# Investigation of electrolytic hydrogen charging on the welding of a Line Pipe Steel API 5L X52 and its impact on fracture toughness using SENT specimens.

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**ABSTRACT**

*Hydrogen is considered a key alternative to fossil fuels in the broader context of ecological transition. Repurposing methane pipelines to hydrogen is one of the challenges facing the ecological transition. However, hydrogen has the ability to diffuse within metallic lattices, causing the well-known phenomenon of* ***hydrogen embrittlement (HE)*** [1]*. For this reason, materials typically ductile can experience unexpected brittle fractures. For this reason, it is necessary to assess the HE propensity of the current pipeline network to ensure its fitness for hydrogen transport. In this work, the influence of the microstructure of the circumferential welded joint of an* ***X52 pipeline steel*** *was correlated with the amount of hydrogen electrolytically introduced into it. Base material (BM), heat affected zone (HAZ) and fused zone (FZ) were subjected to ½, 1, 2 and 4 hours of continuous charging with a current density J = -10 mA/cm² in a solution composed of $[H_2SO_4]$ = 0.05 and 2 .00 g/L of $CSN_2H_4$. The HAZ used was reproduced from the BM through an appropriate heat treatment and characterized microstructurally and mechanically to verify its similarity to the original one. The electrolytic test revealed that the FZ is the material that can absorb the most hydrogen, followed by BM and HAZ. The BM reaches high concentrations of hydrogen due to the numerous non metallic inclusions that characterize it. Afterward, the materials underwent fracture mechanics tests with* ***single edge notch tension (SENT)*** *specimens. The tests took place both in air and under electrolytic charging to record the change in fracture toughness calculated as the J integral at the maximum force according with* ***BS 8571 standard*** [2]*. BM is the most sensitive material to a hydrogenated environment because it presents the highest drop in toughness between the test in air and in hydrogenated environment.*

***Keywords: HYDROGEN, PIPELINE, X52, FRACTURE MECHANICS, SENT, ELECTROLYTIC CHARGING***

## 1. THE LINE PIPE STEEL API 5L X52

The material used in the tests is a portion of API 5L X52 steel pipe cut from a '70 Italian pipeline. For our tests, we recreated the HAZ from the BM through an appropriate heat treatment and characterized microstructurally and mechanically to verify its similarity to the original one (fig. 1).

