

INVESTIGATION ON ELECTROCHEMICAL INTERACTION BEHAVIORS BETWEEN ADJACENT COATING DEFECTS IN STEEL STRUCTURE

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ADJACENT COATING DEFECTS IN STEEL STRUCTURES

(鋼構造物における近接塗膜欠陥間の電気化学的相互作用挙動の解明に関する研究)

区 分：甲

論 文 内 容 の 要 旨

The corrosion of steel can often be the primary cause of damage to various types of infrastructure. To mitigate corrosion, coating is widely used as the primary protective method for steel. When exposed to atmospheric conditions, the coatings encounter factors such as UV radiation, salinity, moisture, and temperature fluctuations, which can lead to coating deterioration. Assuming the absence of electrochemical interactions between these steel substrates, uniform corrosion is considered for the steel substrate at the location of coating defect. Even for the same metal material, the substrate at different coating defect locations may exhibit different potentials owing to environmental factors such as surface roughness, corrosion products, and dust accumulation. If these potential-affecting factors do not change significantly, this potential difference may persist for a long time. When rainwater or condensed water connects these defects to form an electrical circuit, electrochemical interactions may occur between the metal substrates at the defects, leading to macrocell corrosion.

Two critical conditions for macrocell corrosion are the potential difference between different areas of the steel and the presence of a continuous electrolyte that connects these areas into an electrical circuit. In steel structures exposed to heavy salt in atmospheric conditions (e.g., accumulation of airborne sea salt), the resistivity of the electrolyte can be as low as a few tenths of $\Omega\cdot\text{m}$, which is significantly lower than that of concrete. This low resistivity enables even small potential differences to generate substantial macrocell currents, accelerating corrosion rate, especially during the wet-dry environment. When zinc-rich coatings are applied, the sacrificial anodic protection of steel by Zn powder further complicates these electrochemical interactions. However, only a limited number of studies have explored this phenomenon.

Therefore, this study aims to elucidate the electrochemical interaction behavior between adjacent coating defects in steel structures. The effect of macrocell current on the corrosion rate of carbon steel during immersion and natural drying was investigated by evaluating the variation patterns of macrocell current in different test environments. After clarifying the corrosion mechanism influenced by macrocell current between steel substrates, I further analyzed the electrochemical interaction mechanisms between defects in zinc-rich coatings, considering their application in actual structures. The detailed work in this study is divided into 6 chapters.

Chapter 1 presents the introduction of this study, covering the background, research objective and literature reviews related to the corrosion phenomena investigated in this research, along with the corresponding anti-corrosion measures, fundamental principles, and outlines.

Chapter 2 primarily analyzed the microcell corrosion rate of carbon steel in the immersion environment. Potentiodynamic polarization (PDP) tests were conducted to determine the polarization curves of carbon steel in NaCl solutions of varying concentrations. I also discussed the limitations of the conventional Tafel extrapolation method in accurately determining the corrosion rate of carbon steel.

Chapter 3 focused on the corrosion characteristics of carbon steel after the onset of macrocell corrosion, as identified through macrocell current testing. I hypothesized that the macrocell current was controlled by the oxygen diffusion current density, as suggested by the proportional relationship between macrocell current and cathode area. The results indicated that the size of defects affected the oxygen diffusion mechanism on the electrode surface, influencing the corrosion rate of carbon steel. Finally, by comparing the macrocell current density with the microcell corrosion rate measured in Chapter 2, I confirmed that the magnitude of the macrocell current was indeed controlled by oxygen diffusion.

Chapter 4 analyzed the macrocell corrosion mechanism under natural wet-dry cycles. By applying the mixed potential theory, I investigated the necessary conditions for macrocell corrosion to occur. I also discussed the effects of electrolyte resistivity and the anode-to-cathode area ratio on macrocell corrosion. Finally, I summarized how macrocell current accelerates corrosion in atmospheric environments.

Chapter 5 investigates the macrocell corrosion mechanism between coating defects under zinc-rich coating conditions. First, electrochemical impedance spectroscopy (EIS) was used to analyze the microcell corrosion behavior of carbon steel at zinc-rich coating (ZRC) defects. Then, macrocell current tests were conducted between ZRC defects to evaluate the electrochemical interactions at coating defect sites. Lastly, I discussed the electrochemical interactions between defects influenced by the sacrificial anode effect of zinc.

Chapter 6 summarized the main findings of this study and discussed the challenges and potential breakthroughs in conducting corrosion research from an engineering perspective. The limitations of this research were also analyzed, and future research directions were proposed.