MCI® Protection of Concrete

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Migrating corrosion inhibitors (MCIs) were developed to protect steel rebar from corrosion in concrete. They were designed to be incorporated as an admixture during concrete batching or used for surface impregnation of existing concrete structures. Two investigations are summarized. One examines the effectiveness of MCIs as a corrosion inhibitor for steel rebar when used as an admixture to fresh concrete. The other is a long-term study of MCI concrete impregnation that chronicles corrosion rates of rebar in concrete specimens. Based on data from each study, it was concluded that MCIs are compatible with concrete and effectively delay the onset of corrosion.

Reinforced concrete structures are usually durable in average environments. However, when exposed to variable environmental factors, such as carbonation and/or chloride attack, a structure's integrity and safety can easily be compromised. These attacks reduce the potential service life of a structure and increase maintenance costs. This problem has not been adequately addressed within the engineering community. Obvious design goals should be to enhance concrete's durability and performance and reduce maintenance costs. After years of concrete restoration analysis, civil engineers have concluded that even with relatively new projects, little or no effort has been made to significantly counteract the negative environmental impact on concrete. Improving concrete's reliability needs to be a top priority.

For years, there have been several different protection options. A wide range of corrosion inhibitors are available,[1-4] which can be divided into groups according to application and type of corrosion process (Figure 1). Most products are designed to protect either the concrete *or* the steel rebar (Figure 2).

New migrating corrosion inhibitor (MCI) technology is designed to protect both the concrete and the reinforcement steel. MCIs substantially decrease the corrosion rate of steel rebar embedded in concrete.

MCI Technology

MCIs are based on amino carboxylate chemistry. They are effective "mixed" cathodic and anodic corrosion inhibitors.[5-7] Under normal conditions these substances enhance the vapor pressure.[8-12] Increased pressure causes the inhibitor molecules to diffuse through the concrete. This diffusion process requires a period of time to migrate through the concrete's pores. Once the MCIs migrate to the rebar's surface, a monomolecular protective layer is formed. This suggests that the migratory inhibitors are physically adsorbed onto the metal surfaces.

MCIs can be incorporated as an admixture or can be used by surface impregnation of existing concrete structures. With surface impregnation, diffusion transports the MCIs even into the deeper concrete layers. They will delay and inhibit the onset of corrosion on steel rebar.[10-11]

MCI Admixture Study

MCIs were incorporated into several fresh concrete mix batches with various weight-to-concrete proportions. Two types of additives were prepared with two different MCI dosages, and a statistical analysis was performed (Table 1). The mix included a superplasticizer and an air-entraining agent. MCIs were found to be compatible with all additives used in concrete mixes.

They did not adversely affect any ingredients that were used in the concrete mix.

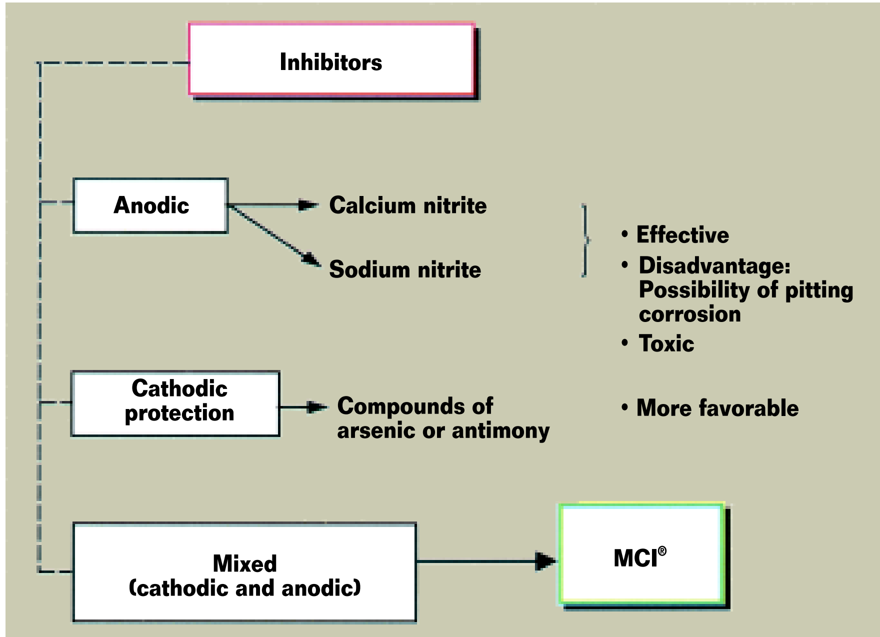
The experimental mix was prepared with 356 kg/m^3 of concrete (label PC 30z 45s) and included a natural fractionated aggregate that had a maximum granulation of 31.5 mm. The prepared mix was formed into similar-sized "block" specimens. The test parameters followed modified ASTM G 109[12] procedures.

