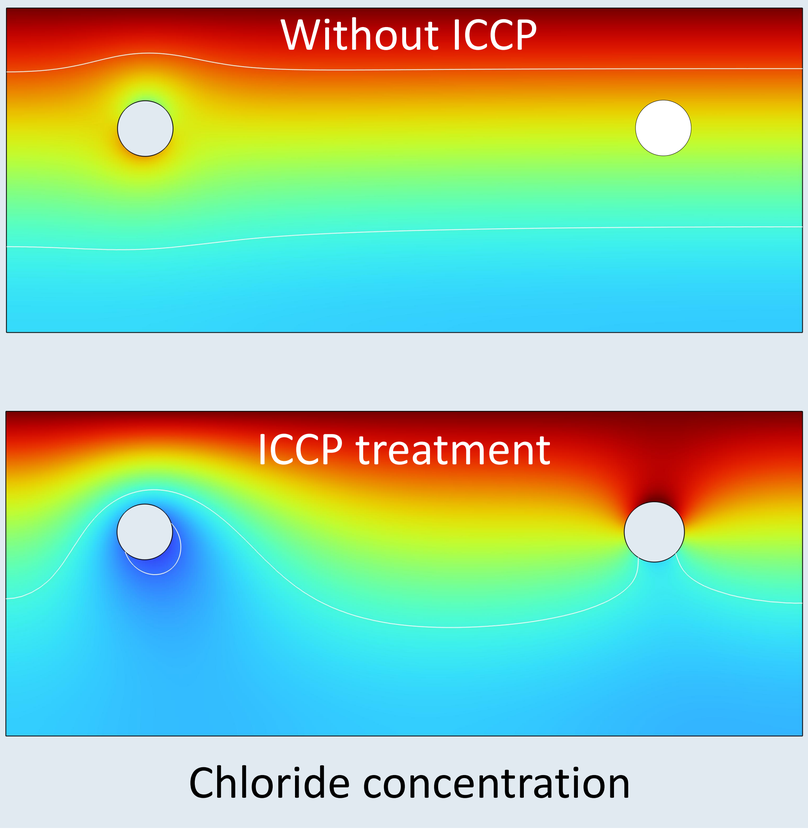


Numerical Evaluation of CFRP Bars as ICCP Anodes in Hybrid CFRP–Steel Reinforced Concrete Structures

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Introduction

Chloride-induced corrosion threatens reinforced concrete (RC) durability, while impressed current cathodic protection (ICCP) is widely used in chloride-contaminated concrete. A hybrid carbon fiber-reinforced polymer (CFRP)/steel RC system has been proposed [1], with CFRP bars serving as reinforcement and distributed ICCP anodes. We developed a coupled corrosion–ICCP model for a hybrid CFRP–steel RC bridge deck. The simulates chloride ingress, steel corrosion, and subsequent ICCP treatment, and systematically investigates how critical parameters, such as impressed current density and protection duration influence ICCP performance.

