TECHBRIEF

Multiple Corrosion Protection Systems for Reinforced Concrete Bridge Components

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This is the interim report on a Federal Highway Administration (FHWA) project that is fully documented in a separate report under the same title (FHWA-HRT-07-043).

Introduction

Epoxy-coated reinforcement (ECR) is the principal concrete reinforcing material currently in use in the United States in corrosive environments. The purpose of this study is to evaluate methods for making ECR more corrosion resistant by using multiple corrosion protection strategies in bridge decks, as well as for bridge members in marine environments where abundant salt, moisture, and high temperatures are prevalent.

This research is being conducted using laboratory and field tests, the results of which will be used to compare the performance of the corrosion protection systems on the basis of chloride threshold, corrosion rate, life expectancy, and cost effectiveness. Fusion-bonded thermoset ECR currently is being evaluated in conjunction with inorganic and organic corrosion inhibitors, bars coated with zinc prior to the application of epoxy, and chemical pretreatments and epoxy formulations that increase the adhesion of the epoxy coating to the reinforcing steel.

Approach

This study involves the evaluation of 11 systems in which ECR is combined with another corrosion protection system. The research includes seven bar types, one uncoated and six with a fusion-bonded epoxy coating. Uncoated conventional reinforcing steel and conventional ECR serve as the controls. The multiple corrosion protection systems include:

- Conventional ECR used in conjunction with one of three corrosion inhibitors (calcium nitrite and two organic inhibitors).
- Bars treated with a primer coating containing microencapsulated calcium nitrite prior to coating with conventional epoxy.

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- Bars with improved adhesion between the epoxy and the reinforcing steel (obtained through the use of either a zinc chromate pretreatment or one of two special epoxies with higher adhesion).
- The combination of bars coated with an improved adhesion epoxy and the addition of calcium nitrite to the mortar or concrete used in the tests.
- Bars with multiple coatings, consisting of a 50-μm (2-mil) layer of 98 percent zinc and 2 percent aluminum that are, in turn, coated with a conventional epoxy.

Before corrosion testing, the researchers evaluated the bars used in this study for coating thickness and the number of holidays (microscopic holes through the coating). The bars were also evaluated for coating adhesion using the cathodic disbondment test. All bars met the requirements of ASTM A 775 for coating thickness, with the exception of the bars coated with the calcium nitrite primer. These bars tended to have larger percentages of coating measurements below 175 μm (7 mils) and 125 μm (5 mils) than the maximum allowable values of 10 and 5 percent, respectively. Only the bars coated with the calcium nitrite primer exhibited holidays, although the number of holidays was below the maximum allowable of three holidays per meter. In the cathodic disbondment test, the average coating disbondment radius was above 4 millimeters (mm) (0.16 inch) (the maximum allowed by ASTM A 775 when qualifying an epoxy) for the conventional ECR and one of the high-adhesion epoxy-coated bars. As observed in earlier studies, however, the performance of the bars in the cathodic disbondment tests was not proven to be a predictor of their performance in the corrosion tests in this study.

The performance of each system is compared to that of conventional ECR and uncoated mild steel reinforcement. This report presents the results of the laboratory tests, most of which are still ongoing. The final report will present the results from the field tests, along with an evaluation of the life expectancy and cost effectiveness of each system. The corrosion tests include rapid macrocell tests, bench-scale tests, and linear polarization resistance. In the tests, concretes with two different water-cement ratios are used to evaluate some systems. The epoxy coating was penetrated by 3-mm-(0.118-inch-) diameter holes to simulate damage that occurs during construction.

The basic test specimen in the rapid macrocell test consists of either a bare reinforcing bar or a bar clad in mortar (mortar-wrapped). The contact surface between the mortar and the bar simulates the contact obtained between concrete and reinforcing bars in structures through the use of realistic water-cement and sand-cement ratios. Bars representing the anode and the cathode are placed in separate containers. At the anode, the bars are surrounded by a simulated concrete pore solution containing a preselected concentration of sodium chloride, while the bars at the cathode are surrounded by the simulated concrete pore solution alone. The two containers are connected by a salt bridge (for ion transfer), and the test specimens are electrically connected across a single 10-ohm resistor. The voltage drop across the resistor is measured to determine the macrocell corrosion current, which is used to calculate the thickness loss of the metal. The specimens also are monitored for the open-circuit corrosion potential of the bars.

The bench-scale tests include the southern exposure and cracked beam tests. Both tests consist of small slabs of concrete containing two mats (top and bottom) of reinforcing steel that are electrically connected across a 10-ohm resistor. A simulated 0.3-mm (12-mil) crack is placed parallel to and above the top reinforcing bars using a stainless steel shim during fabrication of the cracked beam specimens. The concrete remains intact in the southern exposure test specimens. For both bench-scale tests, the slabs are subjected to a 7-day alternate ponding and drying regime, with ponding at 23 ± 2 °C (73 ± 3 °F) for 4 days and drying at 38 °C

(100 °F) for 3 days. Prior to drying, the solution is removed from the upper surface. The ponding and drying regime is continued for 12 weeks, and then the specimens are subjected to continuous ponding for 12 weeks at 23 ± 2 °C (73 ± 3 °F), after which the alternate ponding and drying regime begins again. The two regimes are continued for 96 weeks. The specimens are monitored for macrocell corrosion current and corrosion potential. Selected bench-scale specimens also are monitored for microcell corrosion current using the linear polarization resistance test.

