Aiming for Extended Service Life with Migrating Corrosion Inhibitors

By Ray Schallom III, Jessi Meyer, and Julie Holmquist

Corrosion of embedded steel reinforcement is a threat to all types of reinforced concrete, leading to cracking, spalling, and a shortened service life of the structure. While the pH of new concrete initially protects embedded steel reinforcement by creating a natural passive oxide layer, it inevitably gives way to the effects of carbonation, chloride exposure, and acid rain or other industrial pollutants. The corrosion process initiates, followed by deterioration that challenges the durability and safety of structures.

A variety of technologies have been developed to counteract this process, ranging from corrosion-inhibiting admixtures to cathodic protection (CP). Calcium nitrite (CNI), an older admixture technology, is effective against chloride-induced corrosion, but has disadvantages in that its dosage rate is variable depending on expected exposure to chlorides (the more chloride exposure, the higher the dosage rate). As dosage rates increase, so do CNI's adverse effects on the physical properties of concrete, such as dramatically increased shrinkage and accelerated setting time. CP technologies require reinforcement to be continuous and involve installation of many embedded galvanic anodes, or application of an impressed current, which must be continuously monitored.

MIGRATING CORROSION INHIBITOR TECHNOLOGY

Migrating corrosion inhibitors, which are based on organic amine alcohol and amine carboxylate technology, offer many advantages for extending the service life of concrete structures. They have a set dosage rate, which is five to 30 times lower than that of CNI, and generally have no effect on the physical properties of concrete (strength, shrinkage, and freezing and thawing). Some versions can delay setting time, whereas others are normal set.

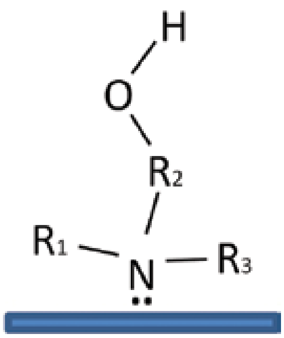

Fig. 1: Illustration of amine alcohol inhibitor, where R1, 2, 3 is H or alkyl group OH tail end group

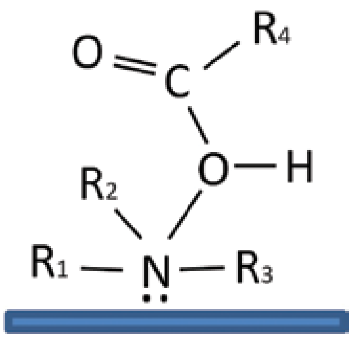

Fig. 2: Illustration of amine carboxylate inhibitor, where R1, 2, 3 is H or alkyl group OH tail end group

Migrating corrosion inhibitors are available in both liquid and powder formulations for ease of application, and are also available as topical treatments for existing structures. When added to the concrete mixture, they are dispersed through the mixing process but also have the ability to migrate through concrete pores by capillary action and vapor diffusion. They travel randomly from areas of high concentration to areas of low concentration, according to Fick's Second Law, until they come into contact with embedded reinforcement.

Migrating corrosion inhibitors are considered mixed corrosion inhibitors, meaning they provide protection to both anodic and cathodic areas. They are attracted to embedded metals and adsorb onto them. Figures 1 and 2 demonstrate the chemistry of amine alcohols and amine carboxylates on the metal surface. This chemistry allows migrating inhibitors to form a tenacious bond that protects the metal from interacting with corrosive elements at both the anode and cathode of a corrosion cell. This protective layer also keeps the pH at the reinforcing bar surface at an optimal level for inhibiting corrosion and reduces existing corrosion rates.[1]

ADVANTAGES OF MIGRATING CORROSION INHIBITORS

Migrating corrosion inhibitor technology has many advantages in terms of effectiveness and user friendliness. As an admixture, migrating corrosion inhibitors can be readily added to shotcrete or other concrete mixtures at a relatively small dosage rate compared to other admixtures (1 to 1.5 pints/yd^3 [0.6 to 1 L/m^3] for liquids, 1 lb/yd^3 [0.6 kg/m^3] for powders). They do not negatively affect concrete properties, and they meet ASTM C1582/C1582M[2] requirements such as flexural strength, compressive strength, setting time, and freezing-and-thawing durability.[3] Migrating corrosion inhibitors are nonhazardous and environmentally friendly and include bio-based options made from by-products of corn. The latest generation amine-carboxylate-based migrating corrosion-inhibiting admixtures have been certified to meet ANSI/NSF 61 requirements for safe use in structures containing potable water. Recent testing indicates that certain migrating corrosion inhibitor technologies are also compatible with CP systems, in some cases reducing the current requirement.[4]

