Designation: G109 – 07 (Reapproved 2013)

Standard Test Method for
Determining Effects of Chemical Admixtures on Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments[1]

This standard is issued under the fixed designation G109; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a procedure for determining the effects of chemical admixtures on the corrosion of metals in concrete. This test method can be used to evaluate materials intended to inhibit chloride-induced corrosion of steel in concrete. It can also be used to evaluate the corrosivity of admixtures in a chloride environment.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A615/A615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
C33 Specification for Concrete Aggregates
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C150 Specification for Portland Cement
C173/C173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory
C231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C511 Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes
C876 Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete
C881/C881M Specification for Epoxy-Resin-Base Bonding Systems for Concrete
C1152/C1152M Test Method for Acid-Soluble Chloride in Mortar and Concrete
D448 Classification for Sizes of Aggregate for Road and Bridge Construction
D632 Specification for Sodium Chloride
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
G3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing
G15 Terminology Relating to Corrosion and Corrosion Testing (Withdrawn 2010)[3]
G33 Practice for Recording Data from Atmospheric Corrosion Tests of Metallic-Coated Steel Specimens
G46 Guide for Examination and Evaluation of Pitting Corrosion

2.2 *NACE Standards:*[4]

SSPC-SP 5/NACE No. 1 White Metal Blast Cleaning

3. Significance and Use

3.1 This test method provides a reliable means for predicting the inhibiting or corrosive properties of admixtures to be used in concrete.

3.2 This test method is useful for development studies of corrosion inhibitors to be used in concrete.

3.3 This test method has been used elsewhere with good agreement between corrosion as measured by this test method

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[1] This test method is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.14 on Corrosion of Metals in Construction Materials.

Current edition approved May 1, 2013. Published July 2013. Originally approved in 1992. Last previous edition approved in 2007 as G109–07. DOI: 10.1520/G0109-07R13.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from The Society for Protective Coatings (SSPC), 40 24th St., 6th Floor, Pittsburgh, PA 15222-4656.

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and corrosion damage on the embedded steel (1-4).[5] This test method might not properly rank the performance of different corrosion inhibitors, especially at concrete covers over the steel less than 40 mm (1.5 in.) or water-to-cement ratios above 0.45. The concrete mixture proportions and cover over the steel are chosen to accelerate chloride ingress. Some inhibitors might have an effect on this process, which could lead to results that would differ from what would be expected in actual use (5).

4. Apparatus

4.1 The apparatus required for the evaluation of corrosion inhibitors includes a high impedance voltmeter (at least one Mohm) capable of measuring to 0.01 mV, a 100 Ω (±5 %) resistor.

5. Reagents and Materials

5.1 *Cement,* that conforms to Type I or Type II of Specification C150. Coarse aggregate shall conform to Specification C33 and Classification D448, with nominal maximum size between 9.5 and 19 mm (⅜ and ¾ in.).

NOTE 1—Preferred maximum size aggregate is 12.5 mm (0.5 in.).

5.2 *Steel Reinforcement Bars,* deformed, meeting the requirement of Specification A615/A615M; with a diameter between 10 mm (0.4 in.) and 16 mm (0.6 in.), and a length of 360 mm (14 in.), drilled and tapped at one end to be fitted with coarse-thread stainless steel and nuts, as described in 5.3 and 5.4. These bars shall be used to manufacture the test specimens, as described in Section 6.

NOTE 2—Interlaboratory test program and statistical data in Section 11 are based upon 13-mm (0.5-in.) steel bars, 12.5-mm maximum size aggregate, and 19-mm (0.75-in.) and 25-mm (1 in.) cover.

5.3 *316 Stainless Steel Screws,* with diameter smaller than bar diameter (coarse thread < 5 mm (0.2 in.)), 25 to 35-mm (1 to 1.5-in.) long (one per bar).

5.4 *316 Stainless Steel Nuts,* two per bar to fit stainless steel screws, as described in 5.3.

