Application Note

Studying Corrosion of Steel with PARSTAT 4000A Potentiostat

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Steel is widely used in various industries due to its excellent mechanical properties and affordability. However, one of the major issues associated with steel is its susceptibility to corrosion, which can significantly affect its durability and reliability. In this application note, we discuss the electrochemical techniques that are widely used to study steel corrosion and provide valuable insights into the corrosion mechanism and corrosion protection strategies.

Introduction

Steel corrosion is a natural process that occurs when steel is exposed to air and moisture. It is the gradual destruction of the metal due to electrochemical reactions between the metal and its environment. When steel corrodes, it can weaken the structure and eventually cause it to fail. It is usually caused by a variety of factors, including exposure to saltwater, air pollution, and chemical pollutants. In addition, poor maintenance and lack of protective coatings can accelerate the corrosion process. To prevent steel corrosion, it is essential to take steps to protect the metal. One common approach is to apply a protective coating such as paint or a rust inhibitor. Another approach is to use a more corrosion-resistant material, such as stainless steel or galvanized steel.

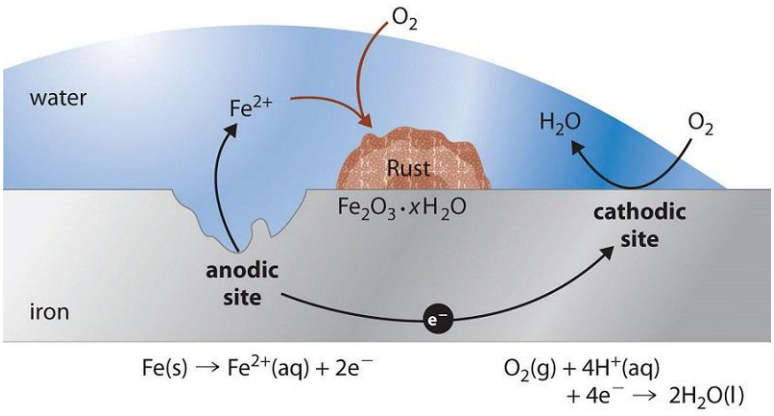

Figure 1. The formation of rust is a consequence of metallic iron corrosion. At a location on the iron's surface, typically an impurity or lattice defect, iron undergoes oxidation to Fe^{2+}(aq). Meanwhile, oxygen is reduced to water at another surface site, which acts as the cathode. Electrons are transferred through the metal, which is electrically conductive, from the anodic site to the cathodic site. Water, a solvent for the initial Fe^{2+} produced, functions as a salt bridge. Rust (Fe_2O_3•xH_2O) is generated by further oxidation of Fe^{2+} by atmospheric oxygen.[1]

The electrochemical process of steel corrosion involves anodic and cathodic reactions. In the presence of an electrolyte, steel forms anodic and cathodic sites. The anodic site is where steel loses electrons and undergoes oxidation, which results in the formation of iron oxide. The most commonly used electrochemical techniques for studying steel corrosion are Potentiodynamic Polarization, Electrochemical Impedance Spectroscopy (EIS), and Electrochemical Noise Analysis (ENA). These techniques can provide valuable information about the corrosion rate, corrosion mechanism, and corrosion protection strategies.

Potentiodynamic Polarization:

Potentiodynamic polarization is a widely used electrochemical technique that measures the corrosion potential and the corrosion current density of the steel. This technique involves scanning the potential of the steel electrode from a cathodic potential to an anodic potential at a constant scan rate while measuring the current density. The polarization curve obtained from this technique can provide information about the corrosion behavior of the steel, such as the pitting potential, passivation potential, and corrosion rate.

Electrochemical Noise Analysis (ENA):

ENA is a non-destructive electrochemical technique that measures the potential and current fluctuations of the steel electrode. The noise data obtained from ENA can be analyzed using statistical and spectral analysis techniques to obtain information about the corrosion mechanism and the corrosion rate of the steel.

Electrochemical Impedance Spectroscopy (EIS):

EIS is a non-destructive electrochemical technique that measures the impedance of the steel electrode as a function of frequency. EIS provides information about the corrosion mechanism and the corrosion protection strategies of the steel. The impedance data obtained from EIS can be analyzed using equivalent circuit models, and the parameters obtained from the model can provide information about the corrosion mechanism and the effectiveness of the corrosion protection strategies.

Scanning Electrochemical Microscopy (SECM):

Scanning Electrochemical Microscopy (SECM) is a more advanced technique that provides high-resolution images of the surface of steel. It involves scanning a microelectrode over the surface of the steel while measuring the current response. By varying the position of the microelectrode, information about the local corrosion behavior can be obtained.

Examples

Researchers at the Beihang University, Beijing recently studied the corrosion properties of cathodically protected X80 Steel under different temperature soil.[2] The study compared the pitting behavior of new corrosion-resistant alloy steel (CR) and low-carbon steel (LC) in a chloride-rich concrete pore solution. Multiple techniques were used to analyze electrochemical behavior, pitting profiles, and chemical components.

