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学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Study on Hydrogen Absorption into High-Strength Low-Alloy Steel During Corrosion in Simulated Atmospheric Environments

(模擬大気腐食環境下における高強度低合金鋼の水素侵入挙動に関する研究)

Stress corrosion cracking (SCC) is a crucial safety concern of steel structures. The coupled effects of tensile stress and corrosive environments on steel can cause crack growth and lead to unexpected and sudden failure. Currently, a potential issue of SCC is to address the hydrogen-induced problems due to a positive correlation between the strength of a metal and its susceptibility to hydrogen embrittlement. For this reason, the wide utilisation of high-strength low-alloy steels in the construction industry, especially in storage and distribution systems for hydrogen, makes hydrogen-assistant failure of these components a critical concern. Atmospheric corrosion is an environmental degradation phenomenon of steel structures and is commonly accompanied by hydrogen evolution as a side reaction. A considerable amount of hydrogen is supposed to be produced and subsequently absorbed by the steel, presenting challenges to the material durability of steel infrastructures. It is, therefore, necessary to consider the potential problems of corrosion and understand the mechanisms of hydrogen-assistant cracking of steel during corrosion in atmospheric environments.

The present thesis concentrates on the impact of environmental factors such as relative humidity (RH), temperature, and salt aerosols on corrosion performance and the corresponding hydrogen uptake during atmospheric corrosion of high-strength low-alloy steels. Chapter 1 provides a fundamental overview of the state of knowledge with respect to atmospheric corrosion of steel and hydrogen-assistant cracking, which provides the information required to understand the background and importance of hydrogen-related issues in the scope of atmospheric corrosion.

The main focus of Chapter 2 lies in determining the hydrogen absorption behaviour of steel during corrosion under different RH conditions. RH is a factor of crucial importance since it is responsible for the presence of electrolytes during atmospheric corrosion. When RH reaches a specific value known as deliquescence relative humidity (DRH), the deposited salts on the steel surfaces will absorb moisture from the air to form aqueous electrolyte layers for corrosion to occur. Thus, the effect of RH on the corrosion and hydrogen absorption of steel under NaCl deposit was investigated by controlling the RH at different levels below the DRH of NaCl during wet-dry cycles. The results suggest hydrogen absorption into steel can occur even if the surrounding RH is below the DRH of NaCl. The amount of permeated hydrogen increases with higher RH in the dry stage of the wet-dry cycles, which is attributed to the prolonged period of the presence of liquid phase inside the corrosion products.

Chapter 3 assesses the applicability of the Hard and Soft Acids and Bases (HSAB) concept in explaining the effect of metal cations of dissolved salts on corrosion kinetics under salt droplets. An analysis of corrosion and hydrogen permeation of steel under aqueous NaCl, MgCl₂, ZnCl₂, and AlCl₃

solution droplets was conducted to investigate the role of different hygroscopic salts and their metal cations in the cyclic wet-dry corrosion. When corrosion occurs under salt droplets containing Mg^{2+} , Zn^{2+} , and Al^{3+} , cation-containing layers are supposed to form on the steel surfaces and present corrosion resistance. Based on the HSAB concept, the metal cations with higher cation hardness are easier to combine with the hard bases such as H_2O and OH^- of the passive films, forming stable protective passive films against corrosion attack under salt droplets.

Chapter 4 verifies whether the concept of the time of wetness (TOW) is practicable to understand the association between hygroscopic salts and the hydrogen absorption behaviour of steel during wet-dry cycles. After water evaporates and steel surfaces become apparently dry, the hygroscopic property of the salts deposited within the porous rust layers plays a dominant role in the corrosion and hydrogen absorption processes. The salts with low deliquescence values retain the presence of thin electrolyte layers with high chloride concentrations within the porous rust structures, affording a prolonged TOW for corrosion and hydrogen absorption into steel.

Chapter 5 summarises the findings and gives the overall conclusion of the research work. Based on the experimental results and analysis, the TOW and HSAB concepts are applicable in explaining the role of salts in the corrosion and hydrogen absorption activity of high-strength low-alloy steel during atmospheric corrosion. This study suggests that localised pitting and acidification under rust layers are responsible for accelerated hydrogen entry into steel during wet-dry cycles.