the function or serviceability of the structure. In addition, being embedded within the concrete protects the anodes from some of the deterioration mechanisms that externally bonded systems are subject to. For installation, embedded galvanic anodes are commonly tied to the reinforcing steel inside of repair areas, or placed in a network of shallow drilled holes. The anodes are currently manufactured in three different shapes, a puck, a cylinder and a small pellet. The puck-shaped anode is 6.4 centimeters in diameter and 2.9 centimeters thick. It is comprised of a disc-shaped zinc core that is cast around a pair of steel tie-wires. The core is encased in a highly alkaline cementitious shell. The pucks are primarily used in rehabilitation applications such as patch repairs (Figure 1), and joints between new and existing concrete. They are typically installed at the perimeter of a repair area by using their built-in tie-wires to fasten them to the exposed reinforcing steel. When a suitable concrete or mortar is placed around the anode, its core will begin to sacrificially protect the surrounding reinforcement.

A similar cylindrical anode is also available, 6.4 centimeters long by 4.3 centimeters in diameter. The primary differences between this anode and the puck are in its exterior shape and the shape of its zinc core. This anode is designed for installation in a 5 centimeter wide drilled hole (Figure 2) in mechanically sound concrete. Its core shape has been designed with multiple fins to maximize anode surface area. This anode is connected to the reinforcing steel by a single steel lead wire. These anodes are used primarily in applications where corrosion activity is already occurring or expected to occur but has not progressed to the point of causing physical deterioration.

The most recent development is the manufacture of an even smaller cylindrical anode, or “pellet”. The pellet is 19 mm in diameter, and 25 mm long. It is placed in a 19 mm hole similarly to the larger cylindrical anode. Aside from its compact size, the pellet anode differs significantly in its composition having no outer cementitious shell. In the previous two anode configurations, the zinc core is surrounded by a cementitious shell which contains chemical additives that maintain the zinc in an electrochemically “active” state. In order to reduce the size of the pellet a new manufacturing process was used incorporating the activators into the zinc and eliminating the need for a bulky shell. There are currently two versions of this anode available, the standard anode and one with a built-in lead wire. Commonly installation is accomplished by drilling a 19 mm hole to make direct contact with the reinforcing steel (Figure 3). After removing all dust and debris from the hole, the anode is placed in the hole and driven against the reinforcing steel with a mallet and punch. The anode deforms against the steel, simultaneously making an electrical and mechanical connection. The remainder of the hole is then filled with a suitable grout material. The alternate version of the pellet has an attached lead wire. This version of the anode is used in situations of very shallow concrete cover (less than 38 mm) when there is not enough depth to place the anode on “top” of the reinforcing steel. These anodes are installed in a similar manner to the cylindrical anodes, with a two-hole method.

Applications

Repair and protection of concrete structures offers many unique challenges from a corrosion perspective. In particular the “Ring-Anode” effect, also called the “Halo” effect is a phenomenon that is frequently overlooked but is a common cause of premature patch-failure. The principles of chloride-induced corrosion are well understood, and corrosion is known to be an electrochemical reaction. Much like a battery, all corrosion cells have an anode and a cathode. During the corrosion process the anodic portion of steel is converted to iron oxide (rust). The ring-anode effect results in an increase in corrosion activity caused by the electrochemical incompatibility created between reinforcing steel within a patch area and the steel embedded within the surrounding concrete. The common procedure for repairing deteriorated concrete involves removal of the damaged material and replacement with new concrete or mortar. While this addresses the immediate serviceability requirements it will not always satisfy long-term durability needs. Research and field experience has shown that it is difficult to match repair materials electrochemically with the parent concrete. Differences in pH, porosity, and chloride content are a few of the factors that create electrical potential differences between repair material and the surrounding concrete. A difference in potential between the repair and the surrounding concrete will generate an electrical current in the reinforcing steel between the two areas, possibly aggravating an existing corrosion problem or creating a new one. For this reason, in chloride exposed structures we often see that “chip and patch” style repairs may only last 3 to 5 years before the corrosion is accelerated enough in the adjacent concrete to create new delaminations and spalled areas. In situations like this the puck shaped anode is particularly beneficial. The anodes are tied onto the reinforcing steel at a regular spacing around the perimeter of the repair area forming a ring of defense against electrochemical incompatibilities. Similarly the pucks can be used in rehabilitation applications such as bridge deck widenings and joint replacements where an interface is created between old concrete and new. In an application like this the goal is not to provide protection over the entire repair area, but to focus it around the edge so that we do not inadvertently aggravate a corrosion cell through our repair efforts.

