Protecting Concrete Reinforcement Using Admixture with Migrating Corrosion Inhibitor and Water-Repellent Component

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Corrosion of embedded rebar in concrete can lead to ultimate deterioration of a concrete structure. Corrosive electrolytes and species can penetrate concrete due to its porous nature. An admixture was developed employing a synergistic blend of migrating corrosion inhibitors and waterproofing ingredients. The admixture enhances the protection by forming a protective film on rebar. In addition, it reduces ingression of water-soluble corrosive species. Electrochemical tests show that this admixture provides superior corrosion protection to the rebar. Additional test results demonstrate that the admixture reduces water permeability with no negative effects on workability, set time, and mechanical properties of concrete.

The corrosion of steel reinforcement in concrete structures is one of the most common reasons for infrastructure failure. The corrosion-caused premature deterioration of a concrete structure is particularly pronounced in coastal areas, in cold climates where winter deicing chemicals have to be used, and in high-humidity locations. Corrosion initiates due to the ingress of moisture, chloride ions, and carbon dioxide (CO_2) through the concrete to the steel surface. After initiation, the corrosion products, iron oxides, and hydroxides develop expansive stresses that crack and spall the concrete cover. This further exposes the reinforcement to direct environmental attack and accelerates deterioration of the structure.

The monetary cost in maintaining safe concrete structures is estimated to be between $18 billion to $21 billion annually in the United States alone.[1] Failed structures also have grave consequences to human lives and to the environment.

A well-designed concrete mix can prolong the life of reinforced concrete structures. There are various waterproofing admixtures on today's market aimed at reducing the intrusion of chloride-containing water into the concrete. The majority are based on polymeric compounds, silicon chemistry, metallic stearates, or hydrophilic crystalline materials such as silicates.[2-6] The protection mechanism of these types of products is to block water or to reduce corrosive species. The products do not directly protect the steel rebar—the entity that plays the most important role in determining the longevity of a concrete structure. Inevitably, some electrolyte ingression will occur, setting the stage for the initiation of rebar corrosion and eventual deterioration of a concrete structure. Incorporating a second protection mechanism to the steel rebar itself is much desired in a well-considered admixture for the long-term integrity of a concrete structure.

Reported here is an admixture developed employing a synergistic blend of migrating corrosion inhibitors (MCIs) and waterproofing ingredients. The new Admixture A enhances the protection by forming a protective film on steel rebar while simultaneously reducing ingression of water-soluble corrosive species through the concrete cover.

The MCIs have been used effectively for the protection of rebar in concrete.[7-10] MCIs form a self-replenishing monomolecular protective layer on steel. They migrate through concrete by capillary infiltration and vapor diffusion to reach the surface of the rebar, and deposit on the steel surface by polar attractions.[7,10]

The inhibitor chosen for Admixture A delays the onset of corrosion by 100%, demonstrated through a ponded-salt solution test[11] according to ASTM G109.[12] In addition, a cracked-beam test (based on ASTM G109) showed that it reduced the average corrosion currents by 50% vs. the control, protecting the embedded rebar even when the concrete developed minor cracks.[11]

Trials were run to find compatibility of the corrosion inhibitor and waterproofing component. Various waterproofing materials were screened to meet the following three criteria: reducing water ingression while not negatively impacting concrete workability and mechanical properties; not requiring a special mixing procedure for its effectiveness; and being a nonrestrictive material during transportation. A blend of silane/siloxane emulsion demonstrated the best performance.

Experimental Procedures

Concrete blocks for water repellency tests were made per ASTM C1582.[13] The dose rate of the Admixture A was 0.5 wt%. A water/cement ratio of 0.5:1 was used. The set time was noted. The concrete blocks were cured for 28 days prior to the water repellency testing.

Water permeation testing was performed according to RILEM Test No. 11.4.[14] The change of water level inside the aforementioned test tube was compared for concrete with the Admixture A or without (control).

