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Project Summary Report 4904-S
Project 0-4904: Feasibility of Hot Dipped (Zinc) Galvanizing
and Other Coatings for the Protection of Reinforcing Steel
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December 2002

PROJECT SUMMARY REPORT

# Feasibility of Hot Dipped (Zinc) Galvanizing and Other Coatings for the Protection of Reinforcing Steel: A Summary

Over the last few decades there has been considerable interest in developing and utilizing reinforcement materials for concrete that provide improved corrosion resistance over traditional black steel. When epoxy coated reinforcement (ECR) was introduced in the 1970s and 1980s, there was optimism that use of this material would result in a significant reduction in corrosion of steel in concrete. Shortly after ECR started to be used on a widespread basis, however, corrosion problems began to surface, particularly in the Florida Keys area. Many of the problems were associated with damage that could be introduced relatively easily during fabrication, transportation, exposure prior to placement, and placement. Some dismissed the Florida problems as isolated events due to the particularly corrosive environment, but others became quite concerned about ECR in general. In addition, the fact that ECR could suffer such serious damage meant there might be opportunities for other types of reinforcement materials in particularly aggressive environments.

From 1990 until 1997, exposure tests were conducted at The University of Texas at Austin (Project 0-1265) to determine the durability of ECR in concrete structures. The objectives were to identify conditions that were conducive to corrosion of ECR in terms of levels of damage, repair of the coating, and concrete cracking; to identify conditions that damage coating during fabrication and concrete placement; to assess patching materials and repair procedures; and to develop guidelines and recommendations for improved performance of ECR.

One type of test that was used in Project 0-1265 was a modified version of the macrocell test used in ASTM G 109 (Standard Test for Determining the Effects of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments). Although this test was initially used to evaluate different corrosion inhibitors, modified versions have been used to evaluate steels as well. Macrocell specimens generally incorporate steel in salt-contaminated concrete (which is contaminated by migration of chlorides as a result of salt water ponding) and steel in essentially salt-free concrete (steel which is at increased depths from the ponded solution). Project 0-1265 involved exposure tests of macrocell specimens and beam specimens.

In 1993, the Federal Highway Administration (FHWA) launched a 5-year research project to evaluate corrosion-resistant bars. The purpose of this research was to develop corrosion-resistant reinforcing bars that would result in a 75 to 100 year design life for concrete structures. The research involved testing more than 52 different organic, inorganic, ceramic, and metallic coatings on steel bars, as well as solid metallic bars. Bars tested included epoxy-coated, other polymer-coated, ceramic-coated, galvanized-clad, stainless steel-clad, nickel-clad, copper-clad, inorganic silicate-clad, solid corrosion-resistant alloy, solid aluminum-bronze, solid stainless steel, and solid titanium reinforcing. The materials were subjected to immersion tests in a number of solutions such as sodium chloride; potassium hydroxide plus sodium hydroxide; and potassium hydroxide, sodium hydroxide plus sodium chloride. The materials were also subjected to cathodic disbondment tests, coating adhesion following cathodic disbondment tests, hot water tests, polarization resistance (PR), electrochemical impedance spectroscopy (EIS) tests, and outdoor exposure tests. The PR tests can provide information about the corrosion rate of metallic reinforcement and the EIS tests are particularly suited for providing information about corrosion mechanisms. The above solutions were used because there is evidence that solutions like saturated calcium hydroxide and/or solutions of sodium hydroxide plus potassium hydroxide can be used to represent the concrete environment that the metallic reinforcement sees. There is not always a direct correlation, but the behavior of metallic materials in these solutions is often similar to that in actual concrete. In addition, the time is much shorter.

The intent of the present work was to utilize the results of Project 1265 (and the results of other work like the FHWA project) to better plan and execute work on a number of different materials. With this in mind, one of the objectives of the present investigation was to conduct tests on macrocell specimens with the aim of determining the corrosion inhibiting effects necessary to extend the service life of concrete structures.

A secondary objective was to investigate the bond performance of several of the different coatings and nontraditional metals in salt-contaminated concrete. If materials are to be used in concrete, this information is essential, since many of the coatings and nontraditional materials may provide excellent corrosion resistance, but poor bond to concrete.

