SAFE PIPELINES FOR HYDROGEN TRANSPORT – RESULTS FROM THE HYLINE PROJECT

L. Jemblie[1], A. Alvaro[1], C. M. Hagen[1], A. B. Hagen[1], B. Nyhus[1], R. Johnsen[2], A. Vinogradov[2], Z. Zhang[2], J. Yamabe[3], H. Matsunaga[4], V. Olden[1]
[1] SINTEF, Trondheim, Norway
[2] Norwegian University of Science and Technology, Norway
[3] Fukuoka University, Japan, [4] Kyushu University, Japan

Corresponding author's e-mail address: Lise.Jemblie@sintef.no

Keywords: Hydrogen affected mechanical properties, Hydrogen uptake and diffusion, Numerical models for predicting hydrogen-induced failure

ABSTRACT

A safe and efficient use of Norway's 8800 km subsea natural gas pipeline network for transporting hydrogen to the market will be a strong driver for the European transition from fossil fuels to renewable energy. In the period 2019 to the end of 2023 SINTEF run the HyLINE project aiming to establish fundamental knowledge about the effects of hydrogen gas on X65 vintage and modern steel pipelines. The research topics included hydrogen uptake and diffusion, nano- and micro-mechanical characterization, fracture toughness and fatigue as well as numerical modelling for fracture assessment. A multi-physics and multi-scale research approach is adopted, investigating the steels response exposed to electrochemical hydrogen charging and pressurized hydrogen gas charging conditions. Some main findings:

- The mechanical properties of the pipeline steel are negatively affected by hydrogen. This includes ductility, fracture toughness and fatigue properties. Especially in the weld simulated HAZ, low fracture toughness values are obtained. A clear indication of the influence of hydrogen pressure on the fracture toughness is seen, also in the low-pressure regime. Tearing of the crack is observed prior to maximum load under electrochemical charging conditions, see Figure 1 [1].

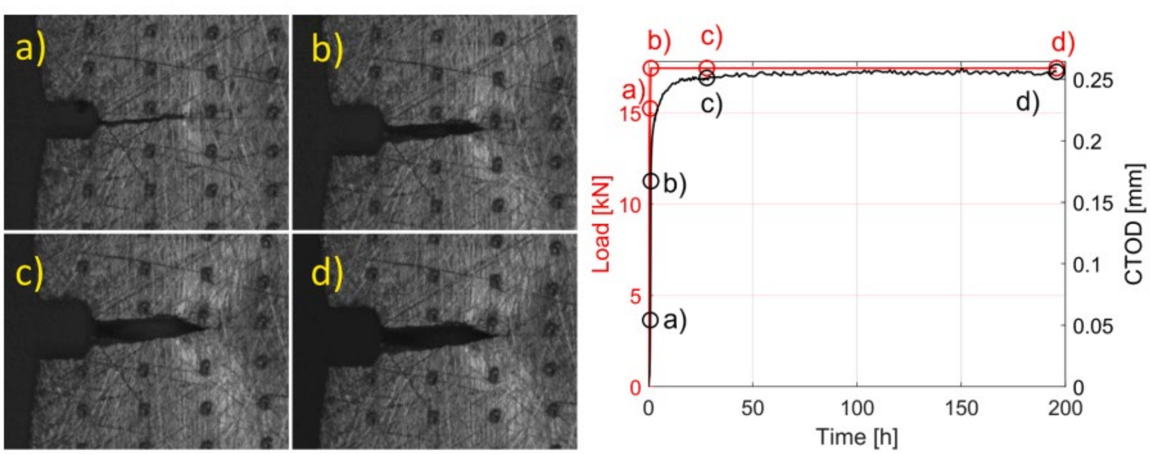

Figure 1 Crack tip observations from constant load fracture toughness testing of X65 pipeline material. a) Onset of tearing. b) Onset of constant loading. c) Crack arrested. d) End of test e) corresponding load and CTOD curve, with location of points a)-d) marked [1]

- Fatigue testing under electrochemical charging conditions, reveals FCGR performance below the design curve from BS 7910. The results are well below the ASME B31.12 limit for crack growth rate in all conditions.
- Equivalency between hydrogen pressure and electrochemical conditions is established [2]. Further verification by fracture mechanics and fatigue testing is however needed.
- Nanoindentation, thermal desorption spectroscopy and micro tensile testing have revealed details on where hydrogen is trapped, how much is diffusible and its influence on the global mechanical properties of the investigated pipeline steels. The results point to inherent differences in the interaction between hydrogen and the material microstructures studied.
- A unified model (H-CGM+) for the continuum scale simulation of HE which is a natural result of the competition of ductile and brittle mechanisms is developed. The model realistically predicts the loss of ductility in hydrogen induced fracture surfaces, consistent with experimental observations [3].

Acknowledgements
This work was financially supported by the Research Council of Norway through the HyLINE [grant number 294739] and H2NINJA [grant number 309378] projects.

References
1. A. O. Myhre, D. Wan, A. Sendrowicz, B. Nyhus, H. Matsunaga, V. Olden, A. Alvaro, A. Vinogradov, Assessing fracture toughness of vintage and modern X65 pipeline steels under in situ electrochemical hydrogen charging using advanced testing methodology. Eng. Fract. Mech., 310, (2024), 110026
2. E. Koren, C. M. Hagen, D. Wang, X. Lu, R. Johnsen, J. Yamabe, Experimental comparison of gaseous and electrochemical hydrogen charging in X65 pipeline steel using the permeation technique, Corrosion Science 215, (2023), 111025
3. M. Lin, H. Yu, D. Wang, A. Diaz, A. Alvaro, V. Olden, E. Koren, Y. Ding, J. He, Z. Zhang. Experimental and numerical study on hydrogen-induced failure of X65 pipeline steel, Materials Science and Engineering: A 894, (2024), 146175