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

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ABSTRACT

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 synergistic blend of migrating corrosion inhibitors and water-proofing 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 while does not negatively affect workability, set time, and mechanical properties of concrete.

Key words: corrosion inhibitor, steel rebar protection, water repellency, concrete

INTRODUCTION

The corrosion of steel reinforcement in concrete structure is one of the most common reasons for infrastructure failure. The corrosion-caused premature deterioration of concrete structure is particularly pronounced in costal 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 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 between $18 to 21 billion annually in the U.S. alone.[1] Failed structures also have grave consequence to human lives and to environment.

A well designed concrete mix can prolong the life of reinforced concrete structures.

There are various waterproofing admixtures on today's market, aiming at reducing 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 this type of products is to block water or to reduce corrosive species. This type of products do not directly protect the steel rebar themselves, 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-thought admixture for the long term integrity of a concrete structure.

Reported here is an admixture developed employing synergistic blend of migrating corrosion inhibitors 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 migrating corrosion inhibitors have been used effectively for the protection of rebar in concrete. [7-10] Migrating corrosion inhibitors form a self-replenishing monomolecular protective layer on steel. They migrate through concrete by capillary infiltration and vapor diffusion to reach rebar surface, and deposit on the steel surface by polar attractions.[7,10]

The inhibitor chosen for the Admixture A delays the onset of corrosion by 100%, demonstrated through a ponded-salt solution test[11]according to ASTM[I] G109.[12] In addition, 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 water proofing materials were screened to meet the following 3 criteria: reducing water ingression while not negatively impacting concrete workability and mechanical properties; not requiring special mixing procedure for its effectiveness; and being a non-restrictive material during transportation. A blend of Silane/Siloxane emulsion demonstrated best performance.

EXPERIMENTAL PROCEDURE

Concrete blocks for water repellency test were made per ASTM C1582.[13] The dose rate of the Admixture A was 0.5% of cement by weight. A Water/Cement ratio of 0.5:1 was used. The set

[I] ASTM International, 100 Barr Harbor Dr., PO Box C700, West Conshohocken, PA, 19428 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[II] 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 *Alberta Sealer Immersion Test* (Alberta Transportation Technical Standard[III] BT001)[15] , and *BS*[IV]*1881 Part 122*[16]*.* In the Alberta Test BT001, the weight changes of the concrete blocks, before and after being immersed in tap water for 120 hrs with 25mm headspace, were measured for those with the Admixture A or without (control). The test of *BS1881 Part 122* on Admixture A was conducted by the Infrastructure Sustainability and Assessment Center, School of Engineering, American University in Dubai[V].

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[VI], and at the School of Engineering, American University in Dubai.

Linear Polarization Resistance (LPR) Test was carried out in a 1L electrolyte of 3.5% NaCl and 4g $Ca(OH)_2$ in DI water. Admixture A was added at 1.42% by wt. A working electrode C1215 was conditioned in the above electrolyte for 4h and 24h and its corrosion rates were measured with or without the addition of the Admixture A.

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 R_p were measured.

RESULTS

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

Table 1
Concrete Set Time

Sample	Set time
w/ Admixture A	~4hrs
Control (w/o Admixture A)	~4hrs

Water Repellency Tests were consisted of water permeation test and water adsorption test. Permeation Test showed that concrete treated with Admixture A provided 100% improvement

II RILEM, Reunion Internationale des Laboratoires d'Essals et de Recherches sur les Materiaux and Stuctures
III Alberta Transportation, Technical Standard Branch, 4999-98 Ave., Edmonton, Alberta, Canada, T6B 2X3,
IV British Standards Institute, 389 Chiswick High Rd, London, W4 4AL, United Kingdom
V American University in Dubai, Sheikh Zayed Road, Media City, Dubai United Arab Emirates
VI American Engineering Testing, 550 Cleveland Ave N, St Paul, MN 55114

vs. the untreated control, Table 2. 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.

Table 2
Water Permeation Test

Sample	0 min	30min	1hr	18hrs	5 days	%Improv -5days
w/ Admixture A	0”	0”	0”	0”	0”	100%
Control	0”	0.1”	0.2”	0.8”	2.5”	--

Table 3
Water Absorption Test
(Alberta Technical Standard BT001)

Sample	Ini Wt (g)	End Wt (g)	ΔW (g)	Water Absorption (%)	%Improv
w/ 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 (%)	% Improv
w/ Admixture A	1.5	57%
Control	3.5	**--**

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

Table 5
Concrete Property Tests

	Test 1[VII]		**Test 2**[VIII]	
	Control	w/ Admixture A	Control	w/ Admixture A
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	4040	3850	5070	4713
28 days	5410	4780	6743	5583

[VII] Test performed at American Engineering Testing
[VIII] Test performed at School of Engineering, American University in Dubai

Corrosion Tests of Linear Polarization Resistance (LPR) and Electrochemical Impedance Spectroscopy (EIS) were carried out. LPR test showed that when 1.42% (wt) Admixture A was added to an electrolyte of 3% NaCl and 0.4% $Ca(OH)_2$, corrosion rate reduced 68% vs. the control after a 4hr contact period; the corrosion rate reduced 89% after 24hr, Table 6. The LPR results illustrated good corrosion protection power of Admixture A in electrolyte. EIS test showed that after being immersed in 3% NaCl solution for 12 days, the rebar embedded in concrete containing Admixture A exhibited 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 the one without. The result confirmed the corrosion protection capability of Admixture A in concrete.

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

Table 6
Linear Polarization Resistance

	Corr. Rate (mpy) -Control-	Corr. Rate (mpy) -w/ Admixture A-	% Improv
After 4h conditioning	1.07	0.34	68%
After 24h conditioning	4.22	0.45	89%

Table 7
EIS Measurement
(12 day immersion in 3% NaCl solution)

Sample	Rp (Kohm)	%improv
w/ Admixture A	59.60	354
Control	13.25	--

CONCLUSIONS

After substantial amount of screening, a new Admixture A containing both migrating corrosion inhibitor and 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 control, a concrete without the admixture, while maintaining a favorable concrete property profile in compression strength and workability. At the same time, the Admixture A increases concrete water repellency. The data showed approximately 55% reduction in water adsorption test and approximately 100% reduction in permeation test.

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