Applications also arise when corrosion activity is known to be occurring in a structure, but deterioration has not proceeded to the point of causing delamination or spalling to the concrete. Often during an inspection program areas of deterioration will be located and repaired using traditional approaches, but no further consideration is given to the areas of apparently “good” concrete. It is usually more cost-effective in the long term to consider pre-emptive protection for these areas rather than having to mobilize to the site again for additional future rehabilitation work. It is for these sections of mechanically sound concrete that the cylindrical, or drilled-in anodes are designed. While it would not usually make sense to chip out pockets of sound concrete to allow installation of an anode, dropping an anode into a drilled hole is practical. Typically a grid pattern of 50 mm holes (diameter) will be drilled in the area to be protected. The anodes are connected to the reinforcing steel via an adjacent hole that is drilled to intercept the nearest part of the reinforcing grid. Real-world applications tend to include structures such as balconies, where installation of traditional forms of electrochemical protection can be prohibitively expensive on small, discrete surfaces. Additionally, it may also be wise to install preventative protection in the sound portions of a structure that is undergoing rehabilitation at other locations. It can be less expensive to take advantage of a current shut-down rather than have to mobilize to the site again in the future.

The small pellet-shaped anodes have been designed for applications where the larger cylindrical anodes are found to be too bulky. Specifically in pre-stressed concrete bridge girders and similar structures. These girders are often subject to chloride contamination at their ends due to leakage through the deck joints above. Over time the reinforcing steel in a localized zone at the girder end will begin to corrode, however conventional repair techniques can prove difficult. The thin section of many girders, and small bearing surface mean that concrete removal must be carried out carefully, and temporary shoring may be required. The close spacing of the reinforcing steel and shallow repair depth may make the use of puck style anodes practically difficult. The easiest solution is to use a small anode that can be drilled into sound portions of the girder, and between the stirrups if necessary. The ultra compact size of the pellets makes this possible. Typically the anodes will be placed in a grid pattern throughout the area requiring protection. Because the holes are only 19 mm in diameter they create a very small footprint on the surface of the structure. Installation is relatively quick requiring a rebar locator, a hammer drill, and simple hand tools. Pre-stressed structures are a special case, requiring special care during installation. The anodes are attached to the stirrups, however it must be verified that the strands are electrically continuous with the stirrups in order to be sure that they will receive an equal level of protection. This is usually accomplished by exposing the strands at the end face of the girder.

Benefits

Embedded Galvanic Anodes are relatively new to the concrete repair industry, however they are based on old technology. The development of new variations of these anodes continues as new needs are recognized. They provide a level of electrochemical protection for the reinforcing steel, thereby extending the life deteriorated and contaminated concrete structures. Their discrete nature and simple installation prove them to be a very versatile product, useful in applications that were formerly considered impractical for electrochemical protection. By being embedded within a concrete matrix they are protected from damage by traffic loading, weather, and vandalism. They are hidden within the structure, causing a minimum change in appearance, and no change in the functionality or serviceability of the structure. The galvanic nature of these anodes makes them self-powered, and self-regulating, requiring no extra maintenance or monitoring during their operational life. The anodes do have a limited life-span that will vary according to a number of factors, including the density of reinforcing steel, average temperature and humidity within the concrete, and the level of corrosion activity. Under normal operating conditions, the anodes are designed to last 10 to 15 years. Embedded galvanic anodes are designed to be a more efficient approach to traditional concrete repairs. They are not a guarantee to eliminate corrosion entirely from a structure, but they are a simple method of enhancing the performance of repair and rehabilitation projects that are being undertaken currently without any real corrosion protection. They provide a new option for owners and specifiers.

Much of the concrete infrastructure that we rely on today was built in the 1960’s and 70’s and will be requiring rehabilitation in the near future. Throughout North America repair costs of an aging infrastructure are escalating. It has been estimated in the United States that the annual cost of corrosion to concrete bridges alone is 4 billion dollars (2). The costs of traffic congestion and down time are not as easily quantified but are becoming more apparent as major rehabilitation projects disrupt our everyday lives. The indirect life-cycle costs to repair highway bridges are estimated to be 10 times as much as the direct costs of maintenance and repair (2).

Ultimately embedded galvanic anodes are designed to combat corrosion of reinforcing steel. By corroding sacrificially the anodes extend the life of the steel, and in turn extend the time until the next rehabilitation is required. A fundamental aspect of sustainable development is to encourage the development of technologies that further our economic and social well-being (3). New technology including Embedded Galvanic Anodes can play a vital role in helping to preserve our concrete infrastructure, and maximize their value to the user.

References

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2) Yunovich, Thompson, Bal Vanyos and Lave, “Highway Bridges: $8.3 billion/year”, www.corrosioncost.com, 2003
3) Manitoba Conservation, “Principles and Guidelines of Sustainable Development”, www.gov.mb.ca/natres

