Effect of cathodic hydrogen charging on the fracture toughness of a X52 pipeline steel welds tested with SENT specimens

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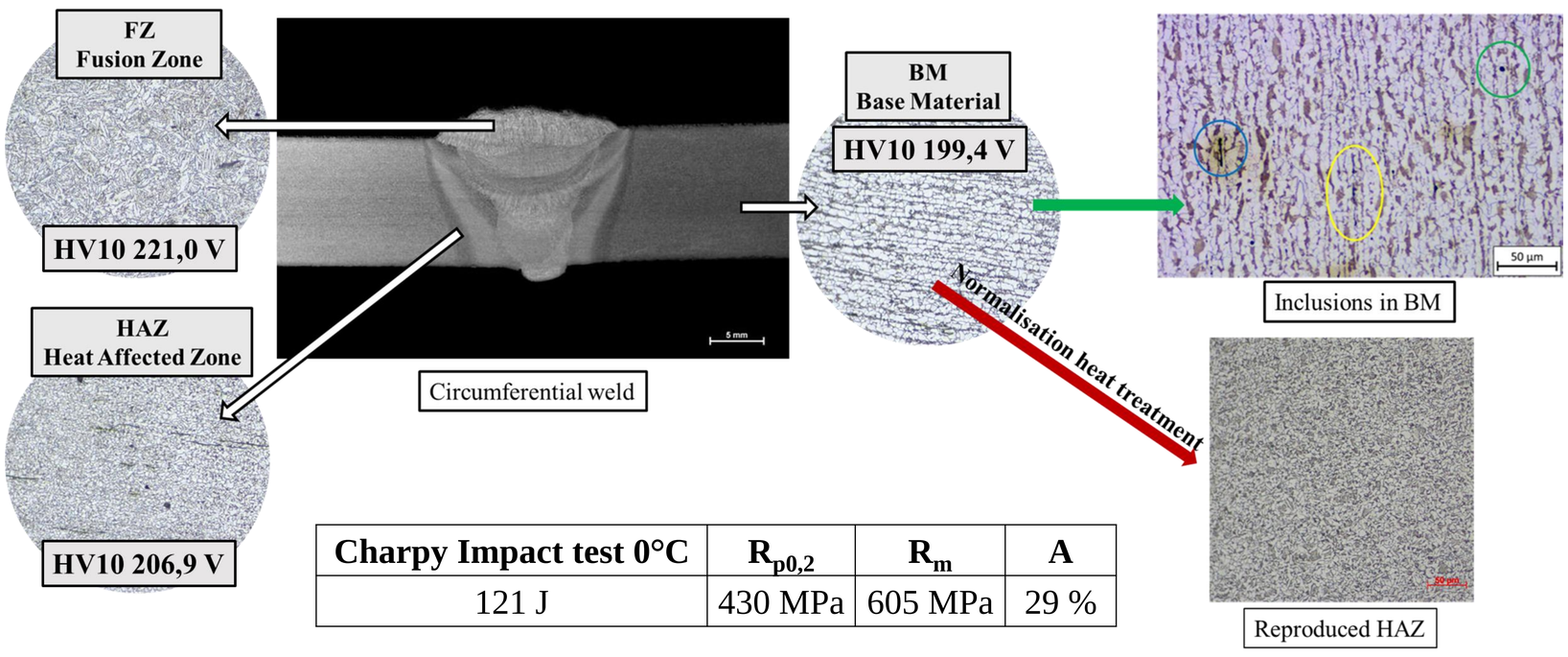
Introduction

