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Protecting Reinforced Concrete Structures with Thermal Sprayed Zinc Anodes

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ABSTRACT

Metallic zinc coatings provide corrosion protection for steel by acting first as a barrier coating and secondly as a sacrificial anode. Whether exposed to the atmosphere or embedded in concrete, if the coating is scratched or compromised in any way, the zinc will still provide galvanic protection to the steel. In the same way, concrete structures reinforced with plain or bare steel showing signs of distress can be galvanically protected with external zinc anodes. Thermal sprayed metallic zinc on the exposed surface of the concrete can be electrically connected to the steel reinforcement and provide corrosion protection to the steel. The external zinc anode will corrode instead of the steel reinforcement, reducing formation of corrosion products which stress and degrade the concrete. Thermal sprayed zinc coatings were used as anodes in ICCP systems on the historic reinforced concrete Cape Creek Bridge, Yaquina Bay Bridge and Depoe Bay Bridge on US Route 101 in Oregon. The 20-plus-year performance confirms that the service life of reinforced concrete structures can be significantly and economically extended by using metallic zinc anodes to protect the plain steel reinforcement from further corrosion.

Key words: Thermal sprayed zinc, sacrificial anode, corrosion, rebar

INTRODUCTION

Corrosion of bare steel reinforcement (rebar) is the most significant cause of concrete degradation. The decrease in pH of a concrete structure with time due to carbonation increases the susceptibility of the rebar to corrosion. Atmospheric deposition of chlorides in marine environments can also play a role. Atmospheric deposition of chlorides is strongly influenced by distance from the sea coast, height above water level and prevailing wind direction. Annual precipitation is an indicator of corrosivity, due to increased time of wetness, but on marine coasts, can actually wash off salt deposits and reduce corrosivity. More importantly, a significant use of road de-icing salts during winter maintenance periods

has accelerated deterioration of reinforced concrete structures. The cause of accelerated deterioration of reinforced concrete structures when using road de-icing salts is the well known chloride induced corrosion of the plain (black) reinforcing steel, resulting in spalling of the concrete cover. The build-up of corrosion products on the reinforcing steel surface exert pressure on the concrete which lead to cracking and spalling of the concrete cover. Initial signs of rebar corrosion are red rust staining seeping out of cracks in the concrete. If left unchecked, the rebar corrosion continues, resulting in expensive repairs, decreased load carrying capacity and premature structure replacements.

Embedded steel may be protected against corrosion simply by making a connection between the steel and a metallic zinc anode. When two different metals are in electrical contact, and bridged by an electrolyte, current flows from the anodic or less noble (base) metal to the cathodic or more noble metal. In the case of iron (steel) and zinc, the base zinc anode will protect the more noble iron. This is the principle for sacrificial cathodic protection for reinforced concrete when zinc anodes are used.¹

Impressed current cathodic protection (ICCP) systems consist of anodes that are connected to a power source that provides a continuous current. A control system is needed to provide enough current for the ICCP system to protect the target structure. Cathodic protection transformer-rectifier units automatically adjust the operating voltage to maintain the optimum current output. For large complex target structures, such as bridges, the ICCP systems are often designed with multiple independent zones.²

The Oregon Department of Transportation (ODOT) selected thermal sprayed zinc coatings for use as anodes in ICCP systems on the historic Cape Creek Bridge (1932 construction), the Yaquina Bay Bridge (1936 construction) and the Depoe Bay Bridge (1927 construction).³ These three bridges are magnificent arch bridges on U.S. Route 101 designed in the Art Moderne style and listed in the National Register of Historic Places. The decision to repair these older bridges with a thermal sprayed zinc anode based ICCP system involved issues of public finance and safety but also historical significance. The sprayed zinc anodes complement the historic structures, all while protecting the rebar by reducing the rate of corrosion, regenerating an alkaline environment around the rebar, and moving chloride ions away from the rebar.

THERMAL SPRAYED ZINC ANODES

Thermal sprayed zinc anodes are well established as a component of ICCP systems for the corrosion protection of reinforced concrete structures.⁴ Two different techniques can be used to apply the thermal spray zinc coating to concrete, namely flame spraying or arc spraying.⁵ Flame spraying uses an acetylene-oxygen flame to melt a zinc wire that is continuously fed into this flame. A stream of gas, generally compressed air, then propels the molten metal droplets in the direction of the surface. The droplets impact and solidify on the surface to build up a coating to the desired thickness. In arc spraying, two zinc wires are brought together at an angle between 30 and 60°. An imposed voltage difference between them creates an electric arc, which melts the wires. A gas flow, of either compressed air or a special gas, then atomizes and propels the molten metal droplets toward the concrete. Zinc wire used for thermal spraying can be made from pure zinc or zinc alloys. Pure zinc wire is preferred for thermal spraying as an anode material for ICCP systems.⁴ A comparison of the melting rates between the flame spray and arc spray techniques shows an increase in deposition efficiency and coating rate with the arc spray process.⁶

The arc spray process was selected by ODOT for the Cape Creek Bridge, the Yaquina Bay Bridge and the Depoe Bay Bridge since it could be easily applied to the complex shapes found on the three bridges. Zinc anodes minimize the dead load added to the structure, and the gray color of zinc also looks very much like concrete, which was an important consideration for the rehabilitation of the historic bridges. Also, the low electrical resistivity of zinc allows uniform distribution of the cathodic protection current.⁷

The thermal sprayed zinc anode is produced by impacting semi-solid droplets of zinc on a roughened concrete surface. This produces a metallic zinc layer with micro-pores and oxide coatings on the individually solidified particles. Coating thickness is dependent on the time of spray, and the anodes were at least 500um (20mils) thick on the three bridges.⁸ Porosity typically makes up 5-7% of the coating volume. The overall coating has characteristics similar to solid metallic zinc.

ODOT practice for installation of zinc anodes includes initial abrasive blasting of the entire surface in the work area on the bridge, followed by any needed repair of the concrete and the installation of the anode terminal plates. Then the concrete surface receiving the zinc anodes is grit blasted before thermally spraying the zinc anodes onto the concrete surface.⁹

Degraded concrete must be evaluated before repair. The evaluation of aging concrete structures can include a visual inspection, delamination survey, concrete cover evaluation, half-cell potential mapping, and total chloride content determination.¹⁰ As long as corrosion of the steel reinforcement has not impaired the structural integrity of the bridge, the concrete can be repaired and rehabilitated before installation of the thermal sprayed zinc anodes. Delaminated concrete should be removed to below the top layer of reinforcing steel so that it can be enclosed within new concrete.

The ICCP zinc anode zones are each approximately 300m² to 500m² in size. Each zone has a connection to the reinforcing steel (cathode) and the thermal sprayed zinc (anode). The connections are placed near the center of the zone and spaced approximately 3m apart. For the cathode connection (Figure 1) an access hole is made through the concrete to the reinforcing steel, where a threaded brass bar is welded to the exposed steel. The access hole is refilled, and the ICCP negative wire is attached to the threaded bar. The reinforcing steel must be in electrically continuous contact through the structure to be protected.



1A



1B

Figure 1. Junction box showing installation steps for the connection to the cathode. 1A, Attachment of a threaded brass bar to the exposed reinforcing steel. 1B, Backfilled access hole with brass connection post standing proud. (Note negative wire at bottom of junction box still to be connected)

For redundancy, at least two 6.4cm diameter brass terminal plates are installed for each zinc anode zone. At this location the ICCP system positive wire terminates and the electric current is distributed to the zinc anode. The anode terminal plates (Figure 2) are secured in place with non-conductive resin