Use of Cathodic Protection in a Shotcrete System

By Jesse Osborne

Used successfully for over 100 years, shotcrete, or gunite, is concrete that is conveyed or transported with a concrete pump or pneumatic gun and sprayed into place. While the method has remained relatively constant, the equipment, materials, and applications are continuously improved and expanded. Today, concrete can be applied through the use of robotics in areas formerly considered inaccessible or unsafe, shotcrete can be batched as self-consolidating concrete (SCC), and materials containing macrofibers can be placed thinner while still maintaining structural integrity. Along with the continuous improvement, there are also some occurrences that have plagued shotcrete for years.

One of the chief issues is corrosion of steel reinforcement. The use of synthetic fibers has reduced the dependency on steel; however, steel cannot be easily replaced in all applications. When steel reinforcement is used, it is a good idea to protect it with the use of one of the available corrosion control methods currently available. There are various methods of protection available to the concrete industry. Calcium nitrite has been available for many years and has a proven track record of success. The mechanism for this method of protection essentially slows the ingress of chloride and "binds" it up through a process referred to as ion exchange before it reaches steel reinforcement. Cathodic protection is also used extensively in the concrete repair segments, as well as in new construction. Cathodic protection involves the use of zinc anodes. This method of corrosion protection has been available for some time, but its use in shotcrete is comparatively new.

Under normal conditions, steel in concrete is essentially protected. There is a passive layer that protects the steel in concrete due to the high pH of portland cement. However, when chlorides or CO_2 eventually reach the steel, the passive protective layer breaks down and corrosion is initiated by the creation of several microscopic corrosion cells.

Corrosion is an electrochemical process involving the flow of electrons through metal and the flow of ions through an electrolyte. There are four necessary components to a corrosion cell: an anode, a cathode, a metallic path, and an electrolyte. In a corrosion cell, the most active metal will act as the anode with the most noble metal acting as the cathode. Corrosion typically occurs at the anode. Because of inconsistencies in the purity of structural steel, it is likely to have microscopic corrosion cells within a single piece of steel. The corrosion cell will look like this:

Anode = parts of the structural steel
Cathode = parts of the structural steel
Metallic path = the steel itself
Electrolyte = shotcrete

Cathodic protection works by introducing a more active metal (zinc) to the electrolyte (in this case, shotcrete) and connecting it metallically to the structural steel using the tie wires that are attached to the anode. Because zinc is a more active metal than steel, all of the steel becomes the cathode. So the alternative (more active) corrosion cell will now look like this:

Anode = sacrificial element
Cathode = structural steel
Metallic path = galvanized steel tie wires
Electrolyte = shotcrete

Cathodic protection dates back almost 200 years and can be traced to British naval vessels, where it was used to slow the corrosion of the steel hulls on ships. Its use in concrete repair and protections has been common for the last 30 to 40 years. These anodes are manually attached to steel reinforcement before the concrete or shotcrete is placed. While these anodes eventually require replacement, they will extend the expected repair interval by two to three times, making them a worthy investment.

The concept of cathodic protection in concrete and concrete repair is relatively straightforward and widely accepted. The mechanism by which it works (explained previously) is fairly simple.

The anodes corrode in place of the reinforcing steel. To achieve this, there are some stipulations that need to be addressed to ensure adequate protection. First, the anodes need to be spaced properly. To properly space the anodes, some information needs to be acquired. For instance, what is the chloride content of the existing structure (in concrete repair cases) or what is the expected chloride content (for new structures)? To properly determine the chloride content of the structure, the surrounding content should be tested in accordance with ASTM C1218/C1218M. Once the chloride content is determined, the steel reinforcement needs to be identified. The reinforcing bar size, density, and distribution are also considered in the spacing of the anodes. Examples of how this information is used to determine the anode spacing is shown in Fig. 1 and 2.

This type of spacing criteria is used when the concrete/shotcrete has a volumetric resistivity of less than 15,000 ohm-cm. When the concrete/shotcrete has a volumetric resistivity higher than 15,000 ohm-cm, a correction factor is typically applied. Shotcrete often includes silica fume in both wet and dry mixtures. Silica fume will naturally increase the matrix resistivity, so testing the resistivity is highly recommended. The testing equipment is relatively inexpensive and easy to operate. Once the chloride content (or expected chloride content for new structures) is determined, the reinforcing bar density is identified and the resistivity is tested; the anode spacing factor is then set. For the anodes to work properly, they should be in full contact with the reinforcing steel that they are going to protect and also need to be fully encapsulated in the surrounding concrete or shotcrete. Normally, this is not an issue. However, in shotcrete, full encapsulation takes a little bit more attention. Shotcrete should be placed by ACI certified and experienced nozzlemen. Special attention should be used to ensure that adequate encapsulation of the anodes is performed. If complete coverage is not obtained, there is a risk of more concentrated chloride migration to more focused areas of the anode, which would lead to premature repair of the area.