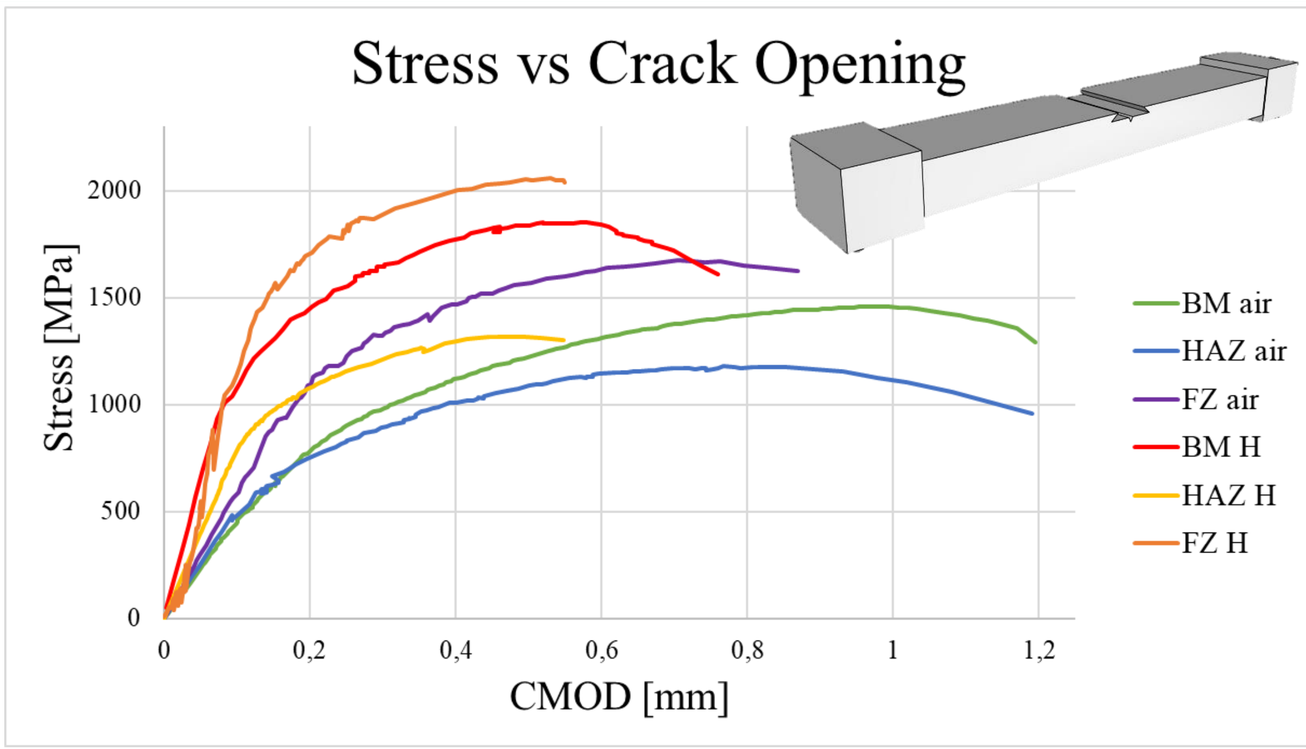
In recent years, attention towards hydrogen as a green energy source has increased significantly. However, the transition to hydrogen presents some challenges regarding the fitness for service of metallic materials in a hydrogenated environment. In fact, hydrogen can diffuse within the crystalline lattices of metals, worsening their mechanical properties, in particular their fracture toughness **(hydrogen embrittlement, HE** [1]), without noticeable signs. A type of material that requires close attention is the **API 5L** family **pipeline steels**, because unexpected breakages in gas pipelines may be dangerously lethal [2]. The welds present in gas pipelines are critical areas because they can host residual stresses, manufacturing defects, geometric imperfections, particular microstructures which are preferential sites for hydrogen accumulation [3]. For this reason, it is necessary to assess the HE propensity of the current pipeline network to ensure its fitness for hydrogen transport.

API 5L X52 Line Pipe Steel

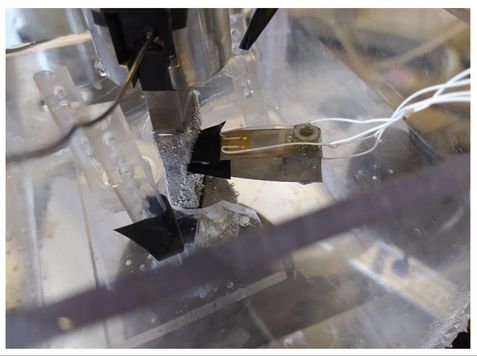


Charpy Impact test 0°C	$R_{p0,2}$	R_m	A
121 J	430 MPa	605 MPa	29 %

Fracture Mechanics Test



Stress vs. Crack Mounth Opening Displacement (CMOD) curves of SENT specimens tested