These prepared specimens also included three 14-mm diameter bars inserted at two different levels of the concrete. One bar was at 3.0 cm from the specimen's surface, acting as an anode. The other two bars were connected in series, 2.5 cm apart and 11.5 cm from the concrete surface, as cathodes. A Plexiglas† "wall" was constructed around the top edge of the concrete block. This fluid containment area was used to create a pool. The pool was filled with a 3% sodium chloride (NaCl) water solution that was in direct contact with the specimen's surface. Contact time for each cycle was 4 consecutive days. After the NaCl/water solution was drained, the samples were placed in an environmental chamber for the next 3 days of the cycle. To speed up the drying process, the chamber was set at an elevated temperature of 60°C.

Next, a 100-Ω resistor was connected between the cathode and the anode bars. The voltage between the anode and the cathode was measured after each weekly cycle, and from these readings the current was calculated and noted. The study was continued until the specimen's current achieved a 10-μA deviation, or for 1 year, whichever was first. Concurrently, the potential difference between the anode and the reference electrode (copper/copper sulfate [Cu/$CuSO_4$]) was also measured according to ASTM C 876.[13] Figures 3 and 4 show the results regarding potential differences.

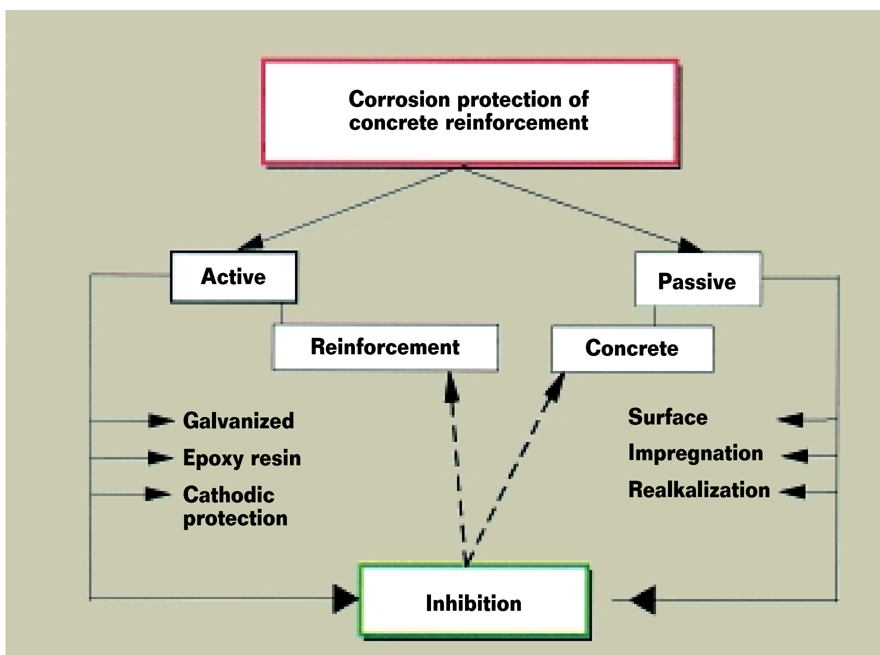
†Trade name.

FIGURE 1



Types of corrosion inhibitors for concrete.

FIGURE 2



Methods of protecting the concrete reinforcement from corrosion.

The data indicate that the effectiveness of MCIs increases substantially with elevated dosage rates. As dosage rates were increased to 3 L/m^3, the level of corrosion activity became statistically insignificant. This suggests that proper dosage is an important issue when using MCIs in a fresh concrete mixture.