CORROSION-INHIBITING PERFORMANCE

The use of migrating corrosion inhibitor admixtures can double or triple the time to corrosion initiation and, once corrosion starts, reduce corrosion rates by five to 15 times compared to a control.[1] Compared to other admixtures, such as CNI or amine esters, they do exceptionally well under modified ASTM G109 testing (refer to Fig. 3). This testing introduces cracks into the concrete test specimens, making it easier for corrosive elements to reach the surface of the reinforcing bar. In one example of this, corrosion rates for samples treated with a migrating corrosion inhibitor admixture stayed significantly lower than those of CNI and amine-ester treated concrete during 20 cycles of saltwater ponding.[5]

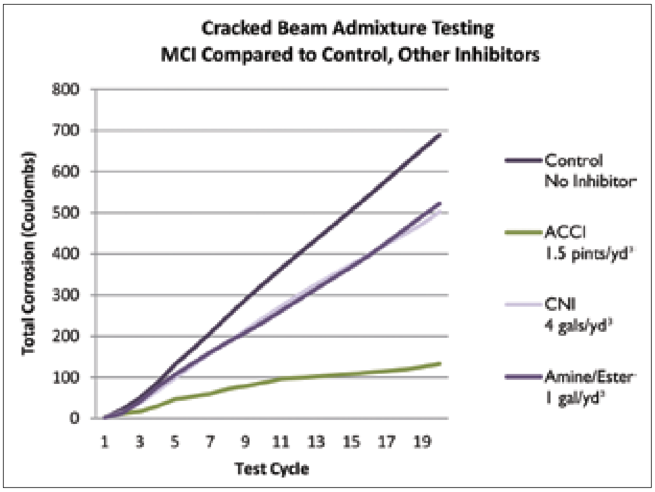

Fig. 3: A normal set version (version used with shotcrete) of an amine carboxylate migrating corrosion inhibitor admixture (ACCI) showed significantly higher corrosion protection under modified ASTM G109 cracked beam testing, an accelerated but more intense version of ASTM G109 saltwater ponding
Image courtesy of Cortec Corporation

USES OF MIGRATING CORROSION INHIBITOR IN SHOTCRETE

Migrating corrosion inhibitor technology has more than 30 years of historical use in reinforced concrete, and more than 15 years of use with shotcrete applications. As far back as 2001, a repair project using migrating corrosion inhibitors won an ICRI Award of Excellence for the Transportation category. The project involved repairing the Crib Point Jetty in Western Port Bay, Victoria, Australia. The jetty had experienced substantial spalling, cracking, and degradation caused by corrosion in the harsh concrete environment. The degraded concrete and steel reinforcement was removed from any of the deteriorating concrete piers and beams, and new reinforcement was added as needed. The repair was completed by applying shotcrete repair mortar that contained migrating corrosion inhibitors to reduce further corrosion in the structure.[6]

Fig. 4: Liberty Tunnel before repair
Photo by Dennis Bittner

Tunnels and Bridges

In the state of Pennsylvania, District 11 has used a migrating corrosion inhibitor in its wet- and dry-mix shotcrete for over 8 years. In patched areas, PENN DOT has included an anode system for extra protection. One of these projects was the repair of the Liberty Tunnel in Pittsburgh (refer to Fig. 4 and 5). Teams removed the surface layer of damaged concrete and then shotcreted the replacement concrete containing migrating corrosion inhibitors. This helps protect against the insipient ring anode effect, where the addition of new concrete can counter and productively encourage the spread of corrosion to adjacent concrete.

District 11 also used shotcrete with a migrating corrosion inhibiting admixture on some of the supports of the Rankin Bridge in Pittsburgh. The crew repaired damaged areas with shotcrete and applied a finish coat to the entire

Fig. 5: Liberty Tunnel finished section
Photo by Dennis Bittner

Fig. 6: Rankin Bridge pier repairs
Photo by Dennis Bittner

Fig. 7: Finished Rankin Bridge pier repair
Photo by Dennis Bittner

piling structure (refer to Fig. 6 and 7). Work on both projects was completed by Mosites Construction Co., Pittsburgh, PA.

Amusement Park Volcano

Kings Dominion amusement park in Doswell, VA, has a volcano that was constructed over 40 years ago, using 0.375 in. (10 mm) reinforcement and plaster lath, with 2 in. (50 mm) thick low-velocity sand and cement. The structure held up quite well until the last ride was built in and around the 100 ft (30 m) high volcano shell. This left holes where the pipe supports holding the track for the ride were placed. Special rubber boots were installed around the pipes before the placing of the new high-strength, silica fume shotcrete. However, freezing-and-thawing conditions triggered condensation around the supports, causing some of the steel reinforcement to rust.