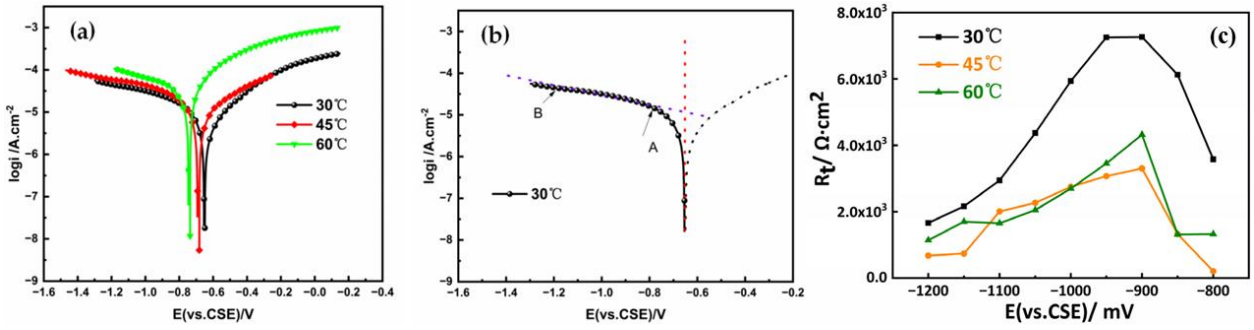

Figure 2. (a) Tafel polarization curves of X-80 in soil extracts at different temperatures, (b) Cathodic polarization curve at 30 °C, (c) charge transfer resistance (Rt) versus potential plots.[2]

Jin Li and co-workers examined the influence of surface roughness on pitting corrosion of 2205 duplex stainless steel. The study utilizes electrochemical noise measurements (ENM) to investigate the corrosion behavior. The results show exceptional capabilities of **PARSTAT 4000A** for ENM in very low current and voltage ranges. The results indicate that the surface roughness significantly affects the pitting corrosion behavior of the 2205 duplex stainless steel.

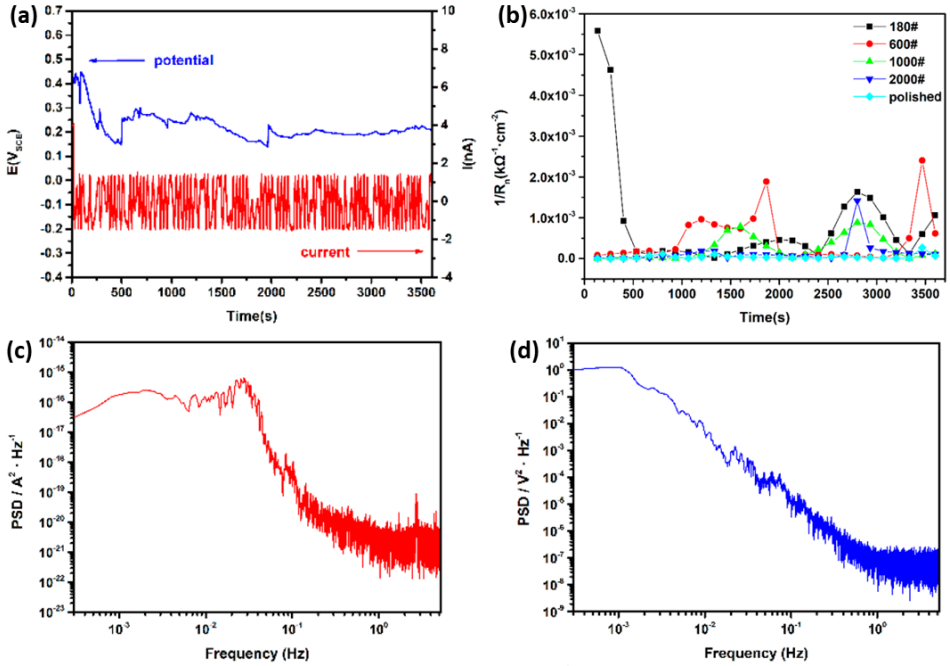

Figure 3. (a) Typical EN patterns, (b) Reciprocal of EN resistance ($1/R_n$), (c) Current PSD, and (d) Voltage PSD for DSS 2205 polished with 180# in 10% $FeCl_3$ solution at 50 °C.[3]

Considering the low current range capabilities of **PARSTAT 4000A potentiostat**, recent research from the Chinese Academy of Sciences studied anti-corrosion properties of Migratory Corrosion Inhibitors (MCIs) on reinforced concrete exposed to varying degrees of chloride erosion. The research demonstrates sophisticated Tafel measurements down to the current range of attoampere (aA= 10^{-18} A).

