Effect of elastic and plastic deformation on hydrogen permeation process in X80 pipeline steel

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Abstract Industrial pipelines, crucial for transporting oil and natural gas, are susceptible to hydrogen-induced failures due to hydrogen ingress and local stress concentration[1]. Understanding hydrogen's role in pipeline steel under various stress-strain conditions is essential. This study investigated hydrogen permeation kinetics in X80 pipeline steel under different stress-strain conditions using Devanathan-Stachurski (DS) cell experiments and DFT calculations [2]. Results showed that the increased stress slightly raises the diffusion coefficient meanwhile significantly boosts subsurface hydrogen concentration. Shallow hydrogen traps formed under plastic deformation hindered hydrogen permeation. Both in situ synchrotron radiation characterization during tensile process and TDS tests confirmed that the shallow hydrogen traps correspond to dislocations in the microstructure. The study established relationship between stress and subsurface hydrogen concentration as well as the correlation between plastic deformation and trap density in X80 steel. As a result, hydrogen permeation kinetics model for X80 steel under stress condition was developed. Numerical simulation of a notched DS hydrogen permeation sample highlights the effect of local stress concentration on hydrogen permeation.

Keywords Hydrogen permeation; Hydrogen trap; Tensile stress; Pipeline steels; High-energy X-ray diffraction; Finite element modelling.

Reference

[1] S. Zheng, Y. Qin, W. Li, F. et al.. Effect of hydrogen traps on hydrogen permeation in X80 pipeline steel —— a joint experimental and modelling study. INT J HYDROGEN ENERG. 48 (2023), 4773-4788.

[2] S. Chen, M. Liu, C. Leygraf, et al.. First-principles analysis of the stability and hydrogen adsorption properties of the α-Ti/α2-Ti3Al interface towards clarified hydrogen embrittlement mechanism of titanium alloys. INT J HYDROGEN ENERG. 72 (2024), 338-348