

# Microstructural and fractographic investigation of hydrogen embrittlement sensitivity of X70 pipeline steels

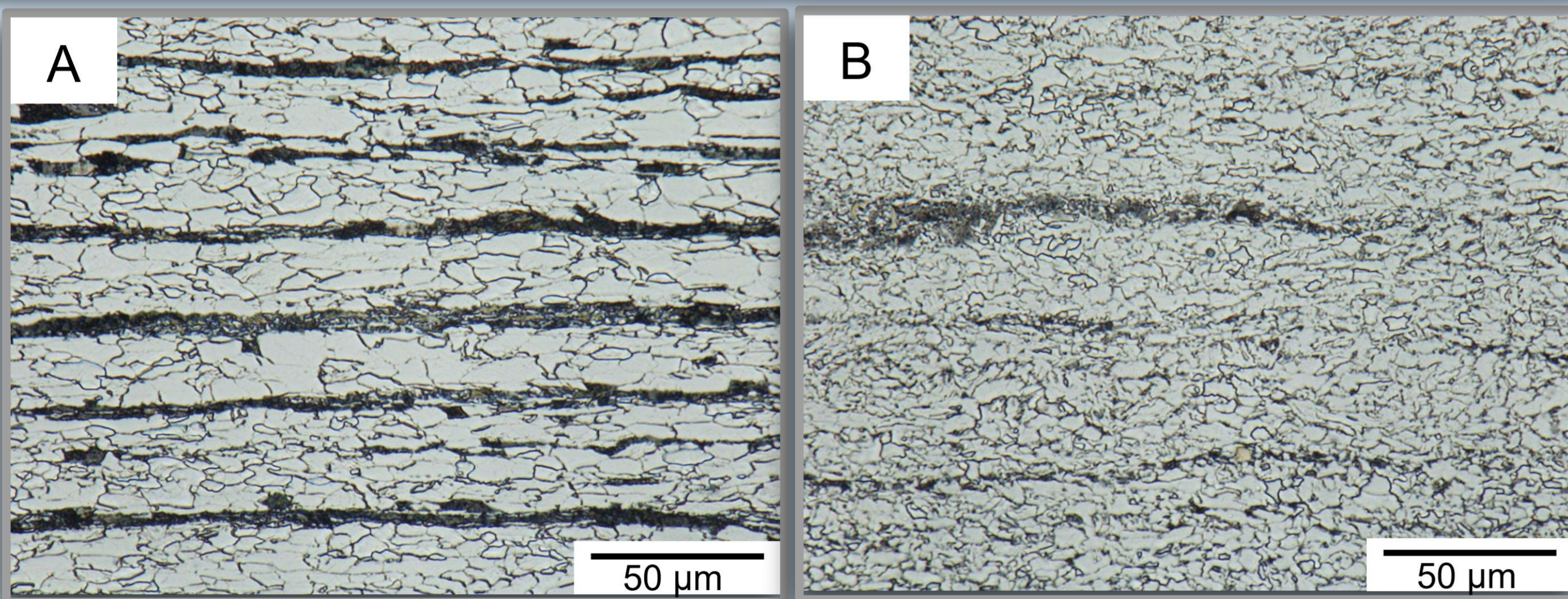
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## Background

Hydrogen offers a sustainable energy solution amidst the climate change crisis, but potential hydrogen assisted pipeline degradation remains a major hindrance. Fractography is used to examine this degradation in pipeline steels from hydrogen exposure.