Water absorption testing was conducted using the Alberta Sealer Immersion

TABLE 1. CONCRETE SET TIME

Sample	Set time
With Admixture A	~4 h
Control (without Admixture A)	~4 h

TABLE 2. WATER PERMEATION TEST

Sample	0 min (in)	30 min (in)	1 h (in)	18 h (in)	5 days (in)	% Improvement
With Admixture A	0	0	0	0	0	100
Control (Without Admixture A)	0	0.1	0.2	0.8	2.5	—

TABLE 3. WATER ABSORPTION TEST (ALBERTA TECHNICAL STANDARD BT001)

Sample	Initial Weight (g)	End Weight (g)	ΔW (g)	Water Absorption (%)	% Improvement
With Admixture A	936.8	948.8	12.0	1.3	55
Control	893.0	920.0	27.0	3.0	—

TABLE 4. WATER ABSORPTION TEST (BS1881 PART 122)

Sample	Water Absorption (%)	% Improvement
With Admixture A	1.5	57
Control	3.5	—

TABLE 5. CONCRETE PROPERTY TESTS

	Test 1		Test 2	
	Control	With Admixture	Control	With Admixture
Slump (mm)	95.3	177.8	55.0	55.0
Air Content (%)	2.8	4.5	1.1	1.3
Compressive Strength (psi)				
7 days	4,040	3,850	5,070	4,713
28 days	5,410	4,780	6,743	5,583

TABLE 6. LINEAR POLARIZATION RESISTANCE

	Corrosion Rate: Control (mpy)	Corrosion Rate: Admixture A (mpy)	% Improvement
After 4 h conditioning	1.07	0.34	68
After 24 h conditioning	4.22	0.45	89

TABLE 7. EIS MEASUREMENT (12-DAY IMMERSION IN 3% NaCl SOLUTION)

Sample	Rp (Kohm)	% Improvement
With Admixture A	59.60	354
Control	13.25	—

Test (Alberta Transportation Technical Standard BT001[15]), and BS 1881 Part 122.[16] In the BT001 test, the weight changes of the concrete blocks, before and after being immersed in tap water for 120 h with 25-mm headspace, were measured for those with the Admixture A or without (control). The BS 1881 Part 122 test on Admixture A was conducted by the Infrastructure Sustainability and Assessment Center, School of Engineering, American University in Dubai.

The concrete properties of slump (ASTM C143[17]), air content (ASTM C231[18]), and compression strength (ASTM C39[19]), were tested at the American Engineering Testing facility (St. Paul, Minnesota) and at the School of Engineering, American University in Dubai.

A linear polarization resistance (LPR) Test was carried out in a 1-L electrolyte of 3.5% sodium chloride (NaCl) and 4 g of calcium hydroxide [$Ca(OH)_2$] in deionized water. Admixture A was added at 1.42 wt%. A working electrode of C1215 carbon steel (UNS G12150) was conditioned in the above electrolyte for 4 h and 24 h and its corrosion rates were measured with or without the addition of the Admixture A.

An electrochemical impedance spectroscopy (EIS) test was carried out on concrete specimens with or without Admixture A (0.5% of the cementitious material). The rebar-inserted concrete blocks ("lollypops") were made per ASTM C192[20] and ASTM C1582 using ordinary basic rebars. After being cured for 28 days, the blocks were immersed in 3% NaCl solution for 12 days and their polarization resistances (Rp) were measured.

Results

The set time was not affected by the addition of Admixture A (Table 1).

Water repellency tests consisted of a water permeation test and water adsorption test. The permeation test showed that concrete treated with Admixture A provided 100% improvement vs. the untreated control (Table 2). The adsorption test per Alberta Technical Standard BT001 showed that concrete treated with Admixture A absorbed 55% less water vs. the untreated control (Table 3). Another water absorption test, BS 1881 Part 122, showed a similar improvement of 57% (Table 4). All water repellency tests indicated that Admixture A produced a concrete of less water permeability and thus of fewer electrolyte ingression when placed in service in harsh environments.

Concrete property tests on slump, air content, and compression strength showed that the addition of Admixture A resulted a more workable concrete with some slight changes in mechanical properties (Table 5).

