MECHANICAL CHARACTERIZATION AND DEFECT ANALYSIS OF NATURAL GAS PIPELINE STEEL TOWARDS HYDROGEN INJECTION

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Abstract

Repurposing of natural gas infrastructure towards hydrogen injection implies its mechanical viability assurance. This study focuses on the structural integrity assessment of vintage steel API 5L Grade B (used in natural gas infrastructure), especially in what concerns the ductility loss due to hydrogen embrittlement and its effect on common damage occurrence, such as plain denting.

1. Introduction

The increasing concern in the minimization of greenhouse gas emissions has given rise to studying hydrogen as an energy carrier. Moreover, the existing natural gas grid may provide a cost-effective solution towards the transportation and distribution of hydrogen, which could certainly shorten the energy transition period. However, the mechanical properties of pipeline steels can differ in the presence of hydrogen, with particular relevance to fatigue life and ductility. The safety and integrity of pipeline operation can be ensured by appropriate defect analysis. Alternatively to the often innacurate and conservative [1] design-by-formula, the potential hazard of plain dent [2] dictates the need for systematic and thorough approach of those defects (i.e. through design-by-analysis), particularly given the lower ductility of steel in hydrogen atmosphere. In the current study, the depth- and strain-based criteria for assessing plain dent defects are compared with finite element analysis

2. Results

Experimental tensile tests were performed on vintage pipeline steel material (API 5L Grade B) and tested in two different enviroments, in detail: (i) standard atmosphere and (ii) constant pressure of 10 MPa with gaseous 100% H_2, at a strain rate of 10^{-4} s^{-1}. The engineering stress-strain data is ilustrated in Figure *1*. In terms of mechanical strength, no differences are observed. In addition, both tested conditions exhibit a pronounced yield stress plateau. The comparision between these results shows an average ductility loss due to the presence of H_2, thus confirming the sensitiveness of this material to gaseous H_2.

An analytical and numerical approach is proposed to investigate the integrity of a dented straight pipe subject to the internal pressure for natural gas distribution network, 20 bar [3]. Given the nature of the ongoing project (repurposing of natural gas grid towards H2 injection), different methododologies based on ASME B31.12 and ASME B31.8 are proposed. According to these two codes, a design-by-formula and design-by-analysis can be compared. Following the latter, a finer portrayal of material behavior is required, including its plastic domain. This calibration can be performed taking into account the experimental data presented in the Figure *1*. Non-linear finite element simulations of a straight pipe assuming a geometric defect (i.e. plain dent) were conducted for two material conditions described in this study.

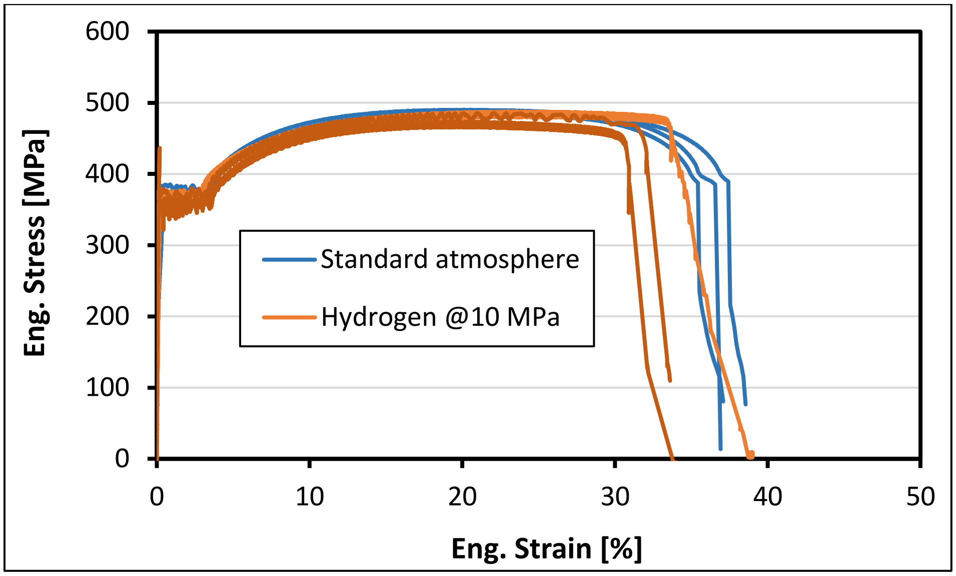

Figure 1 – Tensile test results conducted on API 5L Grade B steel under different atmosphere conditions: (i) standard atmosphere and (ii) pressurized H_2 (100%) at 10 MPa.

3. Conclusions

The proposed methodology allows for understanding the influence of H_2 (and its consequent embrittlement) on the plastic strength of a straight pipe. It enables estimating the capacity to withstand the internal pressure (20 bar) considering the existence of a permanent defect, in addition to providing guidelines for the operation and maintenance plan of a pipeline network. In order to minimize operational costs associated to defects repairing actions (and, thus, operational stoppage), it is preferable to keep pipeline in-service (presurrized). Due to the lack of relevant data on that matter within H_2 usage, the presented results propose operating limit conditions, based on the influence of H_2 embrittlement.

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References

[1] Zhao, Jian, Yun-Rong Lv, and Y. Frank Cheng. "Standards and methods for dent assessment and failure prediction of pipelines: A critical review." *Petroleum Science* (2022).

[2] Abdelmoety, Ahmed K., et al. "Strain-based reliability analysis of dented pipelines using a response surface method." *Journal of Pipeline Science and Engineering* 2.1 (2022): 29-38.

[3] Portaria nº 390/94, Portaria 390/94, Diário da República n.º 138/1994, Série I-B de 1994-06-17.