

Evaluation of Strategies Used for Protecting Steel in Concrete

Bala S. Haran, Soto Lorna, Ralph E. White and Branko N. Popov

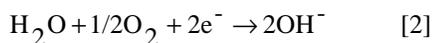
Center of Electrochemical Engineering
Department of Chemical Engineering
University of South Carolina, Columbia 29208

Introduction

Corrosion of steel in concrete is an electrochemical process involving (i) an anode, sites on steel where corrosion occurs and (ii) cathode, sites on rebar where oxygen reduction occurs. This is given by:



In order to maintain charge balance, electrons liberated at the anode are consumed at the cathode by the following reaction:



The ferrous ion from the anode combines with chloride to produce ferrous chloride. Chloride ions penetrate through the concrete cover and destroy this passive film.^{1,2} Breaking of the passive film involves formation of ferrous chloride complex. The nature of corrosion involves formation of galvanic cells both anodic and cathodic. The rate of cathodic reaction is controlled by the presence of oxygen and moisture in the concrete.

Protection of steel in concrete can be achieved by (i) choosing high resistant materials such as stainless steel, (ii) coating the steel with sacrificial elements such as zinc, or (iii) using inhibitors in the concrete mixture. Empirical studies have shown that depassivation of steel occurs when the chloride concentration reaches a critical threshold value. This value varies based on the concrete constituents and rebar type. Once the film breaks corrosion starts and the structure fails within 1-5 years.^{3,4} The goal of this study is to compare the performance of carbon steel rods protected using inhibitors and galvanized zinc. The behavior of stainless steel rebars in environments containing chloride and without it is also studied. Theoretical models predicting the lifetime of concrete structures have been developed to consider the transport of chloride ions through concrete.⁵

Experimental

Cylindrical concrete test specimens were prepared. The rebars used for testing were centrally embedded in concrete. Four sets of rebars were used in the studies – three based on #3 (0.9525 cm) carbon steel, #4 (1.27 cm), #6 (1.905 cm) and one #4 galvanized steel (1.27 cm and 3 mils thick Zn). Concrete mixtures with different concentrations of inhibitor were also prepared. The water to cement ratio was kept constant at 0.5. The concrete test cylinders were cured in water for a period of 14 days prior to the commencement of testing. After curing, the concrete samples were stored in PVC containers containing a test solution of deionized water. Two set of samples were studied – one with the addition of 3.5 wt% NaCl to the test solution and one with no chloride. For a control sample, the pH of the test solution in contact with the concrete interface was allowed to result from the composition of the concrete mix. The pH of the other sets of samples was kept at pH =12. Three sets of samples were used for all experiments. The concrete corrosion rates in these samples were determined using linear

polarization and impedance spectroscopy. Chloride permeation data have also been collected at new and existing bridges at various locations along the coast of South Carolina.

Results and Discussion

Experiments have been done to determine the effect of concrete cover thickness on the corrosion rate and the corrosion initiation time. The effect of concrete permeability on the chloride concentration profiles in the concrete cover has also been studied. In the absence of chloride, addition of inhibitor in the concrete mixture leads to the formation of a strong Fe₂O₃ passive film on the surface of carbon steel. Measurement of corrosion rate data indicates that this film is stable and protects the underlying metal from dissolution in concrete. However, calcium nitrite is ineffective in forming a similar passive film on the surface of zinc. Both the potential and corrosion rate data indicate that zinc dissolves sacrificially and protects the underlying iron. In the presence of chloride ions, the corrosion rate increases with time for carbon steel rebars. The inhibitor delays the onset of corrosion depending on the concentration of nitrite added in the mix. For galvanized steel the corrosion rate is initially high indicating rapid dissolution of zinc. Subsequently, the rate decreases and a steady state value reached after 20 months. Further studies need to be done to evaluate the behavior of the Zn depleted rebars in concrete with different nitrite concentrations. Finally, surface analysis indicates that in the presence of chloride ions, Zn corrodes to zinc hydroxy chloride. In high chloride content environments, use of Zn as a sacrificial coating could lead to increase in stresses in the structure due to the formation of voluminous corrosion products. Calcium nitrite is ineffective in forming a stable passive film on galvanized steel in concrete both in the presence and absence of chloride ions.

Studies are currently being done to evaluate the corrosion performance of stainless steel rebars in concrete in the presence and absence of chloride ions.

Acknowledgment

Authors acknowledge the financial support by South Carolina Department of Transportation (SCDOT) under contract No. 804-4-27-95.

References

1. E. V. Subramanian and H. G. Wheat, *Corrosion*, **45**, 43 (1989).
2. D. A. Hausmann, *Materials Protection*, **1**, 19 (1967).
3. O. E. Gjorv, K. Tan and Min-Hong Zhang, *ACI Materials Journal*, **91**, 447 (1994).
4. N. C. Berke and M. C. Hicks, *ASTM STP 1137*, Philadelphia (1992).
5. P. Arora, B. N. Popov, B. S. Haran, M. Rama, S. N. Popova and R. E. White, *Corr. Sci.*, **39**, 739 (1997).