Figures

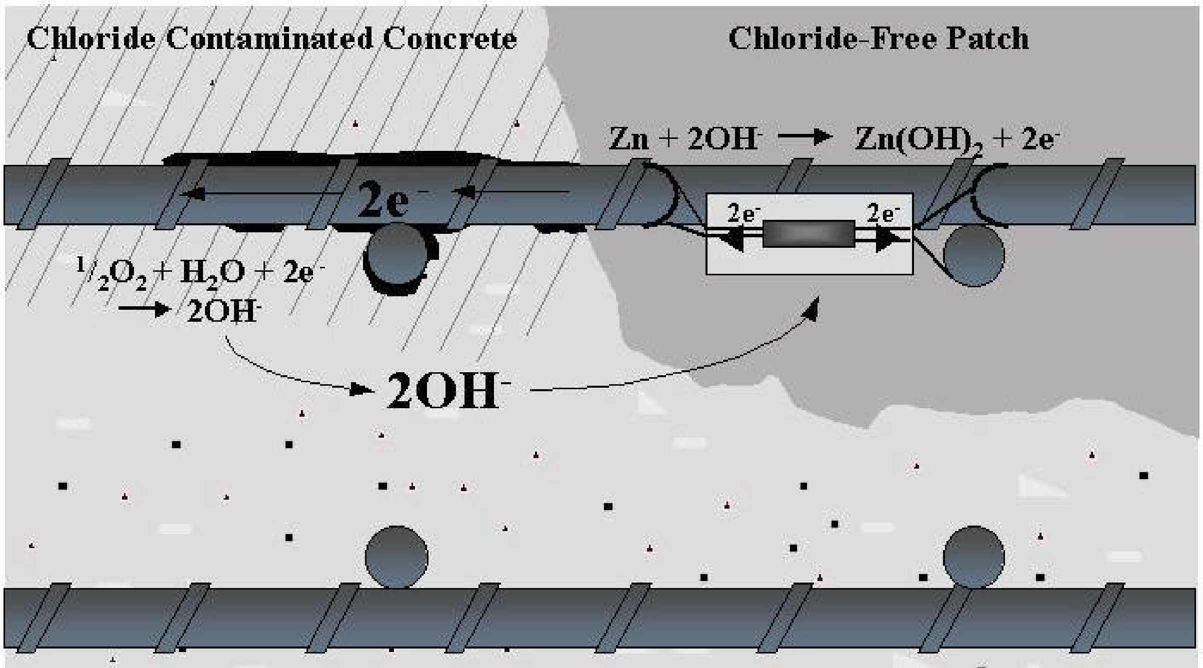

Figure 1 Puck shaped anode installed at edge of concrete patch repair

Figure 2 Cylindrical anode installed via "two hole" method in sound concrete

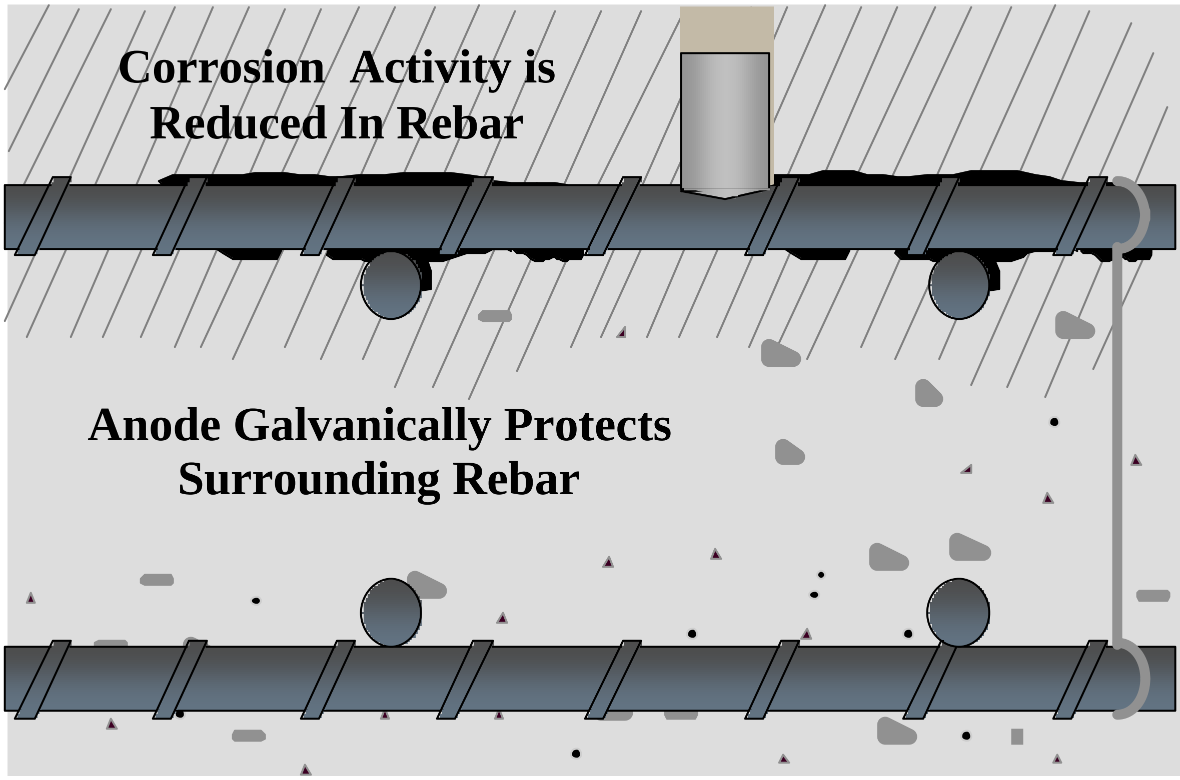

Figure 3 Pellet style anode installed in small drilled hole on “top” of reinforcing steel