## Materials Characterization

### TD plane optical microscopy images of X70 pipeline's middle section

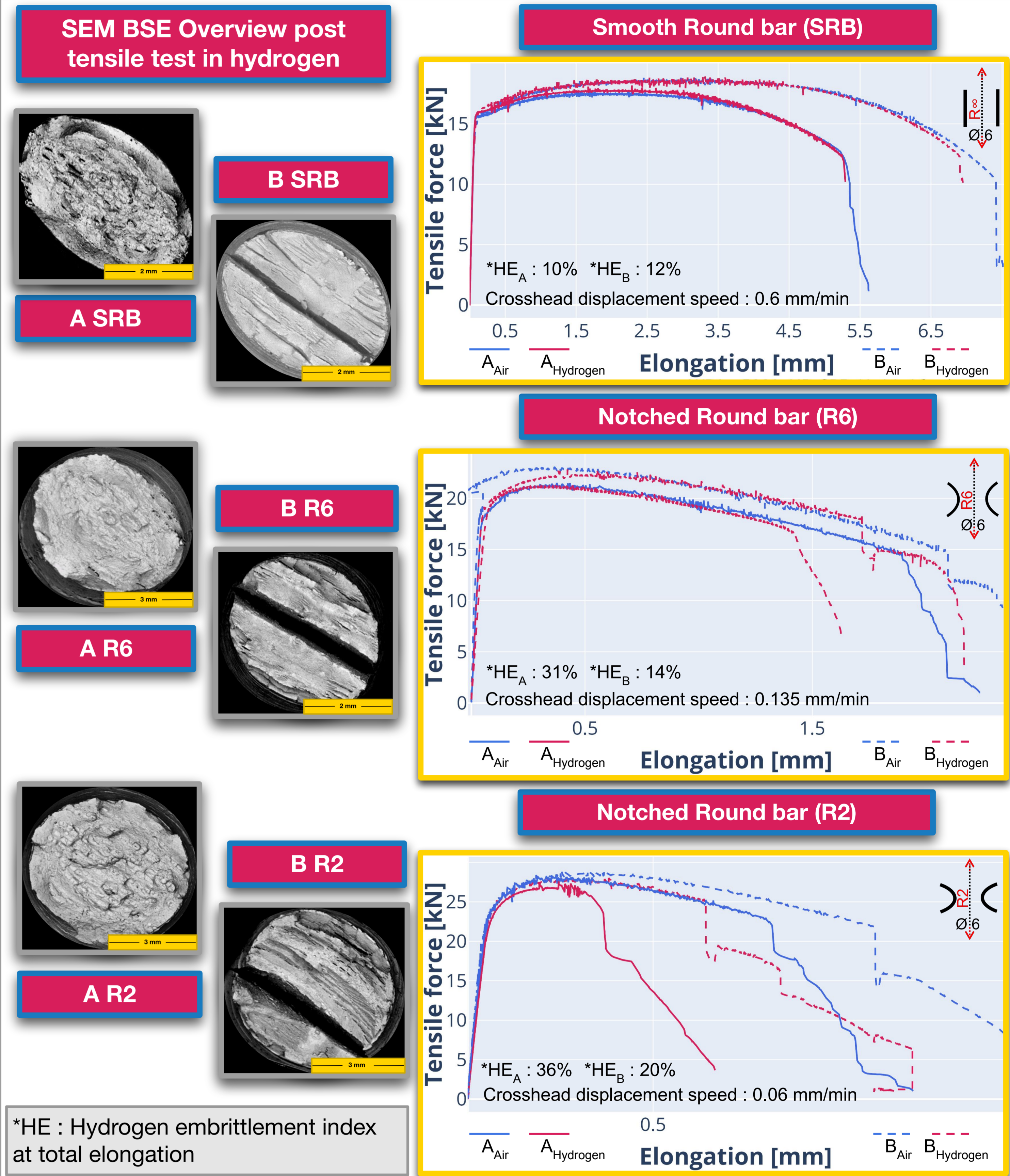


Material A has **continuous** ferrite-pearlite bands throughout its thickness, while Material B has **fragmented** bands concentrated only in the middle section of the pipeline.

Material Properties	A	B
Carbon equivalent ( $CE_{Iw}$ )	0.41	0.40
Hardness (HV10)	207 ± 5	224 ± 3
Ferrite grain size (µm)	7.2 ± 0.3	5.5 ± 0.3
Pearlite fraction (%) (including bainite/martensite)	22.3 ± 4.7	10.4 ± 1.3
Inclusion size (µm <sup>2</sup> )	5.87 ± 3.8	6.12 ± 3.9
Hydrogen content (wppm)	1.24 ± 0.14	1.63 ± 0.18
Apparent diffusivity (10 <sup>-10</sup> m <sup>2</sup> /s)	1.56 ± 0.11	0.60 ± 0.06

## Methodology

### Ex-situ tensile test of electrochemically charged hydrogen samples



- **H Charging** 18h at 0.8mA/cm<sup>2</sup> in 0.5M H<sub>2</sub>SO<sub>4</sub> + 1g/l thiourea
- **Test** Constant strain rate of 0.00025/s until rupture

Microstructure affects hydrogen diffusion. Fractographic pattern recognition can identify failure mechanisms.

## Results & Discussion

**Dimples**

Circular & sheared dimples giving rise to microvoid coalescence

**Splits & Delamination**

**Split** area with small material connection  
**Delamination** area disconnected across the entire cross-section

**Stairs**

Material area resembling a staircase

**Fisheyes**

Fisheyes can be circular or elongated based on the initiation around a specific feature (e.g. inclusion)

**Material A**

**Material B**

Segregation band      Delaminations / Splits  
 Separation between adjacent segregation bands  
 Fisheye

## Conclusion

- Material A is **more hydrogen embrittlement sensitive** than B at **higher stress triaxiality**.
- Segregation bands, inclusions, and ferrite-pearlite interfaces are the sensitive spots.

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