Hystories Final Conference

Material selection for well casings and tubings

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hystories
Hydrogen Storage in European Subsurface

Acknowledgment

The Project is co-founded by European Union

Clean Hydrogen Partnership

Outline

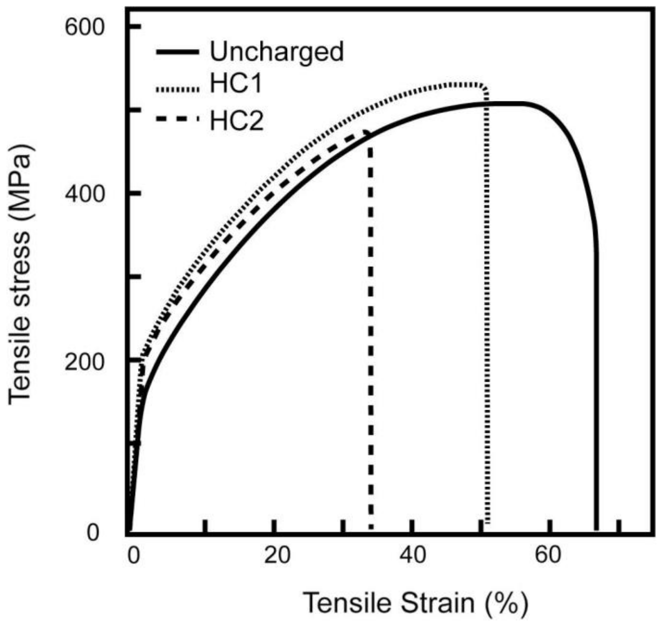
1

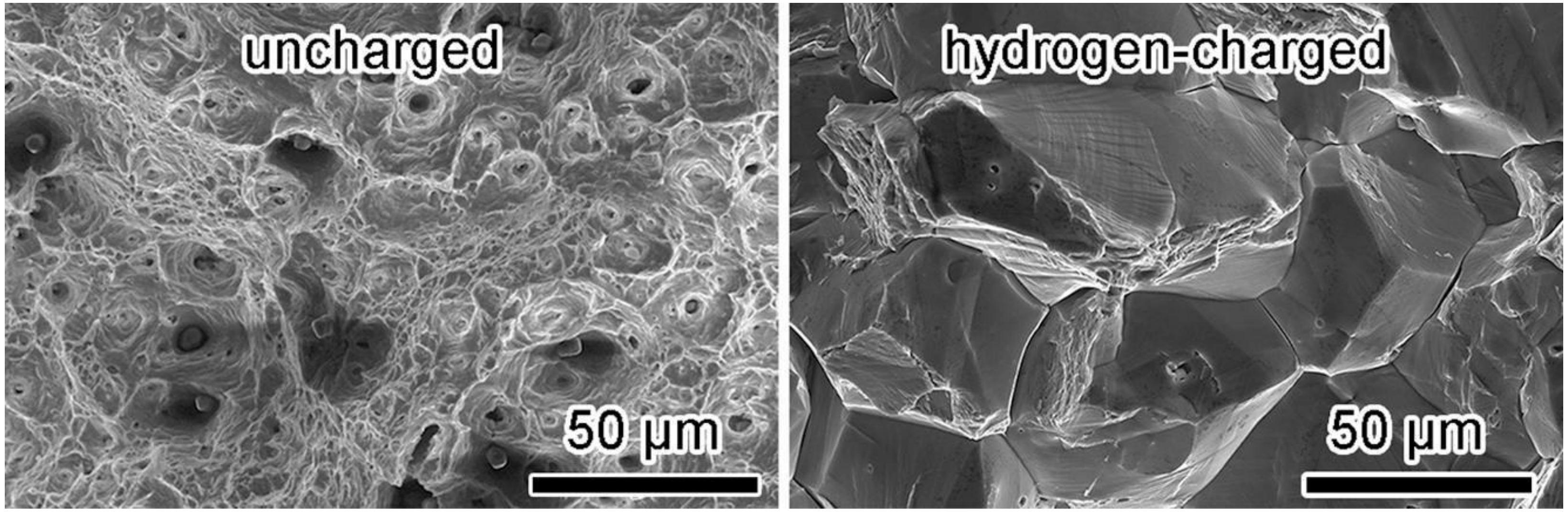
Goal of WP4

1. Goal of WP4

Evaluate various tubing and casing materials for completion in depleted fields for hydrogen underground storage.

High pressure H_2 can yield to hydrogen embrittlement of steels.