A third objective was to obtain information about research in other states and use of some of these alternative materials from other states.

## What We Did...

### Experimental Procedure

At the outset of this investigation, manufacturers were invited to submit materials for study, and several materials were chosen. Among them were bars with newer formulations of epoxy (bars with bendable epoxy coatings and nonbendable epoxy coatings), bars made with other organic coatings such as nylon and polyvinyl chloride (PVC), bars made with galvanized steel (coated before or after bending), bars made with stainless steel-clad steel and bars made with 304 stainless steel.

The modified version of ASTM G109 that was used in Project 0-1265 was the major focus of the testing. Candidate materials were cast in concrete having dimensions approximately 254 mm in length, 229 mm in depth, and 203 mm in height. Other than cleaning with a wire brush and degreasing in methanol, the rebars were used in the "as-received" condition. No attempt was made to induce damage. Coated materials had few defects. Current was obtained using Ohm's law and average current values were plotted as a function of time for each type of material. Values of current greater than 10 microamps typically indicate corrosion activity.

A dike was placed above the macrocells to contain the 3.5% sodium chloride solution that was ponded onto the macrocells on a cyclical basis: two weeks of exposure, followed by two weeks dry. A typical macrocell specimen configuration is shown in Figure 1. The two straight bars were connected together to act as one, and the top bent bar and bottom straight bars were connected using a 100 ohm resistor. Some of the concrete specimens contained the corrosion resistant steel in both the top mat and the bottom mat, while the majority of the concrete specimens contained the corrosion resistant steel in the top mat and black steel in the bottom mat. The latter is considered to be the worst case from a corrosion point of view. Additional specimens were cast with only a bent corrosion resistant bar at the top or only straight black bars at the bottom. This allowed flexibility so that, if desired, different alternative materials could be connected together. The schedule of macrocell specimens is shown in Table 1. In all, 176 specimens were cast.

Several sets of companion tests included immersion in salt-free and salt-contaminated saturated calcium hydroxide as well as polarization resistance testing of 0.5 in. (13 mm) diameter black steel, galvanized steel, and stainless steel in those solutions as well. For these tests, bent bars of the same types used for the macrocells were used. The bars were masked off with heat-shrink tape so that approximately 6 in. (152 mm) could be exposed to the solution. The bars were initially placed in salt-free saturated calcium hydroxide and polarization resistance tests were conducted daily over a six-day period during which sodium chloride was added at 48 and 96 hours. The equivalent of the threshold amount of sodium chloride (0.011 moles/liter) was added after 48 hours and the equivalent of 3.5% (or 0.513 moles/liter) was added after 96 hours of immersion. (Figure 3.3 in Reference 2).

