

Effect of Constant Load on Hydrogen Diffusion and Trapping of API X65 Grade Linepipe Steel

Gyutae Park and Kyoo Young Kim*
Graduate Institute of Ferrous Technology, POSTECH, Pohang, Korea

Hwan Gyo Jung and Seong Ung Koh
Technical Research Center, POSCO, Pohang, Korea

The present research aims at investigating the hydrogen diffusion and trapping behavior of API X65 grade linepipe steel under constant load test, which is one of the standard sulfide stress cracking (SSC) evaluation methods. The modified electrochemical hydrogen permeation technique is combined to constant load test. Reproducible hydrogen permeation transients are obtained by carefully controlling the electrochemical surface condition without palladium coating. As the applied load increased, steady state permeability and hydrogen diffusivity decreased, and diffusible hydrogen content increased. These results indicate that more hydrogen has reacted with metallurgical defects in the steel which are sensitive to SSC initiation or propagation.

INTRODUCTION

Hydrogen-induced cracking (HIC) and sulfide stress cracking (SSC) are hydrogen-related cracking phenomena of carbon steel upon exposure to a wet sour environment at ambient pressure and temperature (NACE, 2002). The presences of hydrogen in the steel and its interaction with metallurgical defects, which are sensitive to hydrogen cracking, have been widely accepted as a primary cracking mechanism (NACE, 2003). Even though the relationship between hydrogen behavior and HIC has been extensively investigated, still debatable is what is the role of hydrogen on SSC failure, and which hydrogen parameter is a key factor because of the limitations of currently available hydrogen analysis techniques, which are merged directly with standard SSC evaluation methods. Although several researchers have attempted to combine the electrochemical hydrogen permeation cell with the universal tensile machine (Hwang and Bernstein, 1983; Brass and Chene, 2006), the stress regime is different from that of standard SSC methods, which are to impose a constant load smaller than threshold stress, and it is not clear if hydrogen diffusion and trapping parameters measured under an unrealistic stress regime can be correlated with SSC resistance.

The electrochemical hydrogen permeation technique, first introduced by Devanathan and Stachurski (1964) and standardized as ISO17081 (2004), is a laboratory-scale experiment to investigate hydrogen diffusion and trapping behavior in metallic material. It is easy to perform the testing in the laboratory and enables to measure various hydrogen parameters such as apparent hydrogen diffusivity, permeability and indirectly diffusible hydrogen content using modified Fick's first law regarding hydrogen trapping. How-

ever, the surface condition should be kept constant and boundary conditions should satisfy well Fick's law of diffusion in order to generate reproducible results continuously (Turnbull, 1995). A thin palladium (Pd) coating layer electrochemically deposited on the specimen surface at the hydrogen detection side has been widely used to enhance hydrogen oxidation as well as to avoid a change of surface condition during hydrogen diffusion (Manolatos et al., 1995a) because of its inertness in corrosive media and suppression of recombination reaction for diffusing hydrogen atoms. Nevertheless, it is not easy to acquire a uniform Pd coating consistently using electro-deposition. Even soft Pd coating with yield strength (YS) lower than that of carbon steel can be plastically deformed upon imposition of elastic stress to the specimen with Pd coating, which generates a nonuniform Pd coating with defects and impedes the reliability of the hydrogen permeation curve (Hwang and Bernstein, 1983). A stable oxide layer has been proposed instead of using Pd coating. However, the hydrogen oxidation rate is significantly reduced because of slow hydrogen diffusion through the oxide layer and formation of hydrogen bubbles, which indicates some of the diffusing hydrogen atoms are recombined so that they are not added up to the total hydrogen oxidation current (Manolatos et al., 1995b). Several attempts to apply an oxide layer to the electrochemical hydrogen permeation technique have revealed that the oxide layer is electrochemically very stable in an anaerobic 0.1 M NaOH solution during the overall testing time, and diffusing hydrogen atoms are oxidized at the interface between oxide layer and steel matrix (Casanova and Crousier, 1996).

In this research, a stable oxide layer developed by imposing passivation potential in the anaerobic 0.1 M NaOH solution is used instead of Pd coating, and several surface pre-treatments are applied to satisfy consistent boundary conditions. An electrochemical hydrogen permeation cell and a tensile specimen are particularly designed to combine with a dead weight machine to simulate the same stress regime as the standard SSC evaluation method. The effect of constant load on hydrogen diffusion and trapping behavior is discussed in terms of internal changes in microstructure during elastic deformation and hydrogen permeation.

*ISOPE Member.

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