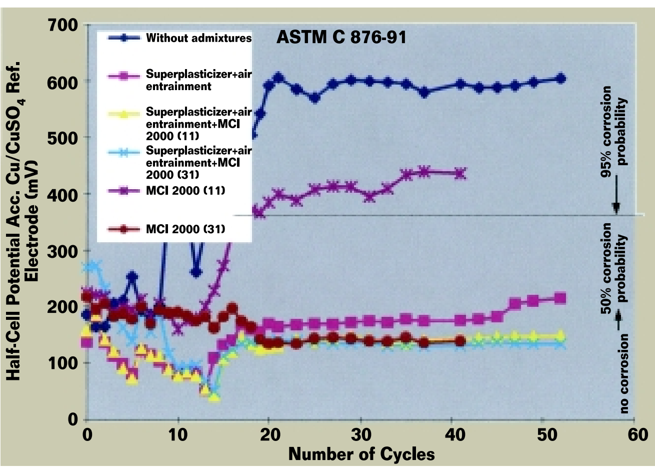
TABLE 1
CONCRETE COMPOUNDS FOR RESEARCH

		Compound Label					
Components:	Units	I	II	III	IV	V	VI
Cement PC 30z 45 s	kg/m^3			356			
w/c	—	0.5	0.38	0.35	0.39	0.5	0.5
Admixtures:							
Superplasticizer	% on weight of cement	—	2.0	2.0	2.0	—	—
Air entraining agent	% on weight of cement	—	0.05	0.05	0.05	—	—
MCI	L/m^3	—	—	1.0	3.0	1.0	3.0

MCI Surface Impregnation Treatment Study

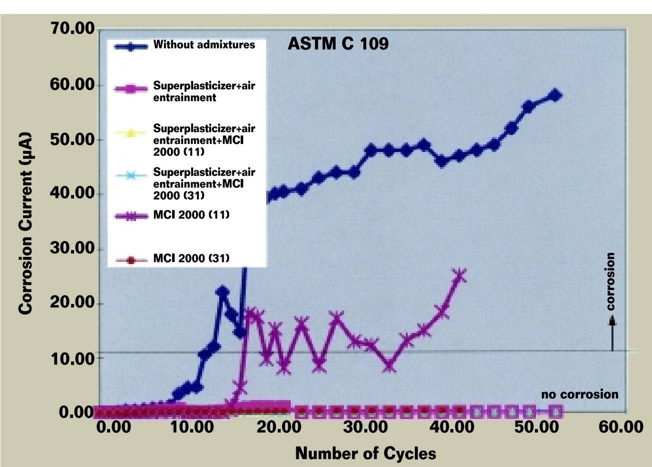
Long-term testing of concrete with MCI surface impregnation was begun in November 1994. After 4 years of continuous testing, it was concluded that the effectiveness of MCIs was observed and confirmed by the test data. Significant differences were found between MCI-treated and non-treated specimens.[14]

FIGURE 3



Corrosion potential vs time.

FIGURE 4



Corrosion potential vs time.

Steel rebar was embedded in the specimen blocks. The rebar was 13-mm diameter polished steel. It was covered by 3 cm of concrete. The concrete used in the preparation of the specimen blocks was mixed with NaCl (3 kg/m^3) to quickly activate the corrosion process. A 3.5% NaCl/water solution was then placed in direct contact with the surface of the specimen. The solution was applied for 1 week (40°C, 100% RH), then dried for 1 week (50°C, 30% RH). This procedure was designed to simulate an accelerated real corrosion process in the field.

After 1,311 days of continuous testing, the control specimens were totally corroded. The average corrosion rate was 73 to 92 µm/y. The specimens that had been treated with MCIs experienced corrosion of only ~10 to 12 µm/y, and in some cases there was little or no corrosion. The corrosion process with MCI-treated specimens was 17% that of the untreated control group specimens.

Several cracks were observed on the control specimens. The study data indicate that cracks with a width ≥2 mm tended to retain more air and water in their cavities. This condition seemed to aid in a greater buildup of electrolytic response (which was caused by polarization) between the bars. Figure 5 shows the occurrence of cracks on the control specimens and the absence of similar cracks on the MCI-treated specimens (after 1,311 days of continuous exposure).

It may be premature to estimate how these test periods correspond to real environments in the field. However, it can be concluded that when MCIs were applied, the corrosion speed was significantly reduced by more than 83%. Therefore, if the test specimens were to be placed in the natural environment, the corrosion rate of the rebar would be ~10 to 12 µm/y. The coefficient number of this rate could be calculated as 5.2 to 6.6 times the test period. In other words, the experimental period to date—4 years—should correspond to 20 to 24 years in the natural environment for MCI-protected products.

Conclusion

The goal of this research was to identify the influence of migratory inhibitors on steel rebar corrosion in concrete. MCIs were added to a fresh concrete mixture or used for surface impregnation of existing concrete structures. The study of MCIs was based on procedures defined and modified from the ASTM G 109 standard. The results clearly indicate that the examined migratory inhibitors are compatible with the components of the concrete structure. Results of sample analysis indicate that, with proper dosage, MCIs significantly retard corrosion. MCIs play an important role in the delay of reinforcement steel corrosion in concrete.

FIGURE 5

(a) (b)

The appearance of untreated and MCI-treated specimens.

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