5.5 *Two-part Waterproof Epoxy*[6,7]—This epoxy shall meet the chemical resistance requirements of a Type IV, Grade 3, Class E of Specification C881/C881M.

5.6 *Sulfuric Acid,* 10 % by mass, for pickling (optional).

5.7 *Electroplater's Tape.*[7,8]

5.8 *Neoprene Tubing,* with 3-mm (⅛-in.) wall thickness and the same ID as the diameter of the bar used.

5.9 *Sodium Chloride,* complying with Specification D632.

5.10 *Salt Solution,* prepared by dissolving 3 parts of sodium chloride (as described in 5.9) in 97 parts of water mass.

5.11 *Epoxy Sealer,* for application to the concrete specimens after manufacture. This sealer shall be of Type III, Grade 1, Class C in accordance with Specification C881/C881M.[7,9]

5.12 *Plastic Dams,* 75-mm (3-in.) wide and 150-mm (6-in.) long with a minimum height of 75 mm (3 in.) for placement on the test specimens. The wall thickness shall be ±1 mm (⅛ ± ¹⁄₃₂ in.).

5.13 *Silicone Caulk,* for sealing the outside of the plastic dam to the top of the concrete specimen.[7,10]

5.14 *Reference Electrode,* such as a saturated calomel or silver/silver chloride electrode for measuring the corrosion potential of the bars, as defined in Terminology G15.

5.15 *Hexane.*

6. Preparation of Test Specimens

6.1 Power wire brush or sand blast the bars to near white metal (see SSPC-SP 5/NACE No. 1), clean by soaking in hexane, and allow to air dry.

NOTE 3—Pickling the bars with 10 % sulfuric acid for 10 to 15 min and rinsing with potable water prior to wire brushing is recommended when the bars have an excessive amount of rust.

6.2 Use the same method to clean all bars in the test program.

6.3 Drill and tap one end of each bar, attach a stainless steel screw and two nuts, as described in 5.3 and 5.4, and tape each end of the bar with electroplater's tape so that a 200-mm (8-in.) portion in the middle of the bar is bare. Place a 90-mm (3.5 in.) length of neoprene tubing, as described in 5.8, over the electroplater's tape at each end of the bar, and fill the length of tubing protruding from the bar ends with the two-part epoxy, as described in 5.5.

6.4 Specimen size is 280 × 150 × 115 mm (11 × 6 × 4.5 in.). Place two bars, as described in 5.2, 25 mm (1 in.) from the bottom, and one bar at the top such that the distance from its top to the top surface of the specimen is twice the maximum aggregate size, as shown in Fig. 1.

NOTE 4—For example, for a 12.5-mm (0.5 in.) aggregate, place the top bar 25 mm (1 in.) from the surface. For a 9.5-mm (0.375-in.) aggregate, place the bar 19 mm (0.75 in.) from the top surface.

6.5 Place the bars in the molds so that 40 mm (approximately 1.5 in.) of the bars are protected within each exit end from the concrete (minimizes edge effects). This will expose 200 mm (8 in.) of steel. Place the bars with the longitudinal ribs so that they are nearer the side of the beam, that is, both ridges are equidistant from the top or bottom of the specimen.

6.6 Make the concrete specimens (controls and those with admixtures to be tested) in accordance with Practice C192/C192M, using the same source of materials. Determine the air content, using either Test Method C231 or C173/C173M. The water-to-cement ratio (w/c) shall not exceed 0.5. The minimum

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[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[6] The sole source of supply of the apparatus known to the committee at this time is PC-Epoxy, made by Protective Coating Co., Allentown, PA.

[7] If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[8] The sole source of supply of the apparatus known to the committee at this time is Minnesota Mining and Manufacturing Company (3M), 1999 Mt. Read Boulevard, Rochester, NY 14615.

[9] The sole source of supply of the apparatus known to the committee at this time is Epoxy Concrete Scaler # 12560, made by Devcon.

