

Abridgment

Laboratory and Field Corrosion Test Methods for Highway Metals Exposed to Inhibited Rock Salt

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Corrosion-inhibited rock salt as an alternative deicing material has been extensively researched through laboratory and field tests of exposed structural steels, aluminum, and galvanized steel. Because ASTM corrosion test methods G4, G31, and B117 do not address this area of corrosion, a series of specifically designed corrosion tests in the laboratory and at bridge and highway sites was undertaken. Realistically sized metal coupons were used in tests undertaken to explore the role of chloride ion concentration in the deicing solution, the ratio of wet/dry time, and the difference between immersion tests and spray tests to achieve wetting with solutions of inhibited and normal rock salt. Test results indicate that a particular inhibited rock salt can cause reductions in weight loss from 25 to 98 percent, with average corrosion reductions of 55 to 70 percent in the laboratory tests. Results from field tests on the Dan Ryan Expressway and the Chicago Skyway during the 1990–1991 winter suggest a similar corrosion reduction of about 65 percent based on the wire resistance change per weight of chloride collected at six highway and bridge sites. Results of the test series during a 2-year period point toward realistic accelerated corrosion test methods to ensure that alternative deicing materials that show good laboratory performance also provide good performance on highways and bridges.

The deterioration of bridge systems and other metal structures along highways has prompted investigations of alternative deicing chemicals to provide reduced corrosion of embedded reinforcing bars in concrete or exposed metals on highway structures. Evaluation of alternative deicing chemicals involves laboratory testing, for both product development and evaluation by potential customers. The purpose of laboratory tests is to evaluate and select materials performing effectively under actual field conditions. Laboratory tests are necessary to avoid the high costs, in terms of both dollars and time, of large-scale field tests made under relatively uncontrolled conditions.

A cyclical wetting and drying procedure for accelerated laboratory testing of deicing chemicals on reinforced concrete specimens, as reported in FHWA and NCHRP studies (*I-10*), is becoming well established. Similar procedures for evaluation of exposed metals are not as well defined in terms of

the relationship between laboratory results and actual field performance. Akzo Salt, in cooperation with Wiss, Janney, Elstner Associates, Inc. (WJE), initiated a program for evaluation of corrosion of bare metal specimens exposed to deicing chemicals by laboratory procedure that could be directly related to relative field performance.

Test practices and methods for studying the corrosion of exposed metal specimens are published by ASTM and the National Association of Corrosion Engineers. Chief among these are ASTM G4, corrosion coupon testing; ASTM G31, laboratory immersion corrosion testing; and ASTM B117, salt spray test. Many investigators have used these ASTM procedures, or variations of them, to compare the corrosion performance of deicing chemicals. Although they provide relative performance in the laboratory, these procedures do not reproduce parameters that may be critical to corrosion reactions in the field. As a result, and as noted in ASTM G31, laboratory evaluation may provide misleading results or results that cannot be used to predict actual field performance.

This Akzo/WJE investigation examined, with the use of realistically sized metal coupons, the role of the ratio of wet/dry time, salt concentration, and cycle length with respect to laboratory corrosion performance relative to actual field performance. In addition, the use of the resistance wire method of measuring field corrosion as a replacement for costly steel coupon mass loss methods was evaluated. The resistance wire method provides the advantage of nondestructive measurement, allowing cumulative data to be obtained from a single specimen over long periods of time at considerably reduced cost.

The referenced ASTM laboratory tests generally use thin steel coupons having small volume/surface (*v/s*) ratios. As noted in ASTM B117, G4, and G31, the specifics of the corrosion test conditions cannot be standardized because accelerated corrosion testing has so many variables. It is also stated in ASTM G31, "In designing any corrosion test, consideration must be given to the various factors discussed in this practice, because these factors have been found to affect greatly the results obtained." In this Akzo/WJE investigation, the geometry of the test coupon was selected to more closely represent the *v/s* ratio found in structural members. Typical wide flange beams and plates have *v/s* ratios from 2 to 40 times greater than the thin specimens commonly used in ASTM

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corrosion testing, but only 1 to 5 times that of the selected $\frac{1}{2} \times \frac{5}{8} \times 4$ -in. specimen. Thus, the selected test specimen is more reasonable when compared with structural shapes.

Field exposure can be divided into three periods: wet time, drying time, and dry time. The authors hypothesized that the relative lengths of wet time and drying time provide the controlling influence on total corrosion of the specimen. That is, corrosion takes place when a corrosive solution is present, and little corrosion occurs during the dry period. Accelerated testing could be better achieved by defining the proper ratio of wet and drying times to dry time to represent actual field conditions and accelerating the test by shortening or eliminating the dry period. Data generated from these tests and tests currently under way indicate that this may be correct.