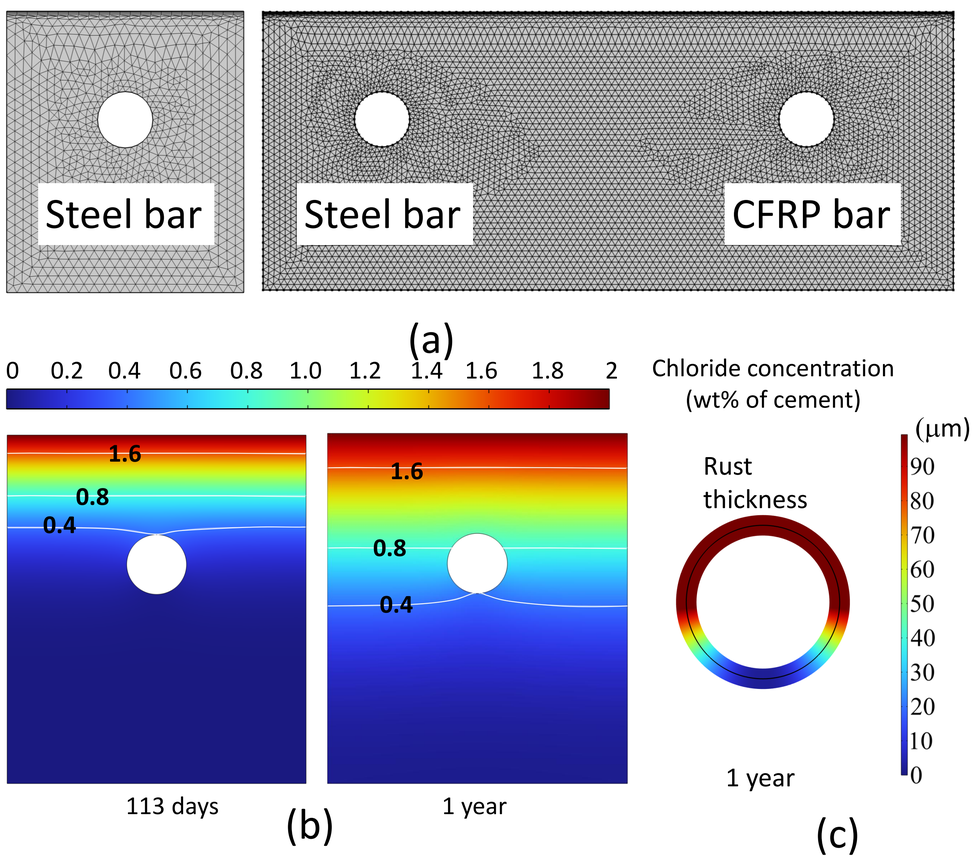


FIGURE 1. (a) Model geometry in COMSOL. (b) Chloride transport in corrosion model. (c) Rust thickness

Methodology

Two coupled 2D time-dependent models were developed in COMSOL Multiphysics 6.4. The corrosion model represented a 60 × 70 mm concrete section with a 6 mm steel-bar radius and 20 mm cover. Chloride ingress and nonuniform steel corrosion were simulated by coupling transport of Cl^-, OH^-, Fe^{2+}, Na^+, and Ca^{2+} with electrode kinetics. The ICCP model used an extended 172 × 70 mm section containing both steel and CFRP bars. The CFRP bar acted as a distributed anode, with a CFRP-to-steel area ratio of 1.0. The cover and surface chloride level were maintained at 20 mm and 2 wt% of cement, respectively. Applied current densities were 10 mA/m^2. Ion concentrations and rust thickness were evaluated.

Results

Under ICCP, the average chloride concentration near the steel decreased rapidly during the first six months. At 10 mA/m^2, it fell from approximately 0.95 to 0.65 wt% of cement. Higher current density produced higher chloride reduction around the steel surface. Over the two-year period, increasing the current density from 10 to 15 mA/m^2 further reduced the chloride concentration from 0.62 to 0.44 wt%, corresponding to an additional reduction of approximately 29%. The reduction pattern is consistent with that of ref [2].

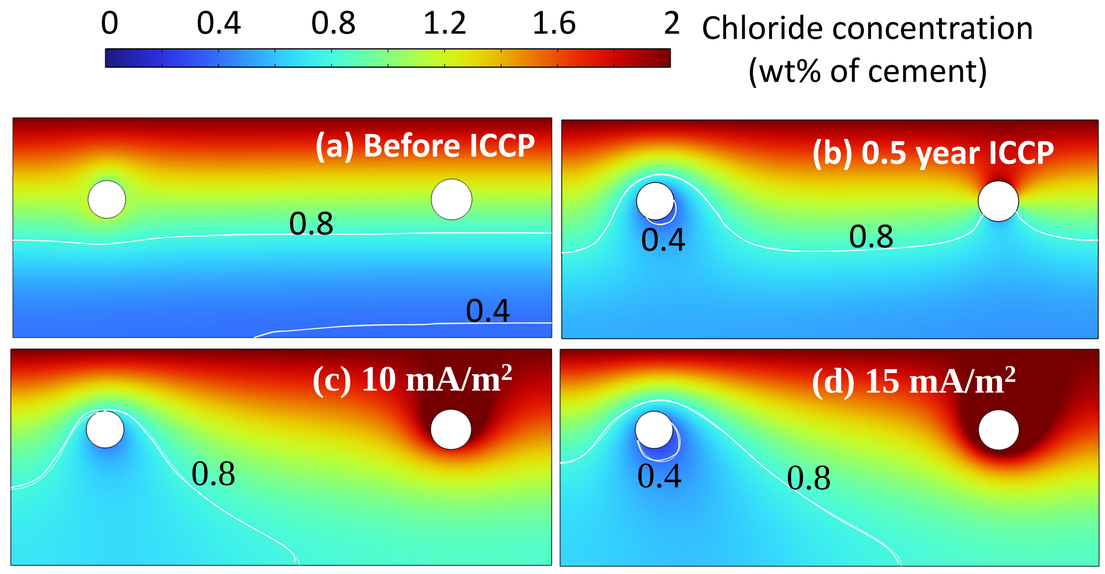


FIGURE 2. Chloride concentration distribution (a)&(b) at different time. (c)&(d) with different current densities.

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