Anode spacing in shotcrete deserves a clear explanation. Cathodic protection depends on chloride migration, or movement, through the concrete/shotcrete matrix. With the higher volumetric resistivity of most shotcrete mixtures due to high cement factors, addition of silica fume, and lower water-cement ratios (*w*/*c*), the

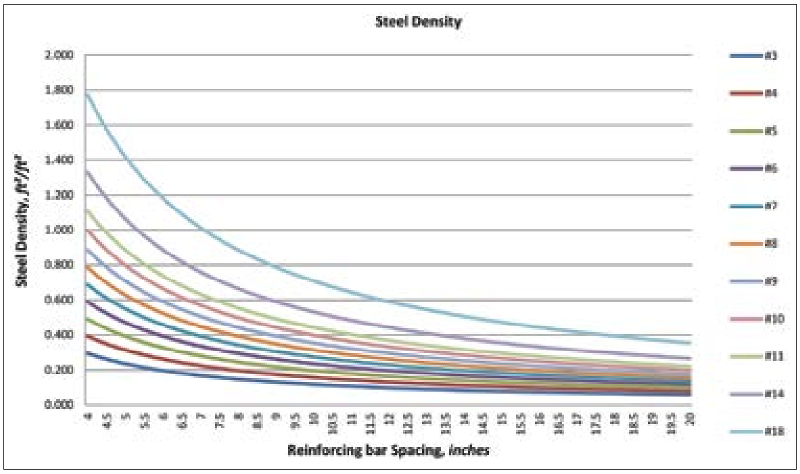

Fig. 1: Steel density

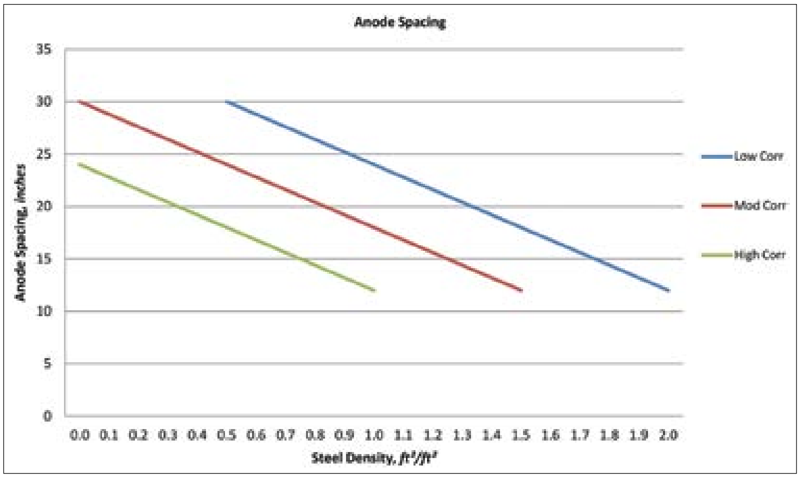

Fig. 2: Anode spacing

Fig. 3: Reinforcing bar sentinel tie-in

Fig. 4: Sentinel install

chloride movement is slowed to the point that the protective coverage range of the anodes is reduced significantly. For this reason, the spacing of the anodes is reduced to ensure protection of the steel. Determination of the resistivity is recommended in all projects and is essential in shotcrete projects. Determining the mixture resistivity, as stated earlier, is fairly simple and inexpensive. The Florida DOT has done extensive testing and published the data and results. This paper is available on the Florida DOT website.

The type of anodes themselves plays a large role in the protection. Typically, the contact area between the anode and reinforcing steel should be stable and insulated to contact only at the ends to prevent "dumping of current" onto the reinforcing bar. This current dumping can lead to overloading the cathodic protection system and cause premature failure of the anodes. Also, the amount of sacrificial material that is used (zinc, in most cases) will play a significant role in the amount of protection and the life span of the anode. Using more zinc in the anodes is essential in high-chloride environments. Increasing the service of the anodes prolongs the time interval for anode replacement, which obviously saves more money. The anodes need to be attached to the reinforcing bar in a manner that will secure them as snugly as possible. They are usually attached to the reinforcement with some type of steel tie. The steel tie portion of the anode is subjected to corrosion, as well; therefore, using a corrosion-resistant material such as galvanized steel for the tie-downs is important. If the ties corrode prematurely, the anode is no longer attached to the reinforcing bar and protection will not occur.

Eventually the anodes require replacement. However, this replacement lasts approximately two to three times longer than conventional concrete before it would need to be repaired, and the replacement is, for the most part, easier than a standard repair (as long as the replacement takes place before corrosion is able to reach the reinforcing bar). There are various testing procedures used to determine when the anodes need to be replaced. Once this testing indicates that it is time to replace, the area around the anode is saw cut and chipped away to reveal the reinforcing bar and a new anode is attached. Repair material comprised of similar material to the original structure is recommended to maintain the same spacing criteria.

The use of shotcrete as a base material, as well as a repair process, is continually growing in popularity. The use of cathodic anodes as a method of corrosion protection is also popular with historical success. The combination of the two materials is an obvious good fit. Initial time, labor, and material costs are overcome by the savings that are experienced by extended repair time cycle.

Reference

"Cathodic Protection Systems—Use of Sacrificial or Galvanic Anodes on In-Service Bridges," NYSDOT Office of Operations, Transportation Maintenance Division, Bridge Maintenance, 2008, 24 pp.

***Jesse Osborne** is currently the Mining and Tunneling Segment Manager for The Euclid Chemical Company, based in Cleveland, OH. He has been with Euclid Chemical for over 10 years and has over 30 years of experience in the concrete and cement construction industry with positions ranging from research and development to product and segment marketing. He is a member of SME and NPCA.*