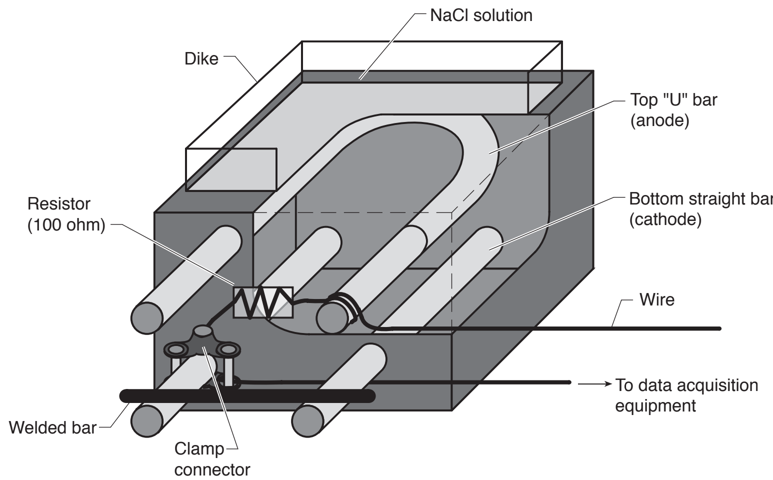


*Figure 1: Typical Project 0-1265 macrocell Specimen*

Pullout testing was the method selected to evaluate the bond performances of different coatings. Such tests can be used to determine the bond strength of bars in conditions in which premature splitting of the surrounding concrete is not critical. The pullout specimen design was based on calculations for the embedment length of the test bar. To minimize the artificial increase of the pullout strength due to increases in the confining forces on the bar at the loaded end, the bars were debonded from the compression reaction surface. Spiral #3 deformed bars surrounded the test bar for additional transverse confinement and crack control. The overall dimensions of the pullout specimen were 10 in. long by 10 in. wide by 10 in. high (Figure 4.4 in Reference 1).

To gain information about research and the use of alternative materials in other states, State Departments of Transportation were asked about any research projects and/or experiences with alternative reinforcement materials. The District of Columbia and 12 states responded.

## What We Found...

The macrocells have now been exposed to sodium chloride ponding for almost four years. It was anticipated that by this time the current versus time plots for most of the materials would be showing significant increases. In Project 0-1265, black steel started showing increases within one year while increases for specimens made with damaged epoxy coated bars followed several months later. In the previous case, the water:cement ratio of the concrete was 0.57. However, the concrete mix in the present investigation had a water:cement ratio closer to 0.40 and a water:cementitious material ratio of about 0.32. This is an exceptionally good quality concrete and not unlike one that would be used with corrosion resistant materials. Because of this, the average current values for all of the types of bars are less than 10 microamps. In fact, the current values for most of the macrocells, other than those containing the #6 black rebar (Control B, Black Steel) and the Galvanized B rebar, are less than 2 microamps.

After 30 months of exposure, the macrocell with the highest current for each material was selected and autopsied. Only the #6 black rebar (Control B, Black Steel) showed any evidence of corrosion, and this was a region on one side of the bar, away from the bend and near the concrete/steel/air interface. Bars from opened macrocells showed the other reinforcement materials to be in very good condition.

Average corrosion rates determined from the polarization resistance tests after exposure to the saturated calcium hydroxide and the equivalent of 3.5% sodium chloride indicated that SS304 performed the best, Black steel the worst, and the galvanized steels were intermediate. While the actual values of the corrosion rates may involve some error due to the inhomogeneities associated with the exposed area, the stress associated with the bend areas, and the error in determining the surface area of the ribbed surface, the relative rankings are not unexpected.

Pullout tests were successfully completed for the PVC and epoxy coatings. No significant differences were observed in the bond strength for the PVC and epoxy coatings. There was a reduction in bond strength (when compared to uncoated bars) for both types of bars.

Other states are beginning to investigate and use alternative materials other than ECR. Alaska, Delaware, Illinois, Kansas, Louisiana, Michigan, North Dakota, Oregon, Pennsylvania, South Dakota and Washington indicated that they have used or are considering using one or more alternative materials. The most common alternative materials being considered are galvanized steel, stainless steel, stainless steel-clad steel and MMFX (a dual-phase steel). As more information is gained from actual experiences, field performance will be extremely valuable in helping to develop test procedures that will be able to predict field behavior within a relatively short period of time.

## The Researchers Recommend...

As alternative materials are proposed and/or used for concrete reinforcement, it is desirable to have a test methodology that can be used to investigate their potential behavior in salt-contaminated concrete. In order to have results in a timely manner, it is usually necessary to damage the material, crack the concrete, or study the material in a simulated concrete solution or a lower quality concrete than would be used in the particular construction application. If the concrete quality is too low, however, there is often little relationship between the laboratory behavior (in which low quality concrete is used) and field behavior (in which much better quality concrete is used). Tests can also be performed in simulated concrete solutions, but there is always the concern that the long-term behavior in concrete will not be similar to the short-term behavior in the solution.

There is also concern that one type of test may not be appropriate for all materials. Because of differences in corrosion mechanisms, test methods that work well to identify corrosion initiation and corrosion behavior for one type of material may not be as appropriate for other types of reinforcement, particularly as the list of candidate materials increases. Therefore, the goal is to develop a number of different types of tests in which at least one of the types involves the presence of cracks and/or damaged bars.