The accelerated laboratory tests and field tests are discussed here. The actual data and a more detailed discussion are presented in a supplemental document available from Akzo Salt Inc.

1989 TEST SERIES ON A36, A572, AND A588 STEEL, GALVANIZED 36 STEEL, AND 6061-T6 ALUMINUM

Two different corrosion inhibition materials (Numbers 1 and 2) were used in a 15 percent NaCl solution. The uninhibited NaCl solution strength was also 15 percent. Two 30-day accelerated corrosion test procedures were used. One test method addressed the cyclical wet and dry environment; the second addressed the partial immersion environment. The mean percent improvement in weight loss for the A36, A588, and A572 steels for Solutions 1 and 2 for the wet/dry test method ranged from 40 to 54 percent.

1990 TEST SERIES ON A36 STEEL WITH 11 DIFFERENT DEICER FORMULATIONS

This test series used the same wet/dry test cycle. Eleven different deicing solutions were evaluated. All solutions used 15 percent NaCl. Ten solutions contained corrosion inhibitors; one was uninhibited.

Test results showed that the 10 formulations increased the effectiveness of the inhibitors tested in 1989 from the 40 to 54 percent range to the 81 to 94 percent range.

1990 TEST SERIES ON ASTM STEEL AND ASTM A615 GRADE 60 REINFORCING BAR STEEL

The objective of this series was twofold: to determine (a) if 15 percent salt solutions containing the inhibitors would be equally effective on A36 prisms and A615 reinforcing steel and (b) if immersion of the specimens in alkaline salt solutions similar to the pH found in concrete would have a passivating effect. A review of the data indicates the following:

- The specimens in 11 different inhibited salt solutions (normal pH of 7) showed a decrease in percent metal loss over those specimens exposed to plain salt solutions. The magni-

tude of improvement ranged from 36 to 94 percent for A36 steel and from 86 to 98 percent for A615 rebar.

- The use of $\text{Ca}(\text{OH})_2$ in the salt water solutions (pH = 12) produced a remarkable 98 percent reduction in the metal loss during the laboratory test series with both steels. This decrease in the metal loss was due solely to pH change.

1990 TEST SERIES ON ASTM A36 STEEL WITH VARIOUS SOLUTION STRENGTHS AND VARIOUS SALT SPRAY/DRY TEST PERIODS

A new 30-day accelerated corrosion procedure and apparatus were developed. Previously, the laboratory test specimens were totally immersed for 60 min during each 6-hr cycle. This total immersion did not allow high oxygen availability during the wet period. The new method used a salt spray instead of total immersion. The salt spray times and number of spray cycles per day were also varied.

Four different deicer solutions were evaluated with six series. The inhibited and uninhibited solutions used NaCl concentrations of 3 and 15 percent. In Series 4–6, one 15-min fresh water rinse each day was used to simulate one short period of daily precipitation.

These data indicate that the inhibitor is effective at both concentrations when the steel surfaces are sprayed for 50 to 80 percent of the test period, with improvement in weight loss ranging from 46 to 90 percent and averaging 70 percent. When sprayed for 25 percent of the total cycle period, the improvement in weight loss ranged from 25 to 84 percent and averaged 54 percent. These data suggest that the average improvement in a typical bridge environment subjected to an inhibited salt spray concentration between 3 and 15 percent could be between 55 and 70 percent.

These test results suggest that as the concentration strength decreased from 15 percent to 3 percent the corrosion-induced weight loss increased from 1.3 to 2.6 times, averaging 1.95 times. This suggests that as highway agencies use less salt or dilute the salt with other materials, the concentration strength of the solutions splashed onto these bridges is probably decreasing, which in turn allows for much greater corrosion-induced weight loss.

FIELD TESTS IN CHICAGO DURING WINTER 1990–1991

The concentration of salt solutions applied on bridge structures and pavements remains largely unknown. Thus, laboratory corrosion experiments may not be representative of actual highway conditions. For this reason, a field study of A36 steel coupons under both inhibited and normal salt environments was initiated. The tests continued through the winter of 1991–1992.

Seven sites were chosen by WJE and the cooperating agencies. As a control measure, three sites (1–3) exposed to normal deicing salts were chosen along I-94 on the Dan Ryan Expressway. Three other sites were deiced with the corrosion inhibiting salt. These sites (4–6) were on the Chicago Skyway. Great care was taken to ensure that the six sites appeared to be similar, although traffic volumes are not equal. The I-

94 sites certainly have much greater traffic volume. All six highway and bridge sites are within a 10 mi radius. A seventh site, on the roof of a WJE building, was chosen to allow an investigation of steel coupons not exposed to deicing salts.