[10] The sole source of supply of the apparatus known to the committee at this time is 3M Marine Adhesive 5200.
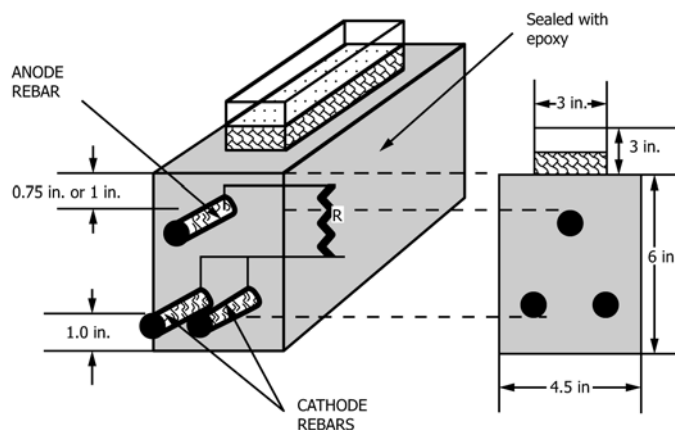
NOTE 1—All measurements in inches (25.4 mm = 1 in.).
FIG. 1 Concrete Beam

NOTE 1—All measurements in inches (not to scale) (25.4 mm = 1 in.).
FIG. 2 Concrete Beam (Side View)

slump is 50 mm (2 in.) (See Test Method C143/C143M). Place and consolidate the concrete in the molds containing the bars in accordance with Practice C192/C192M.

NOTE 5—The concrete parameters used in the interlaboratory test were as follows: cement content of 355 ± 3 kg/m³ (600 ± 5 lb/yd³), 0.50 ± 0.01 w/c (ssd aggregates), and 6 ± 1 % air.

6.7 Add the admixture to be tested at the manufacturer's recommended dosages. A water reducer is allowed, if needed, to achieve the desired slump. Record the admixtures used. Except for the test admixtures, use the same admixtures in all mixtures.

6.8 A minimum of three replicates shall be made. Make the same number of replicates per admixture tested and control (see Note 6). An addition cylinder 100×200 mm (4×8 in.) in diameter shall be produced for background chloride analysis.

NOTE 6—A larger number of replicates is preferred.

6.9 Apply a wood float finish after consolidation. After removal from the forms, cure the specimens for 28 days in a moist room in accordance with Test Method C192/C192M and Specification C511.

6.10 Upon removal from the moist room, hand wire brush the specimens on the concrete top surface (wood floated surface). Allow the specimens to dry for two weeks in a 50 % relative humidity (RH) environment before sealing the four vertical sides with an epoxy sealer, as described in 5.11, in accordance with the manufacturer's recommendation. Place a plastic dam with dimensions, as described in 5.12, on the specimen, as shown in Fig. 1, and about 13 mm (0.5 in.) from each side so that it does not extend over the taped sections of the bars (see Fig. 2). Use a silicone caulk to seal the dam from the outside, and apply epoxy sealer to the top surface outside of the dam.

NOTE 7—Allowing the specimens to dry before applying the concrete epoxy will make the initial exposure to chloride more severe, and more closely follow the interlaboratory test program conditions.

