HYDROGEN EMBRITTLEMENT OF PIPELINE STEELS FOR FUTURE HYDROGEN TRANSPORT AND STORAGE

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ABSTRACT

The future hydrogen transportation and storage infrastructure will consist of repurposed natural gas pipelines as well as new pipelines. Hydrogen absorption into the steel structure can, however, take place, leading to hydrogen embrittlement and conservatism in the allowed operating conditions, especially when cathodic (over)protection is considered as well. Research towards this degradation phenomenon is ongoing and requires a multi-disciplinary and multi-scale approach. The variety of pipeline grades and related microstructures in the grid, however, complicates the interpretation. Moreover, one also needs to take into account welds, where a distinction can be made between weld metal and heat affected zone and which potentially may contain weld imperfections. To judge on the fitness-for-service for hydrogen transport and storage, a screening methodology is being developed on a variety of pipeline steels and welds from the Belgian grid.

The screening methodology includes microstructural characterization, hydrogen characterization as well as mechanical characterization. Moreover, numerical simulation of the mechanical performance and post-mortem analysis are performed. The interplay between the topics is illustrated in Figure 1. Within the microstructural and hydrogen characterization, several parameters are quantified, including grain size, pearlite fraction, Vickers hardness, inclusion fraction, hydrogen diffusivity and hydrogen solubility. Mechanical testing is performed ex-situ, i.e. with hydrogen precharged to the sample. Electrochemical hydrogen charging is applied to avoid safety restrictions that are valid when gaseous hydrogen charging would be applied. However, a transfer function to gaseous hydrogen charging conditions is aimed for. Both quasi-static tensile testing and fracture toughness testing is performed. Apart from small scale testing, upscaling to the component scale is performed as well. Numerical modelling is performed with a finite element diffusion-degradation-damage model on the different tested geometries. The effect of hydrogen on the fracture mechanisms is characterized by scanning electron microscopy on the fracture surface as well as the sample cross-section. Depending on the specific microstructure and hydrogen content, different fracture behavior is observed, ranging from ductile microvoid coalescence to quasi-cleavage and cleavage fracture. Moreover, splits and delaminations as well as fish eyes are regularly encountered in these materials.

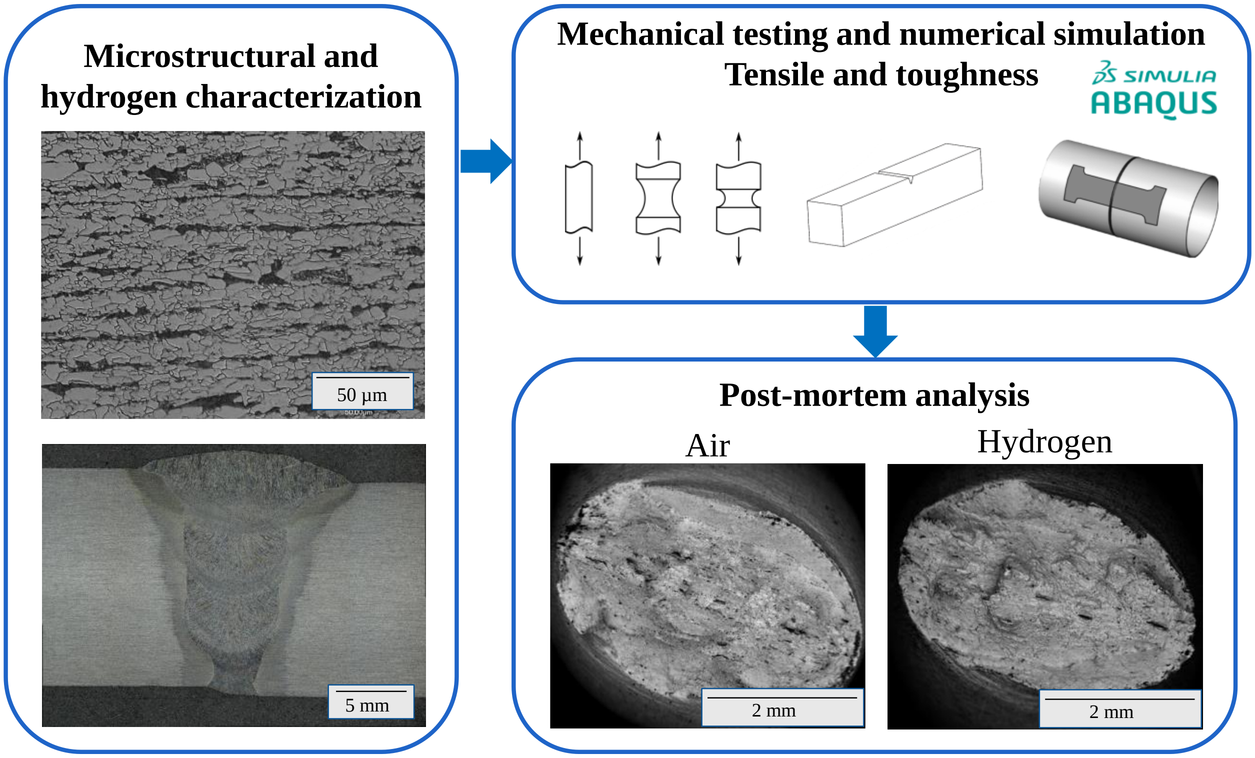

Figure 1: Screening methodology to judge on the fitness-for-service for hydrogen transport of pipeline steels and welds in the Belgian natural gas grid

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