At the end of each month during the 3 months of exposure, a single coupon was collected and tested from each of the six highway sites, and three coupons were collected from the WJE building roof. A prototype test method for determination of corrosion rates in the field was also developed by WJE. Six wire specimens were mounted at each of the seven sites and their electrical resistance measured using a fine-scale ohm meter.

To quantify the salt exposure at each site, a salt spray and water collector was mounted near the steel coupons. The salt solutions were collected at each site at the end of each month and analyzed. The weight losses after three months of winter weather for the atmospherically corroding specimens were 30 to 37 percent of the two other exposures where deicer salts were applied. The relationship between theoretical coupon weight loss and theoretical wire resistance shows a good correlation between theory and field measurements. The amount of wire resistance change per gram of collected inhibited salt in the collectors is 31 percent of that of the normal salt after the 3-month period.

Chloride-induced corrosion, defined as the weight loss at each exposure that is over and above that caused by normal atmospheric corrosion, was calculated by subtracting the average weight loss at Site 7 (WJE) from the average from the other exposures. The average chlorine-induced weight loss per gram of collected inhibited salt is 35 percent of that for the normal salt after the 3-month period. This conclusion is based on the reasonable assumption that the amount of weight loss due to chloride ions is proportional to the quantity of chloride exposure at the site.

CONCLUSION

Extensive laboratory and field tests on exposed steels, aluminum and galvanized steel were undertaken during a 2-year period. These tests were directed toward establishing realistic, accelerated test methods to ensure that alternative deicing materials that provide good corrosion reduction in laboratory tests also exhibit these properties on highway and bridge systems.

Certain corrosion-inhibited rock salt materials achieved reductions in weight loss in laboratory and field tests that averaged about 55 to 70 percent, with some laboratory tests achieving as much as 98 percent weight loss reductions when compared with normal rock salt.

Tests are continuing, and future tests will focus on the role of oxygen and variable chloride concentrations during wet and drying times, as well as the role of the dry time in the corrosion process. Future tests will use automatic data-logging of corrosion activity under bridge site and laboratory conditions to better understand this complex process.

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REFERENCES

1. K. C. Clear. *Time-to-Corrosion of Reinforcing Steel in Concrete Slabs: Vol. 1, Effect of Mix Design and Construction Parameters*. Interim Report FHWA-RD-73/52. FHWA, U.S. Department of Transportation, 1976.
2. K. C. Clear. *Time-to-Corrosion of Reinforcing Steel in Concrete Slabs: Vol. 3, Performance After 830 Daily Salt Applications*. Report FHWA-RD-76/70. FHWA, U.S. Department of Transportation, 1976.
3. K. C. Clear. *Time-to-Corrosion of Reinforcing Steel in Concrete Slabs: Vol. 4, Galvanized Reinforcing Steel*. Report FHWA-RD-82/028. FHWA, U.S. Department of Transportation, 1981.
4. D. W. Pfeifer and M. J. Scali. *NCHRP Report 244: Concrete Sealers for Protection of Bridge Structures*. TRB, National Research Council, Washington, D.C., Dec. 1981.
5. Y. P. Virmani, K. C. Clear, and T. J. Pasko. *Time-to Corrosion of Reinforcing Steel in Concrete Slabs: Vol. 5, Calcium Nitrite Admixture or Epoxy-Coated Reinforcing Bars as Corrosion Protection Systems*. Report FHWA-RD-83/012. FHWA, U.S. Department of Transportation, Sept. 1983.
6. D. W. Pfeifer, J. R. Landgren, and W. F. Perenchio. Concrete, Chlorides, Cover and Corrosion. *Journal of Prestressed Concrete Institute*, Vol. 31, No. 4, July–Aug. 1986.
7. *DCI Performance in Cracked Concrete*. Technical Bulletin TB DCI-87-02. W. R. Grace and Co., Cambridge, Mass., 1987.
8. D. W. Pfeifer, J. R. Landgren, and A. B. Zoob. *Protective Systems for New Prestressed and Substructure Concrete*. Final Report FHWA/RD-86/193. FHWA, U.S. Department of Transportation, April 1987.
9. B. B. Hope, and A. K. C. Ip. Chloride Corrosion Threshold in Concrete. *American Concrete Institute Materials Journal*, July/Aug. 1987.
10. W. F. Perenchio, J. Fraczek, and D. W. Pfeifer. *NCHRP Report 313: Corrosion Protection of Prestressing Systems in Concrete Bridges*, TRB, National Research Council, Washington, D.C., Feb. 1989.