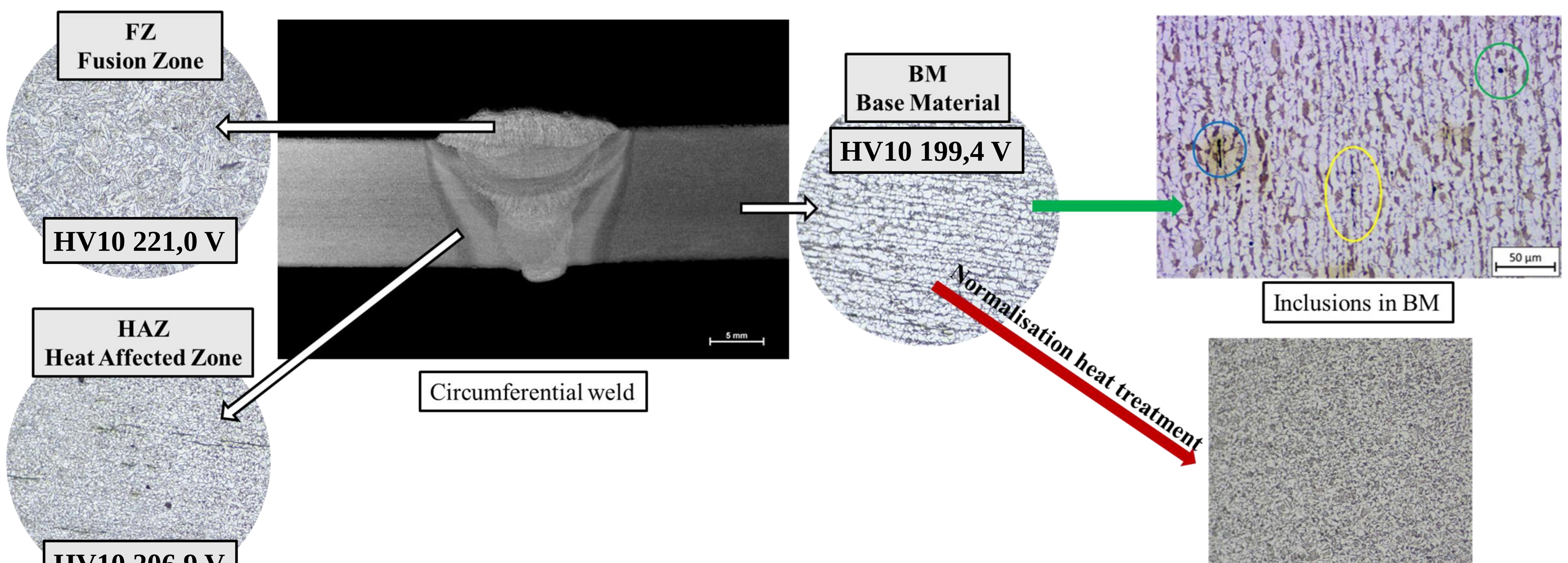
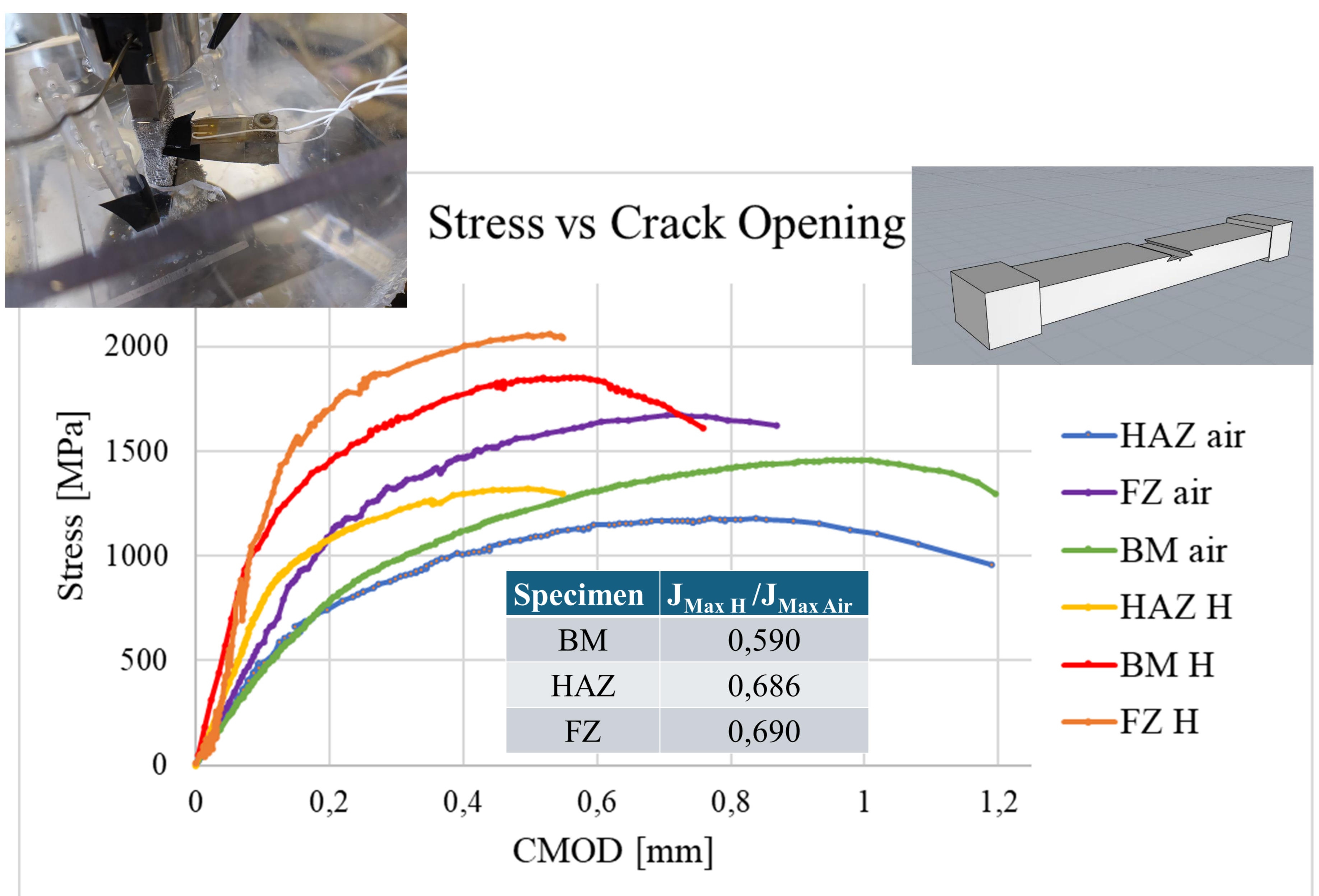