The test results for the completed rapid macrocell tests and a minimum of 56 weeks for the bench-scale tests represent the initial findings of the study. More detailed information will be available as the study progresses. The results obtained to date, however, provide a useful comparison of the relative performance of the systems and of the overall performance of the ECR.

The corrosion losses on the damaged areas on ECR (all systems) have been, for the most part, higher but of a similar magnitude to the average corrosion losses exhibited by uncoated conventional reinforcing steel. The relatively higher losses on the damaged areas may result because the losses recorded for uncoated conventional steel represent values that are averaged over the full contact surface, all of which may not be corroding. Superior performance (over the 15-week test period) was observed for the mortar-wrapped macrocell specimens containing ECR. This bodes well for epoxy-coated bars in the field because the tests indicate that, due to the natural variation in chloride concentration within concrete, all damaged areas on ECR will not come in contact with high chloride contents at the same time. If uncoated steel were used in its place, however, a portion of the unprotected steel would be expected to undergo corrosion.

In terms of overall performance, the use of concrete with a lower water-cement ratio provides an advantage for both uncoated and coated reinforcement in uncracked concrete due to its role in delaying penetration of chlorides. The same advantage does not appear to be available in all cases for cracked concrete; in the current study, concrete with a lower water-cement ratio results in a lower corrosion rate for uncoated steel, but not for damaged ECR.

As has been observed in other studies, increasing the adhesion between the epoxy coating and the reinforcing steel does not appear to provide an advantage over conventional ECR.

In uncracked concrete, the use of corrosion inhibitors and the use of the primer coating containing calcium nitrite appears to provide added protection for damaged ECR; in general, the lower the water-cement ratio, the better the protection. Of the systems incorporating a corrosion inhibitor, the ECR with the primer coating appears to be the most sensitive to the water-cement ratio, performing better when used in concrete with a lower water-cement ratio. The advantages of corrosion inhibitors, however, are lost to varying degrees in cracked concrete, that is, in cases in which chlorides have direct access to the reinforcing steel.

The test results for the bars with multiple (zinc-epoxy) coatings indicate that, in cases in which either both layers are penetrated or just the epoxy is penetrated, the zinc coating provides some protection to the underlying steel. This protection, however, is obtained through the sacrificial loss of zinc. Key points, as yet unknown, but which will be determined prior to the conclusion of this study, are the corrosion threshold of the zinc coating relative to that of exposed steel, and the ability of the 50-μm (2-mil) coating to substantially delay corrosion loss of the underlying steel reinforcement.

Interim Conclusions

- In the short-term tests used in this study, the evaluated epoxy coatings provide superior corrosion protection to the reinforcing steel. The results also indicate that the bars will continue to perform well in the longer term, although the tests performed to date do not evaluate the effects of long-term reductions in the bond between the epoxy and the reinforcing steel.

- The corrosion rate on the exposed regions of damaged ECR is somewhat higher than the average corrosion rate on the surface of uncoated reinforcement subjected to similar exposure conditions.
- The use of concrete with a reduced water-cement ratio improves the corrosion performance of both conventional and epoxy-coated reinforcement in uncracked concrete but has little effect in cracked concrete.
- Increased adhesion between the epoxy coating and reinforcing steel provides no significant improvement in the corrosion resistance of ECR.
- The use of corrosion inhibitors in concrete improves the corrosion resistance of the epoxy-coated steel in uncracked concrete, but not in cracked concrete.
- The bars with the primer coating containing microencapsulated calcium nitrite exhibit improved corrosion performance in uncracked concrete, but not in cracked concrete.
- The zinc coating on the multiple coated bars acts as a sacrificial barrier and provides some corrosion protection to the underlying steel in both uncracked and cracked concrete. The degree of protection, however, cannot be evaluated based on the results available to date and must await the conclusion of the southern exposure and cracked beam tests when the reinforcing bars will be inspected for the presence and type of corrosion products.
- The superior performance of conventional ECR in the current study may be improved with the addition of a corrosion inhibitor to the concrete. This conclusion may be modified as additional data are obtained.

Researcher—This study is being performed by the University of Kansas Center for Research, Inc., 2385 Irving Hill Road, Lawrence, KS 66045-7563, 785–864–3441.

Distribution—This TechBrief is being distributed according to a standard distribution. Direct distribution is being made to the Divisions and Resource Center.

Availability—The publication from which this TechBrief was developed, *Multiple Corrosion Protection Systems for Reinforced Concrete Bridge Components* (FHWA-HRT-07-043), is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. A limited number of copies will be available from the Research and Technology Product Distribution Center, HRTS-03, FHWA, 9701 Philadelphia Court, Unit Q, Lanham, MD 20706, 301–577–0818 (phone), 301–577–1421 (fax).

Key Words—adhesion, chlorides, concrete, corrosion, corrosion inhibitor, durability, epoxy-coated reinforcement, epoxy-coated steel, zinc-coated steel

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