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PREVENTING REBAR CORROSION IN CONCRETE STRUCTURES

by Shiyuan Qian

This article reviews the issue of rebar corrosion, discusses some of the preventive technologies available, and presents information on recent studies conducted by NRC's Institute for Research in Construction.

The corrosion of reinforcing steel bars is one of the main causes of deterioration of reinforced concrete structures in North America. It has become a serious, widespread problem, with repair costs now in the billions of dollars annually. Whether the corroding rebars are seen exposed on delaminated bridge decks or piers, or observed in damaged parking garages, engineers and contractors are all too familiar with the problem, as are anxious property owners who call on them to provide solutions.

De-icing salts applied to roadways and bridges, and salt in seawater for structures built in marine environments are the primary causes of rebar corrosion. The chlorides in salt find their way into the concrete through the pores and cracks and down to the rebar. When the rebar corrodes, the resulting volume expansion induces stresses that lead to cracking, delamination and spalling of the concrete, and eventual loss of bonding between the rebar and the concrete. Extensive deterioration can affect the safety and serviceability of the structure.

The severity of the corrosion problem has generated a great deal of attention in the research field. The National Research Council's Institute for Research in Construction (IRC) has conducted several studies in recent years in an attempt to study the effectiveness of various prevention and repair strategies and technologies that are available and in use in the construction industry.

Concrete treatments

One of these technologies is concrete surface treatments, which can provide a barrier to reduce the ingress of damaging moisture, carbon dioxide and chlorides. These treatments are sprayed onto the concrete and fill the capillary pores close to the surface to produce a hydrophobic finish. The contractor must apply a minimum thickness in a uniform coat to ensure effective results.

Rebar coatings

Protective coatings**,** including epoxies, galvanizing and some cementitious materials containing corrosion inhibitors, can be applied to the rebar to provide a barrier between it and the corrosive environment. The effectiveness of cementitious coatings is still under study, while opinion on the effectiveness of fusion-bonded epoxy-coated reinforcement is mixed. There are still questions regarding debonding and pitting corrosion because the coatings have naturally occurring defective spots produced during fabrication or they may be damaged during transportation and handling.

Zinc in galvanized form is another protective coating that can be used. It is applied to the rebar by hot-dipping. Galvanized rebar is superior to carbon steel rebar; however, its protection against pitting and localized rusting in the presence of high chloride concentrations is somewhat limited. This technology will only delay or postpone the onset of cracking and spalling; it will not prevent them. More research is required to assess its effectiveness for corrosion protection.

Corrosion inhibitors in the concrete mix

Corrosion inhibitors are a class of protective products that are added to the concrete mix to delay and prevent corrosion. As such, they are considered admixtures. Both organic and inorganic inhibitors are commercially available. Calcium nitrite is an inorganic inhibitor and is the most extensively tested corrosion-inhibitive admixture since it was introduced during the 1970's. When applied according to the appropriate specifications and used with high-quality concrete, it performs quite effectively based on experience in the U.S., Japan and the Middle East.

During the 1990's, a number of proprietary organic inhibitors were introduced, including various amines, alkanolamines and emulsified mixtures of esters, alcohols and amines. The mechanisms by which organic inhibitors reduce corrosion remain imperfectly understood. Long-term performance comparable to that of calcium nitrite has not been established.

A researcher measures the rebar corrosion rate on a rebuilt barrier wall on the Vachon bridge.

Cathodic protection

Cathodic protection is a technology that polarizes the rebar to a more negative potential to reduce corrosion. This polarization can be achieved by applying current from an external DC power source or via a connection to a sacrificial anode. The difficulty with this technique is to ensure that an adequate current density and a reasonably uniform current distribution are applied on the rebar. Several materials have been chosen as anode systems such as organic conductive coatings, metallic conductive coatings of thermally sprayed zinc and zinc alloys, and activated titanium mesh. Their performance is dependent on the activity and durability of the anode system. Sometimes the performance can also be significantly affected by the quality of the bond between the sprayed coating and the concrete substrate.

Corrosion-resisting reinforcement

Appropriate stainless steels when embedded in concrete are superior to carbon steel in their ability to resist corrosion. Types 304 and 316 are most readily available and have been used in some concrete bridges in Ontario, Oregon and New Jersey. The initial cost of bridge construction may be higher when stainless steel is used, but when the life cycle cost and the longer life of the structure are factored in, stainless steel could be more cost effective.

A more economical approach is to combine stainless steel and carbon steel – using the stainless steel only in areas with a high risk of corrosion and the carbon steel in the low-risk areas. However, concern about the risk of galvanic corrosion between two different metals has prevented the coupling of these types of rebar in the field.

To find out whether the rate of galvanic corrosion really does increase when stainless steel and carbon steel are coupled, and to what extent, IRC researchers conducted a number of experiments. The results showed that the coupling of stainless steel and carbon steel in concrete structures does not increase the risk of corrosion. In fact, the rate of galvanic corrosion in the stainless steel/carbon steel combination was less than in the corroded carbon steel/un-corroded carbon steel combination. The researchers concluded that a judicious use of stainless steel in areas with a high risk of corrosion can be a cost-effective option for preventing corrosion and improving the durability of concrete structures. However, engineers and contractors must protect the stainless steel from contamination by rust from carbon steel during construction and transportation, because a significant amount of rust attached on the stainless steel can lead to increased galvanic action between the two metals.

Situations that might warrant the use of stainless steel include those areas that are directly exposed to de-icing salts, and therefore most vulnerable to corrosion, such as:

- top layer of reinforcing steel in bridge decks;
- lower portion of columns of highway overpasses (exposed to de-icing salt spray); and
- splash zone of piers in seawater or edge beams of highway bridges.

The study demonstrated that the two different types of reinforcement can be used in both new construction and repair applications.

In recent years, IRC researchers have conducted extensive research on the Vachon bridge in Laval, Quebec, an old bridge in Hawkesbury, Ontario, and a highway bridge overpass near Renfrew, Ontario. This research, along with other projects concerned with parking garages, will produce reliable new information for better protection of reinforced concrete structures against corrosion-induced deterioration.

For further reading about concrete problems and repair issues, readers can consult relevant articles in IRC's Construction Technology Update series at: http://irc.nrc-cnrc.gc.ca/catalogue/ctu.html

Photo captions (choice of 4 photos provided):

1. Corroded concrete column on a highway overpass in Ottawa.
2. A severely damaged parapet on the Vachon bridge in Laval, Quebec, before demolition.
3. A concrete slab on the Vachon bridge after demolition.
4. A researcher measures the rebar corrosion rate on a rebuilt barrier wall on the Vachon bridge. A corrosion inhibitor was added to the concrete used in the reconstruction.

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