***Figure 1:*** *microstructures of BM, original HAZ, FZ, reproduced HAZ and detail of the BM inclusions.*




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

***Figure 3:*** *Stress vs. Crack Mouth Opening Displacement (CMOD) curves of the SENT specimens tested, sketch of the SENT specimen and SENT during the test.*

## 2. HYDROGEN CHARGING TEST

Working electrode → the specimen
Counter electrode → Pt wire
Reference → standard Ag/AgCl electrode
$[H_2SO_4]$ = 0,01 and 2 g/L $CSN_2H_4$ with J = -10 mA/cm2

The higher amount of hydrogen charged by FZ was expected, which is caused by the finer and more disordered microstructure, the high concentration of dislocations and the residual stresses that are typical of the welding process. Similarly, one would expect HAZ to be able to take in more hydrogen than BM but this is not the case. **The morphology of inclusions is crucial in the development of HE** in the steels and is particularly pronounced when they have an elongated shape as happens after a rolling process. This is because hydrogen atoms tend to gather more at the ends of the inclusion where the stress concentration is usually higher [3].

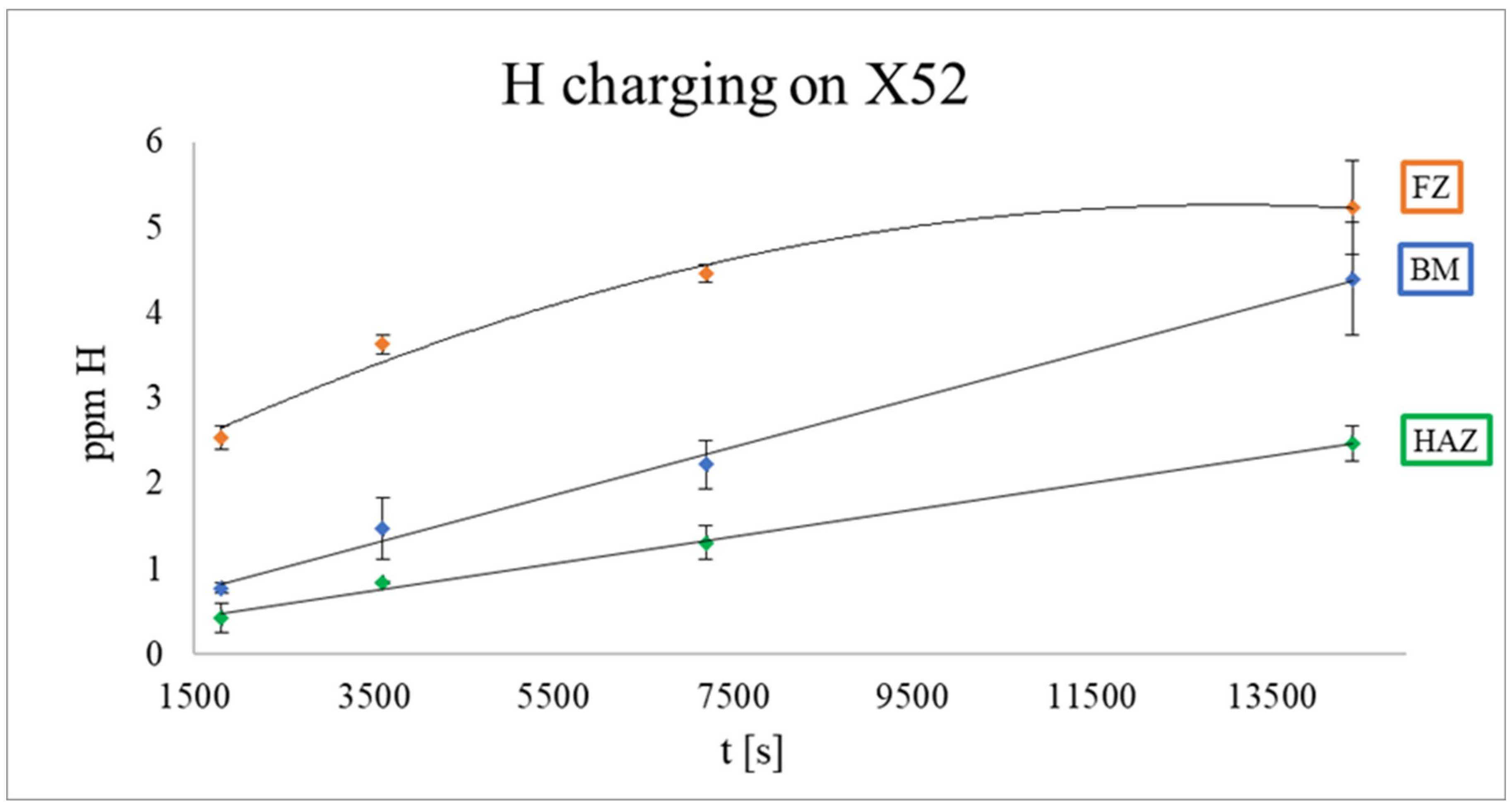



***Figure 2:*** *electrolytic hydrogen charging curves on BM, HAZ and FZ.