

# Investigation of the Corrosion Propagation Characteristics of New Metallic Reinforcing Bars

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## ABSTRACT

The life of a concrete bridge exposed to deicing salt or seawater has often been limited by corrosion of the steel reinforcement. The service life of a concrete structure, degraded by corrosion, is considered to be the sum of the initiation and propagation periods. The initiation phase is the time required for sufficient accumulation of aggressive species at the rebar surface to initiate corrosion. The duration of the propagation phase is the total time until concrete cracking, caused by formation of corrosion products from the steel reinforcement, which occupy a larger volume than the parent steel. The conventional strategy for suppressing corrosion of carbon steel reinforcement has been to apply organic coatings. Unfortunately, a critical weakness of the coating is its susceptibility to mechanical damage during transport and placement. Furthermore, epoxy coated rebar was seen to be ineffective in extending rebar lifetimes, compared to uncoated carbon steel, in concrete constantly exposed to tropical seawater<sup>(1)</sup>. In order to extend concrete structure life, aside from numerous design considerations, improving the inherent corrosion resistance of the rebar is highly desirable<sup>(2)</sup>.

New candidate rebars being considered are; 2205 and 2101 duplex steels, 316LN stainless steel, 316L stainless steel clad (over carbon steel), and MMFX-2 steel rebar. In order to ascertain the potential benefits of implementing a new rebar it is necessary to characterize the corrosion behavior in both the initiation and the propagation phases. These corrosion characteristics are critical when considering the overall lifecycle cost of a concrete structure, since the new candidate rebar materials may incur a substantial increase in cost compared to carbon steel rebar. Therefore, an important aspect of this project is to develop lab techniques to assess these two phases in a shorter time period than allowed in the field. Two approaches are possible, highly sensitive testing or testing which accelerates the initiation process. To advance the capability of lab methods towards providing practical test results, a sand/glass bead mixture has been developed to mimic the mass transport and resistivity characteristics of concrete while enabling rapid set up of test cells and specimen examination following testing.

The concentration of chloride required to initiate substantial corrosion may be determined through potentiostatic and potentiodynamic testing. Earlier testing has shown that chloride threshold tests conducted at initial freshly immersed OCP would be ineffective for some of the candidate rebar materials, due to either chloride saturation of the test solution (saturated  $\text{Ca}(\text{OH})_2$ ) before corrosion was initiated or detection difficulties. Potentiostatic testing conducted at a conservative upper limit of OCP possible for rebars exposed for long times in concrete (+200 mV vs. SCE) has been developed. Potentiostatic polarization is used to simulate such long term OCP's. This method has shown that the chloride threshold values for some candidate rebar materials ( $\text{Cl}^-/\text{OH}^- > 25$ ) are well above that of carbon steel ( $\text{Cl}^-/\text{OH}^- < 1$ ). Determining chloride threshold values for each new rebar is critical since these values dictate the duration of the initiation phase.

Once corrosion has initiated, the morphology and spread of corroding environment (both laterally and radially) must be investigated. It is suspected that, once the corrosive environment has been established, low carbon steel will undergo widespread depassivation

laterally along the surface of the rebar. A preliminary experiment conducted on an array of low carbon steel microelectrodes has substantiated this. Figure 1 shows spreading of aggressive chemistry adjacent to a row of electrodes which were preferentially corroded. In contrast to carbon steel, it is likely that higher chromium content steels (2205, 2101, and 316LN) would only be susceptible to localized pitting due to their inherent resistance to corrosion in acidified solutions. However, the radial corrosion propagation rate may be substantial, and must be considered. Also, special considerations must be made for stainless steel clad rebar. Two outstanding issues regarding the corrosion propagation behavior are: galvanic corrosion between the clad layer and any exposed carbon steel core and localized corrosion which has perforated the stainless steel clad layer, see Figure 2.

The lateral spread of corrosion will be studied with the use of microelectrode arrays that allow for the corrosion behavior of passive areas to be monitored while adjacent to active corroding sites. Radial propagation studies will be conducted in a split cell that allows for separation of the anode and cathode sites. Further analysis of the corrosion products formed by each rebar will give insight into the relative differences in corrosion processes which occur on the different rebar materials. Analysis of the corrosion products to determine properties such as composition and crystal structure may be carried out through various techniques such as energy dispersive x-ray analysis, Auger electron spectroscopy, X-ray diffraction, and Raman spectroscopy. An indication of the deleterious effects of corrosion product agglomeration, with respect to carbon steel, may be seen for each of the different rebar materials.

