

METALLURGICAL EFFECTS ON CHLORIDE ION CORROSION THRESHOLD OF STEEL IN CONCRETE

PROBLEM STATEMENT

Steel reinforced concrete has been extensively used for over a century because it is normally a versatile, economical, and durable construction material. The embedment of reinforcing steel bars (rebar) in concrete both provides a structure with optimal strength and furnishes the rebar with a protective environment. The highly alkaline environment of concrete (normally with pore water $\text{pH} > 13$) results in the formation of a dense, metal-adherent oxide film on the rebar surface, whose rate of corrosion is consequently held at a negligible level. However, the carbonation of concrete (caused by reducing pore water pH below ~ 9) can induce loss of passivity and cause the steel to corrode at significant rates.

Chloride ion contamination is even more detrimental in breaking down passivity. Chloride ions are the major cause for the corrosion of steel reinforcement in concrete. There are several ways by which chlorides can be introduced into concrete. They may exist at small levels within the mix ingredients of concrete (e.g. aggregates), or they may be introduced by the use of a chloride-containing admixture (e.g. calcium chloride as an accelerator) or saline water as mixing water (when fresh water is not available). However, chlorides in concrete most often come from the service environment to which the concrete structure is exposed (e.g., exposure to deicing salt or a marine environment).

Corrosion of steel in concrete has received increasing attention in the last three decades because of its widespread occurrence and the high cost of repairs. The corrosion of steel reinforcement has been widely observed in marine structures, chemical manufacturing plants, bridge decks, parking structures, and underground pipes. According to a Transportation Research Board Report (1991), deicing salts alone result in annual repair/maintenance costs estimated at \$50 to \$200 million for bridge decks, \$100 million for substructures and other components, and \$50 to \$150 million for multi-story car parks.

Investigations on the chloride-induced corrosion of reinforcing steel in concrete have been widely documented. However, two important issues are still unresolved: (1) whether chloride must reach a critical level (often called "chloride threshold") for steel in concrete to corrode, and (2) whether the "chloride threshold," if it exists, can be quantified, particularly as it relates to the condition of the steel itself and the surrounding environment.

OBJECTIVES

FDOT uses the chloride ion corrosion threshold as a key parameter to assess the time to corrosion initiation in marine substructures and as a means to determine the amount of chloride contamination that may exist in other cementitious media such as the grout surrounding post-tensioned high strength steel strands. This research, therefore, seeks to obtain an in-depth understanding of the fundamental causes of corrosion initiation in alkaline media, with emphasis on (1) the effect of the condition of the metal surface on the chloride corrosion threshold and (2) the statistical nature of the processes involved.

FINDINGS AND CONCLUSIONS

Open-circuit immersion tests investigated the effect of metal surface condition on the chloride corrosion threshold ($[Cl^-]_T$). Removing mill scale or any rust from the rebar surface by sandblasting elevated $[Cl^-]_T$ to about twice the value of as-received or prerusted steel. The threshold chloride-to-hydroxide ratio increased with pH, which suggests that the intrinsic inhibiting effect of hydroxide ions is stronger with a higher concentration of those ions. Ranges of total chloride threshold in concrete (C_{TT}) were estimated based on the liquid solution measurements and on available chloride binding data. The values thus estimated were consistent with those observed in concrete used in practice.

The effects of chloride content, pH, steel surface finish, scan rate, and passive film maturity on the distribution of pitting and repassivation potentials were examined with the cyclic polarization technique. The value of the pitting potential was not found to be a unique function of solution composition or steel surface condition, so a statistical approach was used to analyze the results. The variability tended to decrease at high values of the chloride-to-hydroxide ratio. The average value of the pitting potential for a series of replicate tests decreased with chloride content and steel surface roughness but increased with hydroxide ion content and passive film maturity. In contrast, the repassivation potential was nearly independent of solution composition and steel surface finish but found to depend on the severity of corrosion that took place during the return scan of the polarization cycle.

For most of the conditions examined, the average pitting potential was found to decrease significantly as the nominal specimen surface area increased. Neither the relative variability of the pitting potential nor the value of the repassivation potential was strongly affected by the specimen surface area. The experimental observations were in reasonable agreement with the prediction of the stochastic pitting initiation theory. The passivation process of rebar steel in alkaline solutions was found to be gradual and in agreement with the observation that the pitting potential increased with prepassivation time. The steady-state corrosion current density of passive rebar steel in alkaline solutions was estimated to be $0.01\sim 0.001 \mu A/cm^2$.

Researchers recommend incorporating a C_{TT} variability term in future service life prediction procedures; using a representatively large exposed steel surface area for future testing to determine C_{TT} ; performing exploratory cost/benefit analyses to assess possible use of sandblasted rebar surfaces and performing corresponding tests in concrete; performing careful assessment of effect of lowering pore water pH in new concrete formulations; and taking into consideration the effect of rebar potential on C_{TT} in future durability models.

BENEFITS

This investigation has advanced our understanding of the fundamental causes of corrosion initiation in alkaline media, particularly as regards the effect of the condition of the metal surface, and it has rendered ample evidence of the statistical nature of the processes involved. Consequently, this work has provided important insights into how the chloride ion threshold should be considered in future design efforts and in the decision-making process for the maintenance, repair, or rehabilitation of existing structures.

This research project was conducted by Alberto Sagues, Ph.D, P.E., at the University of South Florida. For more information, contact Rick Kessler, P.E., at (352) 337-3205, rick.kessler@dot.state.fl.us.