*

## 3. FRACTURE MECHANICS TEST WITH SENT SPECIMENS

Hydrogen has a deleterious effect on fracture toughness; in fact, it promotes the transition from a ductile to a brittle fracture mechanism. The fracture toughness of a pipeline can be evaluated through fracture mechanics tests. Specimens with SENT geometry have been shown to excellently simulate the stress and strain fields in the crack tip that drive the fracture process in a pipeline [4]. **BM** has the highest fracture toughness in air; however, **it is more affected by the hydrogen** (fig. 3). The fracture surface of the SENT specimen tested in hydrogen shows a brittle fracture zone. In the specimens tested in air, this zone is absent (fig. 4).

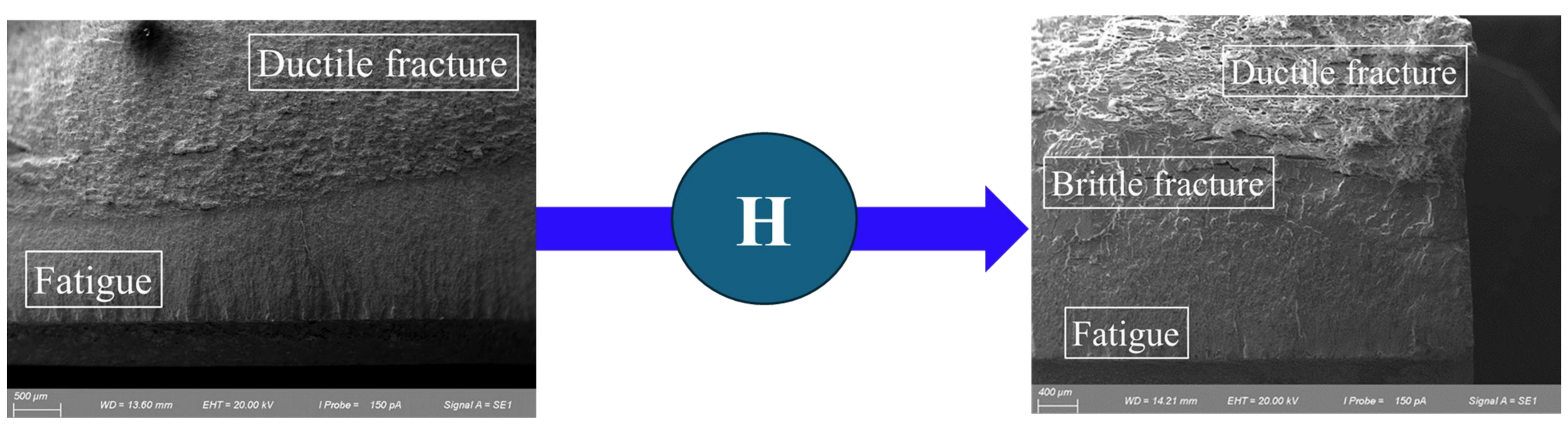



***Figure 4:*** *SENT Fracture surfaces before (left) and after (right) hydrogen effect.*

## 4. CONCLUSION

- In the first 4 hours of charging, **1ppm/h of hydrogen** can be introduced **into the BM** with this self-made set-up.
- **FZ is the material that can charge the most hydrogen**, followed by BM and HAZ, this is due to the particular microstructure of the weld.
- The hydrogen susceptibility of the weld bead appeared to be lower than that of BM; in fact, $J_{MAX}$ results obtained with SENT specimens show that **BM has the highest drop in toughness between air and hydrogen** tests.
- The mechanical test will be repeated using the **elastic compliance method** to obtain the complete toughness behaviour in a hydrogenated environment (J-R curve).

***REFERENCES***

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