Overcoming Existing Corrosion When Using Shotcrete for Repair

By Rachel Stiffler

For over 100 years, shotcrete has been used in a variety of new construction applications, but one of its major uses is in repair, rehabilitation, and repurposing. The shotcrete repair process is increasing in use, both for transportation and building applications. It is ideal for repairing both vertical and overhead surfaces at most thicknesses.

On many rehabilitation projects, there are challenges with corrosion of the existing reinforcing steel. Once the existing concrete has been removed, we can easily evaluate the condition of the reinforcement. The corrosion of the steel has usually been caused by penetration of chlorides into the concrete. When sufficient chloride reaches the reinforcement—typically 0.03% by weight of concrete in non-carbonated concrete—the natural protection of the steel created in the highly alkaline environment of the concrete becomes compromised and corrosion begins.

The iron oxide (rust), created from the expansion of the reinforcement, once corrosion begins, occupies a greater volume than the steel itself, thus causing cracking that can lead to delamination and spalling of the concrete.

When these concrete structures are repaired, the original concrete material remaining is contaminated with residual chloride. When the repair concrete is placed, there is an electrochemical incompatibility that occurs between the new and existing concrete. When this incompatibility is present, new corrosion sites will begin to appear.

The electrical potential of the reinforcing steel within the existing contaminated concrete becomes more electronegative, shifting current to the repaired area. When this happens, concrete deterioration is noticeable in the parent concrete a short time after the repairs are completed.

This is commonly referred to as the "halo effect," "patch accelerated corrosion," or the "ring anode effect" (refer to Fig. 1). Galvanic zinc-based anodes are used to prevent this from occurring. These anodes can be tied onto the reinforcing steel around the perimeter of the patch areas, or on a grid pattern (refer to Fig. 2).

As the anode is connected directly to the cleaned reinforcing steel, the generated current protects the steel. This prevention or control of corrosion is effective within the area defined by the spacing of the anodes.

A good reference for anode installation is the American Concrete Institute's RAP-8 Bulletin, "Installation of Embedded Galvanic Anodes" (reprinted in this issue on page 37). It is available in PDF format as a free download from ACI (**www.concrete.org**). This guideline references installation guidelines and anode nomenclature. The nomenclature refers to a Type 1 anode as being attached and embedded inside the patch area while Type 2 anodes are placed into holes drilled into sound areas. Occasionally, the Type 2 anodes are used in a shotcrete application (refer to Fig. 3). This application is preferred when the concrete cannot be completely removed to expose all reinforcing steel, either for structural reasons or due to very little concrete cover. This is also a proactive approach of anode use when the concrete has not delaminated or spalled, but the testing shows

Fig.1: Example of the halo effect or ring anode effect

Fig.2: Anodes placed on a grid pattern

chloride penetration has occurred. By using both the Type 1 within the patch areas and the Type 2 in the parent concrete, you have provided global protection for your structure.

Anodes work by corroding preferentially to the reinforcing steel. The anode is electrically connected to the reinforcing steel and provides a protective current through that connection. To do that properly, the anode needs to be placed at a spacing that provides the needed amount of current necessary to adequately protect the steel.

The needed information for spacing requirements are reinforcing bar size, density, and steel distribution. Chloride content in the existing concrete is also very useful.

Once the needed information is considered, the spacing can be calculated using this formula:

Surface area of steel/surface area of concrete = steel density ratio

With the higher resistivity of shotcrete material, anode spacing is important. Shotcrete (both wet- and dry-mix) inherently has higher resistivity than most form-and-pour concrete due to higher cement contents, often using microsilica or fly ash supplemental cementitious materials and a lower water-cementitious materials ratio (*w/cm*). Thus, these shotcrete-specific mixture designs will slow the migration of chlorides along with increasing the resistivity of the mixture.

The normal recommendation is to have a resistivity of less than 5900 ohm-in. (15,000 ohm-cm). This allows sufficient protective current to flow from anode to steel. This number also relates to approximately 1500 coulombs using the Rapid Chloride Permeability testing (ASTM C1202). If the concrete mixture used will have a higher than 5900 ohm-in. (15,000 ohm-cm) resistivity, it is suggested to use a bridging or embedding mortar. The conductive bridge is then created with this mortar between the anode and the parent concrete. This also prevents the risk of shadowing or voids behind the anode, as shotcrete may have difficulty wrapping around the backside of the anode. You may use this bridging mortar even with a lower resistivity concrete to help prevent shadowing.

The decision for using a bridging mortar is based on several factors:

- What is resistivity of the parent concrete?
- Should more anodes be used to generate more current for a higher resistivity mixture?
- How close can the anodes be placed to the patch edge?
- Can the anodes be tied on the steel well enough to not be damaged by the shotcrete application or to prevent shadowing?

Once these questions are reviewed and answered, the decision to use the bridging mortar can be made.

There are several anode sizes available today. So, once the steel density ratio is calculated, the decision can be made for proper anode size and zinc content use.

In summary, the use of embedded galvanic anodes in shotcrete repairs gives an additional level of protection from future corrosion. Use of shotcrete in conjunction with this type of cathodic protection is being used on a more regular basis, as more owners and specifiers realize the savings and long-term performance produced with this type of repair process.


Fig.3: Type 2 anodes are placed in series into drilled in holes in the existing concrete prior to shotcrete application

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