### Conclusions

Based on the results to date, all of the materials are continuing to perform well and show very little evidence of corrosion in actual concrete (concrete of extremely high quality). This reinforces the notion that good quality concrete can serve as the first defense against corrosion.

The investigation is ongoing and efforts are being made to develop a number of tests that can provide corrosion information in a more timely manner. Future test procedures will involve concrete containing cracks and reinforcement that contains some reasonable amount of damage.

TxDOT will take over monitoring about half of the remaining specimens, while the investigators will continue to monitor the others.


**REFERENCES**

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2. P.G. Deshpande, "Corrosion Performance of Polymer Coated, Metal Clad and Other Rebars as Reinforcements in Concrete," M.S. Thesis, University of Texas at Austin, May 2000.
3. C. Jung, "Investigation of Corrosion Performance of Coated, Metal Clad, and Other Types of Rebar," M.S. Thesis, University of Texas at Austin, May 2002.
4. Report 4904-1 Corrosion Performance of Polymer-Coated, Metal-Clad and Other Rebars as Reinforcement in Concrete: Literature Review December 2002.
5. Report 4904-2 Corrosion Performance of Polymer-Coated, Metal-Clad and Other Rebars as Reinforcement in Concrete, October 2002.
6. Report 4904-3 Feasibility of Various Coatings for the Protection of Reinforcing Steel-Corrosion and Bond Testing


*Table 1: Schedule of Macrocell Test Specimens*

| Bar Type | Bar Size | Top: Resistant Steel Bottom: Black Steel | Top: Resistant Steel Bottom: Resistant Steel | Top: Resistant Steel Bottom: No Steel | Top: No Steel Bottom: Black Steel |
|---|---|---|---|---|---|
| Control A (Black Steel) | 4 | 4* | 0 | 2** | 2 |
| Galvanized A | 4 | 8 | 4 | 4 | 0 |
| Galvanized B | 4 | 8 | 4 | 4 | 0 |
| Epoxy A | 4 | 8 | 4 | 4 | 0 |
| Epoxy B | 4 | 8 | 4 | 4 | 0 |
| Nonbendable Epoxy | 4 | 8 | 4 | 4 | 0 |
| Nylon | 4 | 8 | 4 | 4 | 0 |
| PVC | 4 | 8 | 4 | 4 | 0 |
| 304 Stainless Steel | 4 | 8 | 4 | 4 | 0 |
| Control B (Black Steel) | 6 | 4* | 0 | 2** | 2 |
| Epoxy A | 6 | 8 | 4 | 4 | 0 |
| 304 Stainless Steel Clad | 6 | 8 | 4 | 4 | 0 |

* Black Steel on top and bottom **Black Steel on top

## For More Details...

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The research is documented in the following reports:

Report 4904-1, *Corrosion Performance of Polymer-Coated, Metal-Clad, and Other Rebars as Reinforcements in Concrete: Literature Review,* October 2002
Report 4904-2, *Macrocell Specimens for Continued Monitoring by TxDOT,* May 2000
Report 4904-3, *Feasibility of Various Coatings for the Protection of Reinforcing Steel--Corrosion and Bond Testing,* May 2000

To obtain copies of a report: CTR Library, Center for Transportation Research, (512) 232-3138, email: ctrlib@uts.cc.utexas.edu

## TxDOT Implementation Status
## December 2003

The results from this project were inconclusive regarding the corrosion performance of various alternate reinforcing materials for reinforcement concrete, because of the length of time required to initiate corrosion under standard laboratory testing methods. The conclusions indicate the desirability of an improved testing protocol for evaluating the corrosion performance of metallic elements embedded in concrete. Towards this end, TxDOT has sponsored research project 0-4825, "Corrosion Performance Tests for Reinforcing Steel in Concrete," which began on September 1, 2003, and is scheduled for completion August 31, 2006. The objective of this new research project is to develop a suite of tests useful for the timely evaluation of corrosion performance of metallic materials embedded in concrete.

## Your Involvement Is Welcome!

## Disclaimer



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