LPR and EIS tests were carried out. LPR tests showed that when 1.42% (wt) Admixture A was added to an electrolyte of 3% NaCl and 0.4% $Ca(OH)_2$, the corrosion rate was reduced 68% vs. the control after a 4-h contact period; the corrosion rate was reduced 89% after 24 h (Table 6). The LPR results illustrated good corrosion protection power of Admixture A in electrolyte. The EIS test showed that after being immersed in 3% NaCl solution for 12 days, the rebar embedded in concrete containing Admixture A exhibited a 354% increase in polarization resistance vs. the control (Table 7). The EIS result indicated that the embedded rebar would be 3.5 times less likely to corrode in a concrete containing Admixture A than in one without. The result confirmed the corrosion protection capability of Admixture A in concrete.

These two sets of corrosion tests demonstrated that the corrosion inhibitors in Admixture A provided synergistic protection to rebar.

Conclusions

After a substantial amount of screening, a new Admixture A containing both MCI and a waterproofing component was formulated. The new Admixture A protects by increasing the Rp experienced by the embedded rebar to 3.5 times than that of a concrete without the admixture while maintaining a favorable concrete property profile in compression strength and workability. At the same time, Admixture A increases concrete water repellency. The data showed approximately 55% reduction in the water adsorption test and approximately 100% reduction in the permeation test.

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References

1. P. Emmons, D. Sordyl, "The State of the Concrete Repair Industry, and a Vision for its Future," *Concrete Repair Bulletin* (July/August 2006): pp. 7-14.
2. "Wacker Silicones, Liquid Hydrophobic Admixtures for Manufactured Concrete Products," product brochure, Wacker Chemie AG, 2012.
3. "Krystol Internal Membrane," technical data sheet, Kryton International, Inc., 2013.
4. "Hycrete W500," product data sheet, Hycrete, Inc., 1004002, 2013.
5. "Rheomix 825," product data sheet, BASF Corp., LIT #1024725, 2010.
6. "Integral Waterpeller," product data sheet, The Euclid Chemical Co., 1998-2013.
7. D. Stark, "Influence of Design and Materials on Corrosion Resistance of Steel in Concrete," R&D Bulletin RD-98.01T (Skokie, Illinois: Portland Cement Association, 1989).
8. D. Bjegovic, B. Miksic, "Migrating Corrosion Inhibitor Protection of Concrete," *MP* 38, 11 (1999): pp. 36-41.
9. D. Rosignoli, L. Gelner, D. Bjegovic, "Anticorrosion Systems in the Maintenance, Repair and Restoration of Structures in Reinforced Concrete," International Conf. Corrosion in Natural and Industrial Environments; Problems and Solutions (Grado, Italy, 1995).
10. B. Bavarian, L. Reiner, "Corrosion Inhibition of Steel Rebar in Concrete by Migrating Corrosion Inhibitors," Eurocorr 2000 (London, U.K.: Maney Publishing, 2000).
11. "Cracked-beam Corrosion Test of Concrete Treated with MCI-2000 and MCI-2020 Corrosion Inhibitor," Wise, Janney, Elstner Associates, Inc. (Jan. 1995).
12. ASTM G109, "Standard Test Method for Determining Effects of Chemical Admixtures on Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments" (West Conshohocken, PA: ASTM, 1992).
13. ASTM C1582, "Standard Test Method for Determining Effects of Chemical Admixtures on Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments" (West Conshohocken, PA: ASTM, 2011).
14. Reunion Internationale des Laboratoires d'Essals et de Recherches sur les Materiaux and Stuctures (Rilem), Water Absorption Tube Test, Rilem 11.4.
15. Alberta Transportation Technical Standard BT001, "Test Procedure for Measuring the Vapor Transmission, Waterproofing and Hiding Powder of Concrete Sealer" (Alberta Transportation, Edmonton, Alberta, Canada: 2000).
16. BS1881 Part 122, "Testing Concrete, Method for Determination of Water Absorption" (London, U.K.: British Standards Institute, 2011).
17. ASTM C143/C143M, "Standard Test Method for Slump of Hydraulic Cement Concrete" (West Conshohocken, PA: ASTM, 2005).
18. ASTM C231, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method: (West Conshohocken, PA: ASTM, 2010).
19. ASTM C39, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" (West Conshohocken, PA: ASTM, 2012).
20. ASTM C192, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory" (West Conshohocken, PA: ASTM, 2013).

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