6.11 Attach wires and resistors.
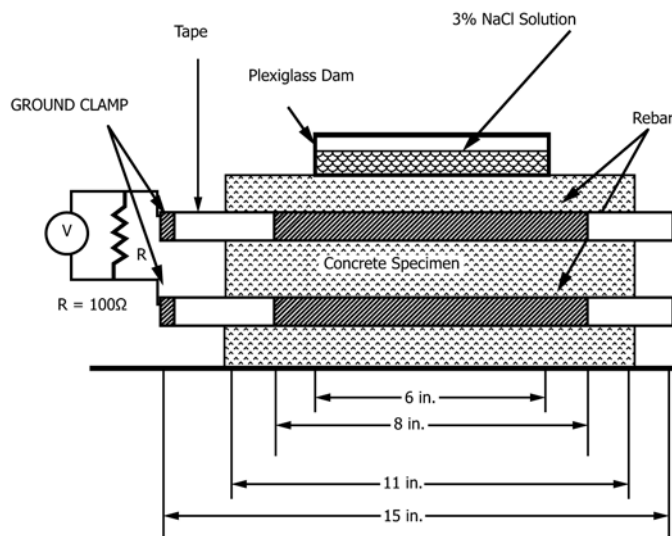
7. Procedure

7.1 Support each test specimen on two nonelectrically conducting supports at least 13-mm (0.5-in.) thick, thus allowing air flow under most of the specimen. Start the test one month after the samples are removed from the 100 % RH atmosphere (moist room). Pond the specimens for two weeks at 23 ± 3°C (73 ± 5°F) with the salt solution, as described in 5.10. The volume of this solution is approximately 400 mL at a depth of 40 mm (1.5 in.). Use a plastic loose fitting cover to minimize evaporation. Maintain a relative humidity around the specimens of 50 ± 5 %. After two weeks, vacuum off the solution and allow the samples to dry for two weeks. Repeat this cycle.

7.2 Measure the voltage across the resistor at the beginning of the second week of ponding using the voltmeter defined in 4.1. Calculate the current, I_j, from the measured voltage across the 100 Ω resistor, V_j, measured in volts (see Note 8) as:

$$I_j = V_j/100$$

NOTE 8—With the common terminal on the bottom bar, negative voltages correspond to positive galvanic current (that is, the top bar is the anode).

7.3 At the same time, measure the corrosion potential of the bars against a reference electrode that is placed in the dam containing the salt solution (see Practice G3 and Test Method C876). Connect the voltmeter between the reference electrode (ground or common terminal) and the bars.

8. Period of Testing

8.1 Monitor the current as a function of time once every four weeks, as described in 7.2, until the average integrated macrocell current of the control specimens is 150 C or greater, as determined in 10.1.8, and at least half the samples show integrated macrocell currents equal to or greater than 150 C (see Note 9).

NOTE 9—The value of 150 C is consistent with a macrocell current of 10 μA over six months. The value of 10 μA was measured by all

laboratories on all specimens showing corrosion (controls and samples with calcium chloride at 19-mm (¾-in.) cover). This degree of integrated macrocell current is sufficient to ensure the presence of sufficient corrosion for visual evaluation.

8.2 In those cases where the admixtures being tested are corrosive, end the test three full cycles after an average integrated macrocell current of 75 C is observed and the integrated macrocell current of at least half the specimens being tested is equal or greater than 75 C.

9. Examination of Embedded Bars

9.1 At the conclusion of testing, break the specimens and examine the reinforcement bars for extent of corrosion, measure the corroded area, and record the percentage of corroded area recorded, as described in Practice G33.

NOTE 10—Photograph the bars at the end of the test to provide a record of the corrosion damage.

9.2 Determine the acid soluble chloride content at the depth corresponding to the cover over the top-reinforcing bar, using Test Method C1152/C1152M.

9.3 Determine the acid soluble chloride content in the specimen produced for background chloride analysis, using Test Method C1152/C1152M. This value is to be subtracted from the acid soluble chloride, as determined in 9.2, to provide a corrected acid soluble chloride content reflecting ingressed chloride.

10. Report

10.1 Report the following information:

10.1.1 Full details of the concrete proportions, air content, and slump of the concrete used in the control and test specimens,

10.1.2 A plot of the corrosion current and potential for each concrete specimen versus time,

10.1.3 A plot of the average integrated current for each condition of concrete versus time,

10.1.4 Time to failure, as considered to be the time for the average macrocell current to reach 10 μA and at least half the samples showing a current greater than 10 μA,

10.1.5 Results of the visual inspection of each bar. The report shall include the percentage of original exposed steel surface corroded and optionally the number and depths of corrosion pits where present, as described in Practice G46,

10.1.6 Photographs of the bars at the end of the test (optional), and

10.1.7 Chloride content at the top reinforcing bar depth from the surface. This value is the corrected total chloride content, as corrected 9.3.