Chloride induced corrosion of reinforcing bars in concrete structures can cause loss of structural integrity. The total lifetime of the structure is the sum of the initiation and propagation periods. The utilization of rebar with greater inherent corrosion resistance, in order to increase the concrete structure lifetime, is currently under investigation. The initiation and propagation stages are being studied through electrochemical testing. This research will enable characterization of the chloride threshold and passive and active corrosion rates. Further analysis of the corrosion products will allow prediction as to the extent of corrosion that can be tolerated before concrete structure degradation occurs.

## **ACKNOWLEDGEMENTS**

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## **REFERENCES**

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2. L.L. Smith, R.J. Kessler, and R.G. Powers: "Corrosion of Epoxy-Coated Rebar in a Marine Environment," *Transportation Research Circular*, Vol. 403, 1993, pp. 36.

## **For Further Reading**

- Paper number 02224 from NACE Corrosion 2002

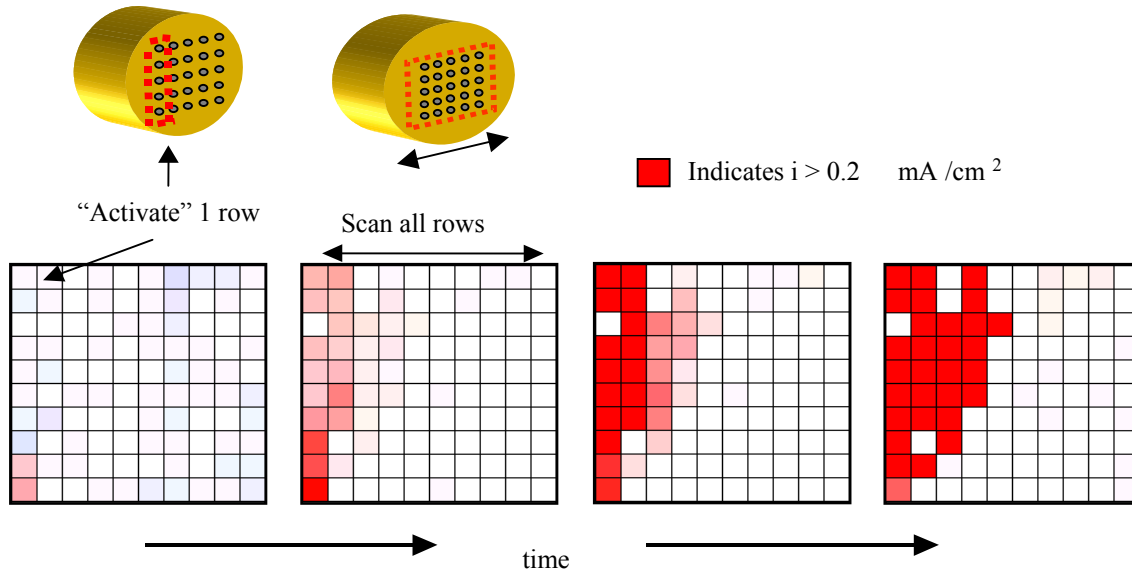


Figure 1. Results of a microelectrode array experiment conducted to monitor the spreading of the aggressive environment created during active corrosion. Electrodes were pure iron (99.5%, 250  $\mu\text{m}$  diameter) in a 100 electrode array (10 X 10, 36  $\mu\text{m}$  spacing). Testing was conducted in sat.  $\text{Ca}(\text{OH})_2$  + 0.1 M NaCl. The first row of 10 electrodes are “activated” through induced pitting by holding a row at 1.0 (V) vs. SCE for 5 minutes. Following such activation, a potentiodynamic scan was performed on all electrodes from 300 mV below OCP. Total scan range was from -0.72 to -0.32 (V) vs. SCE at 1 mV/sec. Corrosion is shown to spread from left to right as indicated by an increase in current density on electrodes that have become active.

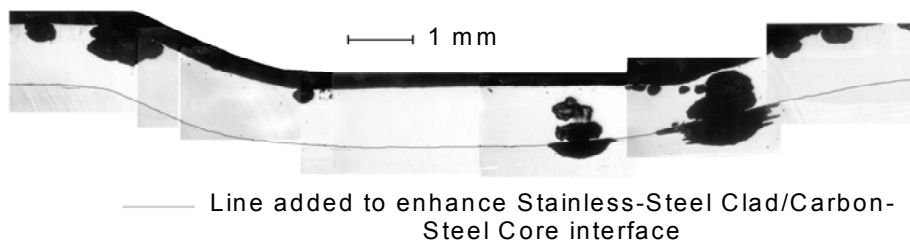


Figure 2. Longitudinal cross section of stainless steel rebar showing the interface between stainless steel cladding and carbon steel core, demonstrating pitting through the clad layer. Pits artificially induced through electrochemical polarization during testing