Evaluation of hydrogen absorption into steel with alternating current responses

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Hydrogen embrittlement of steels has been of increasing concern with increasing their strength. This is because susceptibility of hydrogen embrittlement is highly relevant with the strength of steels. Since steels are commonly used as structural materials in atmospheric environments, hydrogen atoms which can cause hydrogen embrittlement can be generated by reduction reactions of proton or water under atmospheric corrosion conditions. At this time, a part of the hydrogen atoms generated during corrosion can be absorbed into steels and then the absorbed hydrogen atoms can interact with steel matrix, which may cause cracking or degradation. Therefore, it is quite important to evaluate hydrogen adsorption into steel. In this study, hydrogen absorption into steels was investigated by measurements of permeation current responses induced by stimulating hydrogen evolution reaction with potential perturbation.

Figure 1 shows the Devanathan-Stachurski cell used in this study [1]. Samples were a commercial carbon steel sheet which size was 40 mm^{w} x 40 mm^{L} x 0.43 mm^{t}. Both sides of the sample were polished with SiC waterproof papers and the one-side of it was electroplated with Pd about 400 nm in thickness. As shown in Fig. 1, the prepared sample was clamped with two compartments of electrocemical cells; one compartment is for hydrogen entry and the other is for hydrogen withdrawal. In each compartment, a luggin capillary and Pt wire as a counter electrode were installed. The solution used in the compatment for hydrogen-withdrawal side was 0.2 M NaOH. The Pd-coated surface of a steel was polarized at a constant potential of 0.1 V (Ir/IrO_2) to oxidize hydrogen atoms permeated through the steel. On the other hand, the solution in the compartment for hydrogen-entry side was a 0.5 M NaCl solution. Applied potential at a steel surface for hydrogen-entry side was in the range from -1.1 to -0.6 V (SSE).

Figure 2 shows Cole-Cole plots for a steel in 0.5 M NaCl at different polarization potentials. In Fig. 2, electrochemical impedance increases as the polarization potential becomes more noble. Especially, electrochemical impedance measured at the potential less noble than -0.85 V (SSE) shows small semicircles, indicating that hydrogen evolution reaction becomes more activated in this potential region. However, the EIS behavior doesn't change at the potential nobler than -0.75 V (SSE), meaning that oxygen reduction reaction becomes dominant under a diffusion-limiting condition.

Figure 3 shows typical current responses for the hydrogen-entry and hydrogen-withdrawal sides measured at -1.1 V. In Fig.3(b), the current response for the hydrogen-entry side are synchronous with potential perturbation at lower frequencies less than 100 mHz. On the other hand, as shown in Fig. 3(c), hydrogen permeation current responses can hardly be detected at the frequencies higher than 15.8 mHz (from 1 to 1.4 ks). This suggests that absorption reaction of hydrogen atoms into steel is significantly slow compared to hydrogen evolution on a steel. From the results of current responses in Fig. 3, hydrogen absorption efficiency, i_{perm}/i_c, can be estimated to be ca 1.8 x 10^{-4} in the case of -1.1 V. By analyzing current responses due to hydrogen evolution and hydrogen permeation, hydrogen absorption into steel can be successfully evaluated.

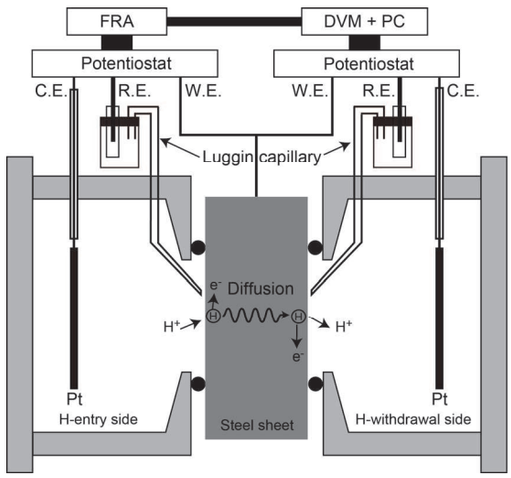

Figure 1 Experimental set-up for the Devanathan-Stachurski hydrogen permeation cell.

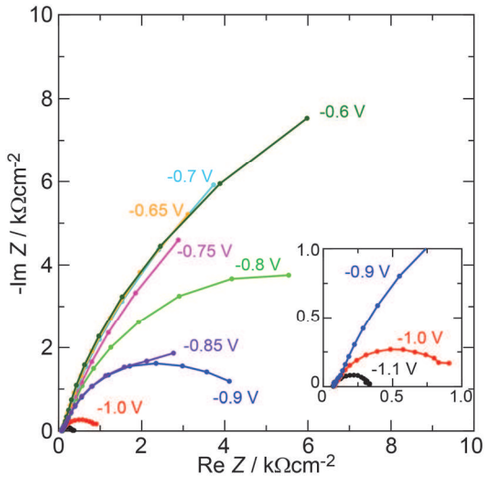

Figure 2 Cole-Cole plots for a steel sheet in 0.5 M NaCl at different potentials.

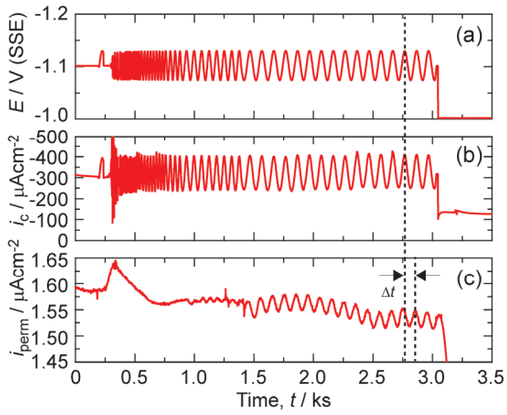

Figure 3 Current responses measured at hydrogen-entry side (b) and hydrogen-withdrawal side (c) with alternating potential inputs (a) at the entry-side of the sheet.

Reference

[1] M. A. V. Devanathan, Z. Stachurski, *Proc. R. Soc., London*, **A270** (1962) 90-102.