10.1.8 The ratio of total integrated current of the test specimen to that of the control and time the test ended. The total integrated current is:

$$TC_j = TC_{j-1} + \left[\left(t_j - t_{j-1} \right) \times \left(i_j + i_{j-1} \right)/2 \right]$$

where:

TC = total corrosion (coulombs),
t_j = time (seconds) at which measurement of the macrocell current is carried out, and
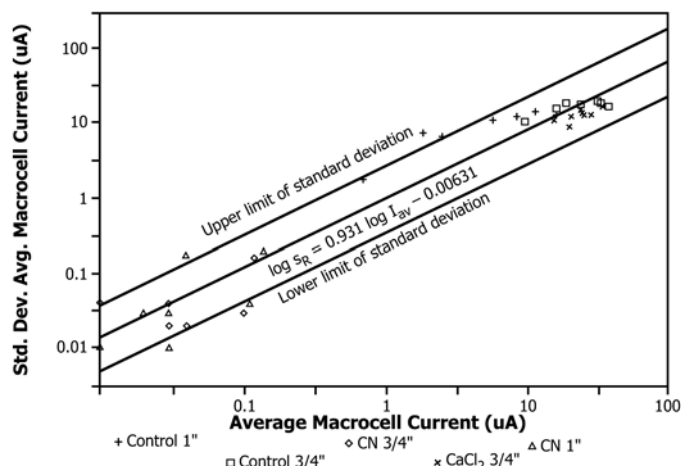i_j = macrocell current (amps) at time, t_j.

FIG. 3 Standard Deviation of Repeatability

A sample calculation is given in Appendix X1.

11. Precision and Bias[11]

11.1 Information on the precision of the results obtained by this test method was derived from an interlaboratory test with two to three specimens per laboratory. Eleven laboratories participated in the study. The repeatability and reproducibility of the test results were dependent on the magnitude of the mean macrocell current.

11.2 Precision is as follows:

11.2.1 *95 % Repeatability Limit (Within Laboratory)*—The within-laboratory precision of the average macrocell current (for each laboratory), as expressed by the repeatability limit, *r*, is given by the following relation:

$$\log r = 0.931 \log I_{avg} + 0.441 \qquad (1)$$

11.2.2 *95 % Reproducibility Limit (Between Laboratories)*—The between-laboratory precision of the average macrocell current (for all laboratories), as expressed by the reproducibility, *R*, is given by the following relation:

$$\log R = 0.833 \log I_{avg} + 0.624 \qquad (2)$$

11.2.3 The repeatability and reproducibility limits of the average macrocell current were calculated in accordance with Practice E177. The respective standard deviations of the variation among test results can be obtained by dividing by 2.8 the values of *r* and *R* calculated using (Eq 1) and (Eq 2). The following equations were then obtained:

$$\log S_r = 0.931 \log I_{avg} - 0.006 \qquad (3)$$

$$\log S_R = 0.833 \log I_{avg} + 0.177 \qquad (4)$$

11.2.4 The data used for compiling the test method precision, together with the statistical parameters as defined in Practice E691, are given in the research report.[11] The graphical representations of the repeatability and reproducibility limits are given in Figs. 3 and 4.