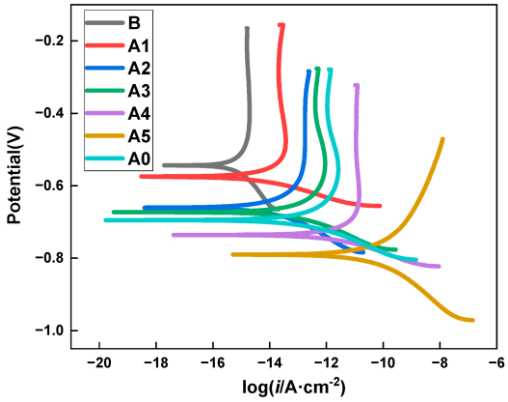

Figure 4. Potentiodynamic polarization curves of specimens coated with MCIs after different degrees of chloride erosion.

Not only the DC techniques, but AC measurement techniques have also been identified equally valuable for corrosion studies on steel. A recent study utilized various electrochemical techniques to examine the steel's corrosion resistance and passivation behavior, including the electrochemical impedance spectroscopy

(EIS).[4] Results indicate that the Cr10Mo1 alloy steel exhibited good passivation behavior in simulated concrete pore solutions, with the passivation film's stability increasing with pH and decreasing with increasing chloride concentrations. The study also found that chloride ions could hinder passivation by disrupting the oxide film and inducing pitting corrosion. Overall, the study highlights the importance of pH and chloride concentration in determining the passivation behavior of Cr10Mo1 alloy steel in simulated concrete pore solutions.

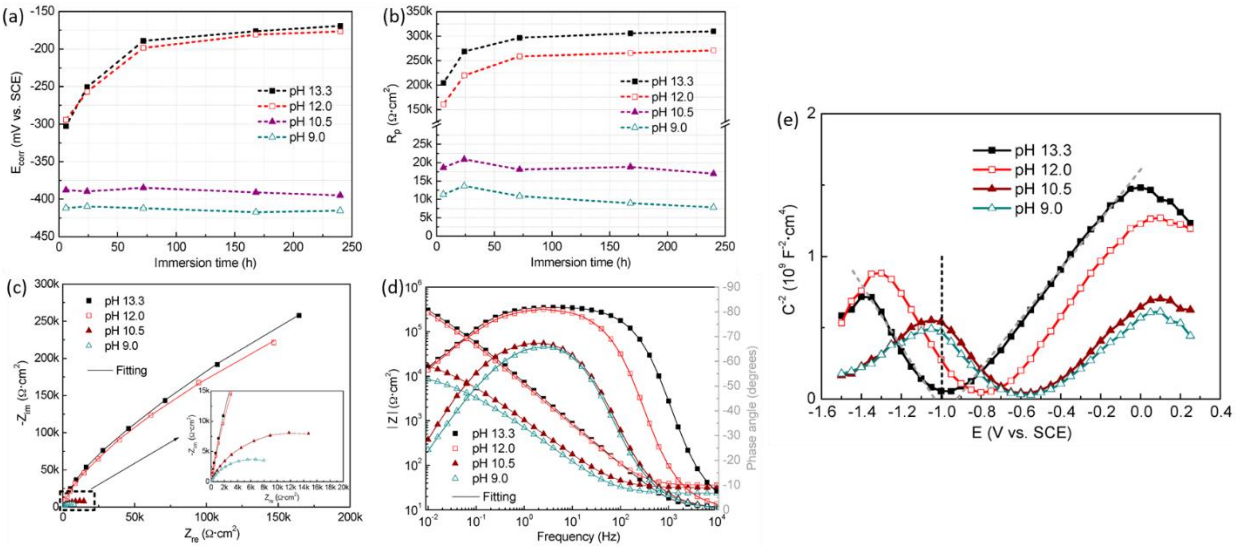

Figure 2. Corrosion potential (Ecorr) and polarization resistance (Rp) of the steel as a function of time in solutions of different pH with 1.0 M Cl^-: (a) Ecorr; and (b) Rp; Measured EIS (in Nyquist and Bode forms) of the steel in solutions of different pH with 1.0 M Cl– after 7 d immersion: (c) Nyquist plots; and (d) Bode plots; (e) Mott-Shottky plots for passive films formed on the steel in solutions with different pH at 7 d immersion in 1.0 M Cl^- [4]

Conclusion

Electrochemical techniques are widely used to study steel corrosion and provide valuable insights into the corrosion mechanism and corrosion protection strategies. Potentiodynamic polarization, EIS, ENA, and SECM are the most commonly used electrochemical techniques for studying steel corrosion. These techniques can provide information about the corrosion rate, corrosion mechanism, and corrosion protection strategies, which are essential for developing effective corrosion protection strategies for steel.

References:

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2. Liu W, Meng Y, Zhao J, Wen W, Gong M, Wu S, Li S, Yu M, Liu J. Electrochemical and Mechanical Properties of Cathodically Protected X80 Steel in Different Temperature Soil. Materials.; 15(16), 5526, https://doi.org/10.3390/ma15165526, 2022.
3. Tang Y, Dai N, Wu J, Jiang Y, Li J. Effect of Surface Roughness on Pitting Corrosion of 2205 Duplex Stainless Steel Investigated by Electrochemical Noise Measurements. Materials, 12(5), 738, https://doi.org/10.3390/ma12050738, 2019.
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