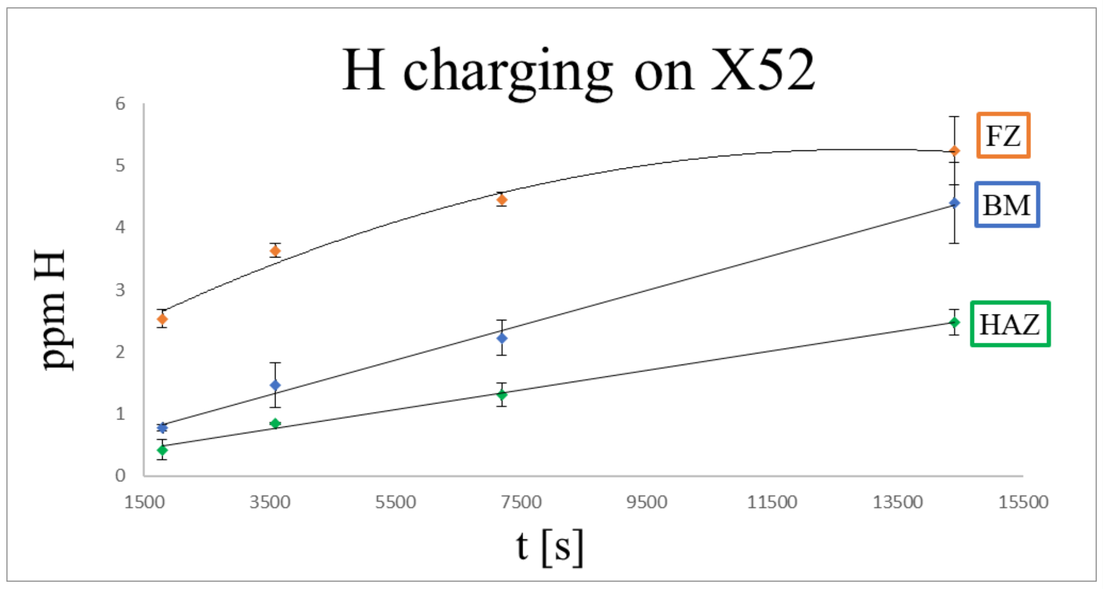


SENT mounted in the electrochemical cell

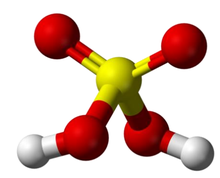
Specimen	$J_{Max\ H}/J_{Max\ Air}$
BM	0,590
HAZ	0,686
FZ	0,690

J_{MAX} is calculated by the Basic Method, accordig with BS8571 standard [4].

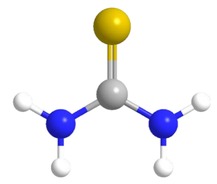
Hydrogen Charging Test



Electrolytic hydrogen charging curves on BM, HAZ and FZ



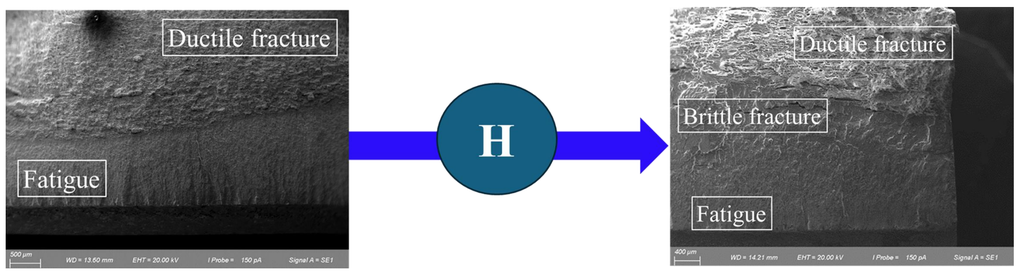
H_2SO_4 0,01 M



CSN_2H_4 2,00 g/L

J = -10 mA/cm^2

Fractography



SENT Fracture surfaces before (left) and after (right) hydrogen effect.

Conclusions and Perspectives

- An economical setup has been developed to perform mechanical tests during electrolytic charging.
- A study on the effect of hydrogen charging time has been conducted and correlated with the microstructure of the BM, HAZ, and FZ.
- The material that absorbs the most hydrogen is FZ, followed by BM and HAZ.
- The susceptibility to hydrogen of the weld bead appeared lower than that of the BM; in fact, the J_{MAX} results obtained with the SENT specimens show that the BM has the highest drop in toughness between tests in air and tests in hydrogen.

References

[1] Nagumo M. Fundamentals of Hydrogen Embrittlement. 1st ed. Springer; 2016.
[2] Kim Y, Chao YJ, Pechersky MJ, Morgan MJ. On the effect of hydrogen on the fracture toughness of steel. International Journal of Fracture 2005; 134: 339-347.
[3] Sharma SK, Maheshwari. A review on welding of high strenght oil and gas pipeline steels. Journal of Natural Gas Science and Engineering 2017; 38: 203-217.
[4] BS8571-2014 Method of test for determination of fracture toughness in metallic materials using single edge notched tension (SENT) specimen.