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[11] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:G01-1009.
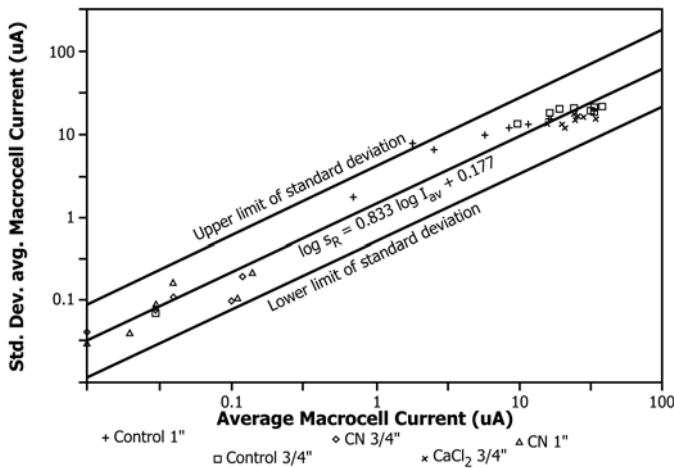
FIG. 4 Standard Deviation of Reproducibility

11.2.5 The time to failure has been analyzed using Practice E691. This analysis is given in the research report.[11]

11.2.6 The maximum end of the 95 % confidence interval for time to failure for control specimens with 19-mm (0.75-in.) concrete cover is six months for both intralaboratory and interlaboratory tests. The maximum ends of the 95 % confidence intervals are two and six months for intra- and interlaboratory tests respectively for specimens containing calcium chloride.

11.2.7 The complete data for percent area corroded is given in the research report.[11] In all cases where there was corrosion, the macrocell current was greater than 9 µA. However, not enough laboratories reported percent area corroded to carry out a statistical analysis following Practice E691.

11.3 *Bias*—The procedure given in this test method has no bias because the effects of chemical admixtures on the corrosion of embedded steel of reinforcement are defined only in terms of this test method.

12. Keywords

12.1 admixtures; concrete; corrosion; corrosivity; inhibitor; reinforcing steel

APPENDIX

(Nonmandatory Information)

X1. TOTAL CORROSION CALCULATION

X1.1 *Total Corrosion Calculation:*

$$TC_j = TC_{j-1} + [(t_j - t_{j-1})*(i_j + i_{j-1})/2] \quad (X1.1)$$

X1.1.1 Assume the following readings were obtained over a 90 day period of time:

Days	0	30	60	90
i_{mac} (µA)	0	20	27	35

X1.1.2 At the end of the first 30 day period the total corrosion is:

$$TC_1 = 0 + [(30 - 0)*86400*(20 + 0)/2*10^{-6}] = 25.92 \text{ C} \quad (X1.2)$$

X1.1.3 At the end of the 60 day period:

$$TC_2 = 25.92 + [(60 - 30)*86400*(20 + 27)/2*10^{-6}] = 86.83 \text{ C} \quad (X1.3)$$

X1.1.4 At the end of the 90 day period:

$$TC_3 = 86.83 + [(90 - 60)*86400*(27 + 35)/2*10^{-6}] = 167.18 \text{ C} \quad (X1.4)$$

Note X1.1—Conversion factor from days to seconds = $24 \times 60 \times 60 = 86\,400$.

REFERENCES

(1) Berke, N. S., Shen, D. F., and Sundberg, K. M., "Comparison of the Polarization Resistance Technique to the Macrocell Corrosion Technique," *Corrosion Rates of Steel in Concrete, ASTM STP 1065*, N. S. Berke, V. Chaker, and D. Whitney, editors, ASTM, August 1990, pp. 38–51.

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(3) Virmani, Y. P., Clear, K. C., and Pasko, T. J., "Time-to Corrosion of Reinforcing Steel in Concrete Slabs, Volume 5: Calcium Nitrite Admixture or Epoxy-Coated Reinforcing Bars as Corrosion Protection Systems," Report No. FHWA/RD-83/-12, Federal Highway Administration, Washington DC, 1983, pp. 71.

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(5) Berke, N. S., Hicks, M. C., Hoopes, R. J., and Tourney, P. J., "Use of Laboratory Techniques to Evaluate Long-Term Durability of Steel Reinforced Concrete Exposed to Chloride Ingress," ACI SP 145-16, 1994 , pp. 299-328.