The areas marked for repair (refer to Fig. 8 through 10) require a 0.375 in. (10 mm) V-groove stay-in-place form, No. 3 (No. 10M) bar reinforcement spaced at 12 in. (300 mm)

Fig. 8: The Kings Dominion amusement park volcano was divided into eight work zones for budgeting
Photo by Ray Schallom

Fig. 9: The 0.375 in. (9.5 mm) V-shape lath, the rubber boot around the pipe support, and reinforcement to be encased into the silica-fume shotcrete
Photo by Ray Schallom

on center, and 2 in. (50 mm) thick high-strength, silica fume concrete mixture with a migrating corrosion inhibitor for corrosion control. Staining (for aesthetic purposes) and waterproofing are applied once the strength requirement is met. The entire work zone is covered and heated during repairs, which can only be conducted from October 31 to March 15 while the park is closed for the season. The scaffolding and protection is removed prior to the park's opening day.

Fig. 10: Volcano Zone 2 repair was quite extensive
Photo by Ray Schallom

Fig. 11: Arial view of the finished stained Kings Dominion amusement park mountain in Zone 2 and Zone 3
2016-2017 season photo by Chris Alburger

Fig. 12: Scaffold and the plastic protection over the mountain areas to be repaired
Photo by Ray Schallom

Fig. 13: Volcano finished stained area in Zone 3
Photo by Jeff Reichart

The project specification called for one or two migrating corrosion inhibitors to be added to the shotcrete, depending on whether a dry, bagged mix or a ready mixed product was used. When the winning contractor, Cemrock, chose the wet-mix process, its ready mix supplier chose a CNI-based corrosion inhibiting admixture that prevented the hardened shotcrete from reaching the specified strength. Once the ready mix producer removed the CNI from the design mixture and began adding an amine-carboxylate-based migrating corrosion inhibitor into the mixture at 1.5 pints/yd (0.62 L/m^3), the strength requirement started to be met on every load.

In Fig. 11, the new lightly stained repaired zones and the old dark weathered zones yet to be repaired and stained are visible. Money budgeted annually includes the scaffolding erection and dismantling, the plastic protection, and the heating of the repaired areas as shown in Fig. 12. All work begins October 31 and must be cleaned up by March 15. This is an ongoing project until completed (Fig. 13).

JC Century Building

The JC Century Building in Binghamton, NY, is undergoing a mass renovation and repurposing to convert an old factory into an apartment complex. The architect has specified that the repairs to the structure must maintain the old construction appearance, such as exposed brick, arched concrete ceilings that look like they have been plastered, and new windows with the same look as the old factory windows. It was determined early on that hand-applying

Fig. 14: JC Century Building: typical ceiling before prep work began
Photo by Rick Conrow

Fig. 15: Before picture of the arch ceilings
Photo by Rick Conrow

overhead concrete repair materials would be too costly, and be difficult to consistently assure good bond to the existing surface. The delaminated concrete surface in the ceiling was removed. The exposed surface was then sandblasted and high-pressure water blasted before reinforcing mesh was installed. The Shotcrete MS® wet-mix product was chosen supplemented by a liquid amine-carboxylate-based migrating corrosion inhibitor from Cortec. The thin repair was finished to look like textured plaster (refer to Fig. 14 through 16). The migrating corrosion inhibitor was chosen to give the existing steel additional corrosion protection given the thin layer application. The property is owned by the Regan Development Company and the shotcrete contractor was KHM INC. of Binghamton, NY.

Conclusions

Migrating corrosion inhibitor technology has been an important discovery in the protection of reinforced concrete from corrosion. It is compatible with both form-and-pour or shotcreted concrete, increasing the convenience of applying corrosion inhibitors to specialized structures or in special repair situations. The technology includes bio-based options and offers compatibility with CP and potable water structures. Migrating corrosion inhibitors have been used in a variety of shotcrete applications and have even shown advantages for achieving required concrete strength in contrast to alternative corrosion inhibitors. Most importantly, they protect reinforced shotcrete structures from corrosion at a very low dose without affecting important concrete properties such as strength and freezing-and-thawing durability.

Fig. 16: Shows a completed section that needed to look like the original old structure
Photo by Rick Conrow

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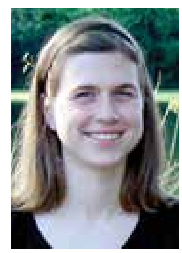

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