CHARACTERIZATION METHODOLOGY OF PIPELINE STEELS USING MINIATURE SPECIMENS

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Abstract
A possible solution to check the fitness-to-service of existing pipeline steels for hydrogen transport is to extract small coupons without interrupting supply operations. From these coupons, it is possible to machine sub-size specimens to characterize ductility and fracture toughness of the base and weld (weld metal and heat affected zone) materials in both air and pressurized hydrogen environments. Using sub-size requires specific facilities. This paper describes a new setup and the associated methodology developed to test sub-size specimens. The method is applied to tests under pressurized hydrogen gas.

1. Introduction
With an increasing demand for green hydrogen, it becomes crucial to check the possibility of using the existing natural gas pipeline network to transport pure hydrogen or mixed with natural gas. However, hydrogen can cause a loss of ductility and fracture toughness in the steels from which the network is constructed. Understanding and controlling the influence of hydrogen gas on pipeline materials before injecting it into existing pipeline infrastructure is of primordial importance. A possible solution to control and characterize the effect of hydrogen on pipe steels is to extract small coupons from pipelines and their welds without interrupting supply operations. From these coupons, it is possible to extract sub-size smooth tensile (mST), sub-size notched tensile (mNT), and sub-size compact tension test specimens (mDCT) to characterize ductility and fracture toughness. Running these tests faces two challenges. First, specific facilities must be designed to cope simultaneously with mechanical loading, extensometry, and hydrogen gas pressure. Second, size effects are to be expected in the case of mini-specimens. In particular, the miniaturized DCT specimens will not meet the requirements for the validating test results, see (ASTM E1820, 2017).

2. Results
A new setup and methodology for gaseous hydrogen tests and its application to pipeline welds: Characterizing materials under actual pressurized hydrogen gaseous service conditions can be technically challenging. It requires experimental techniques suited to high pressures. For this purpose, a new gaseous pressurized hydrogen machine (pressure up to 250 bar) was designed to perform low strain rate (minimum displacement rate: 0.3µm/min) tests for sub-size specimens. The volume of the chamber has been reduced so that an ATEX environment is not needed. The chamber has two large sapphire windows to install cameras and backlights (see Figure. 1). An optical extensometer using an Edge Tracing technique (ET, (Shokeir et al., 2022)) outside the chamber was then developed to control the machine displacement during mechanical tests. Load is measured with a 5kN cell located within the chamber.

Mechanical characterization using sub-size specimens: An API 5L X52 vintage steel pipe segment was used in this study. Standard and sub-size specimens from the base metal and the longitudinal and girth welds can be extracted. Tests were carried out on small and standard ST and NT specimens. Results show that, compared to the standard tensile specimens, the sub-size tensile specimens (ST and NT) exhibit comparable mechanical properties with a slightly higher ultimate tensile strength and increased ductility. Cup-cone fracture disappears in the case of sub-size specimens, thus evidencing a size effect.

Due to their small size (thickness ranging from 2 to 4 mm), the miniaturized DCT specimens do not meet the requirements for valid measurement of toughness results and lead to a size effect on mechanical properties, especially on fracture toughness. Using the ET methodology, it is possible to measure the CMOD corresponding to the load-line displacement so that the standard data analysis procedure can be used. The crack growth resistance obtained using sub-size CT specimens largely underestimates that obtained using standard specimens (see Figure. 2). The ratio of crack initiation toughness values ($J_{0.2}$) is $J_{0.2}^{\mathrm{mDCT}}/J_{0.2}^{\mathrm{CT}} \approx 0.65$. As expected, the measured value for $J_{0.2}^{\mathrm{mDCT}}$ is not valid according to the standard.

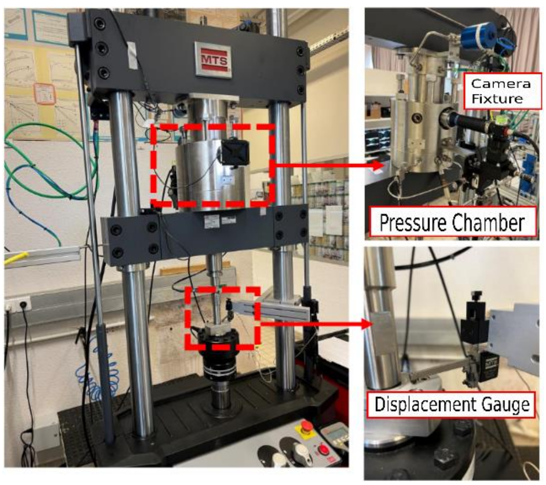

Figure 1: Experimental setup for tests on sub-size specimens under hydrogen environment.

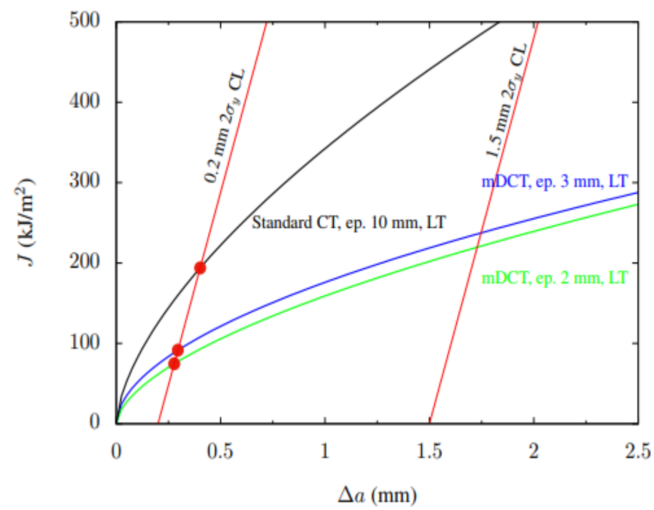

Figure 2: J-Δa curves for standard and sub-size specimens.

3. Conclusions

The mechanical characterization of pipeline steels and their welds can be performed using miniaturized specimens. However, size effects are observed: increased ductility for sub-size notched bars and decreased toughness for sub-size DCT specimens. Such results need to be interpreted using damage models integrating length scales. Such models should allow the computing of valid J-Δa curves. Similar tests will be conducted under gaseous hydrogen using the above-described setup.

4. References

ASTM E1820, 2017. Standard Test Method for Measurement of Fracture Toughness.

Shokeir, Z., Besson, J., Belhadj, C., Petit, T., Madi, Y., 2022. Edge tracing technique to study post-necking behavior and failure in Al alloys and anisotropic plasticity in line pipe steels. Fatigue Fract. Eng. Mater. Struct. 45, 2427–2442. https://doi.org/10.1111/ffe.13754

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