K.E. Nygren, K.M. Bertsch, S. Wang, H. Bei, A. Nagao, I.M. Robertson, Hydrogen embrittlement in compositionally complex FeNiCoCrMn FCC solid solution alloy, Current Opinion in Solid State and Materials Science 22 (2018) 1–7

2

Experimental program

2. Experimental program

Investigated steel grades:

Qualification material

Carbon steels

- K55
- L80
- J55 welded grade

(K55, L80, J55 welded grade: Pre-corroded & notched)

- K55 welded grade
- Cast steel 20MnV5
- Carbon steel P110

CRAs

- Stainless steel 13% Cr
- Stainless steel 316L
- Duplex 2205
- Incoloy 625

Methods:

- Full Steel Characterization
- Autoclave Testing
- Hydrogen Analysis
- Permeation Testing
- Ripple Load Tests

Test conditions:

- Pressure:

Test gas	A [bar]	B [bar]	C [bar]	D [bar]
H_2	120	120	120	120
CO_2	0	15	0	15
H_2S	0	0	1	1

- Temperature:

  room temperature and 120°C

- Immersed in the dry gas phase or in the electrolyte:

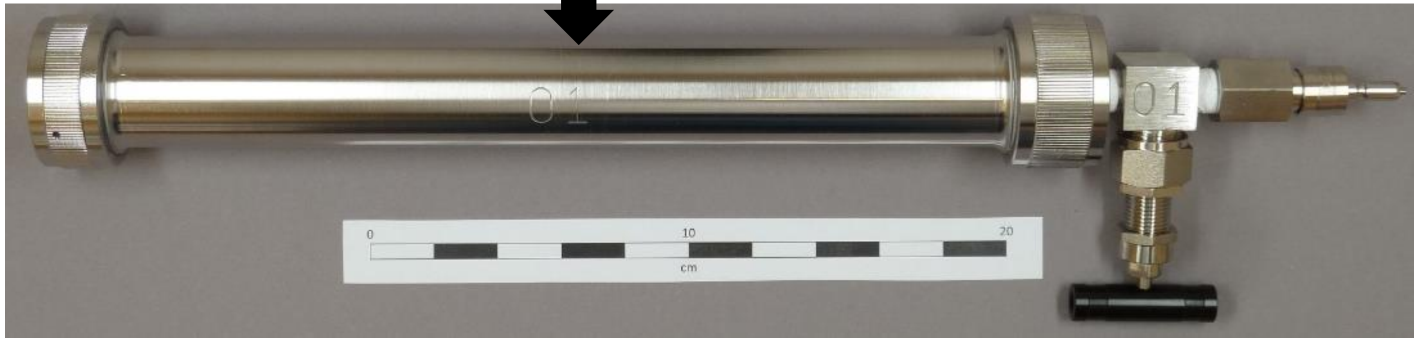
  1 or 200 g/l NaCl

3

Methodology

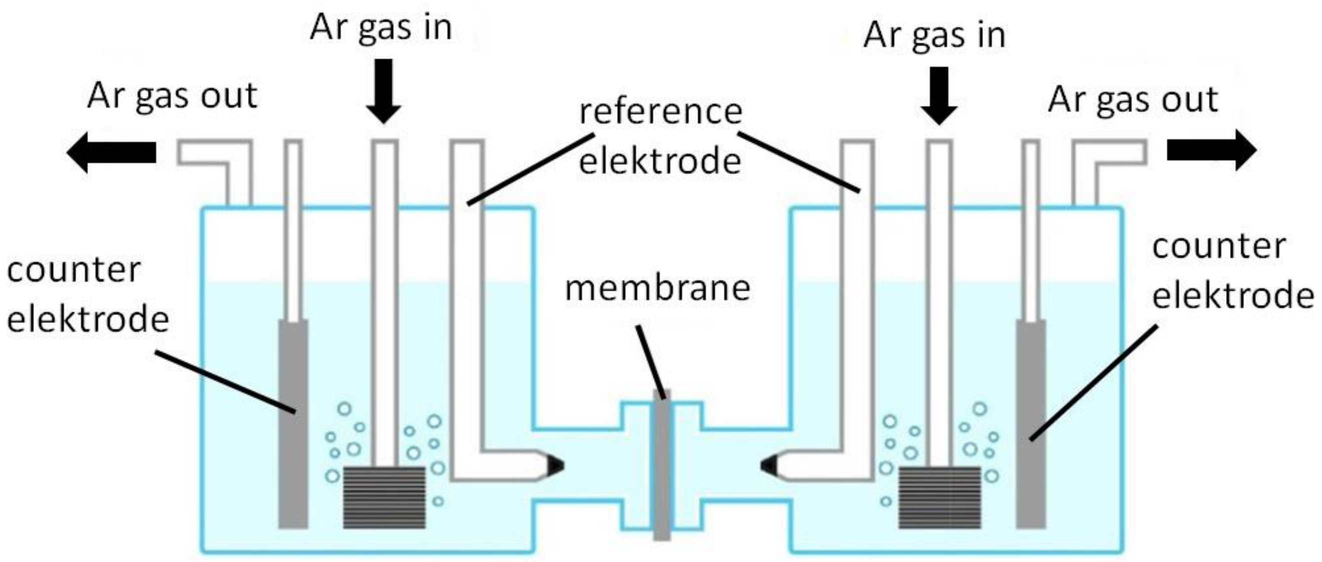
3. Methodology Autoclave Testing

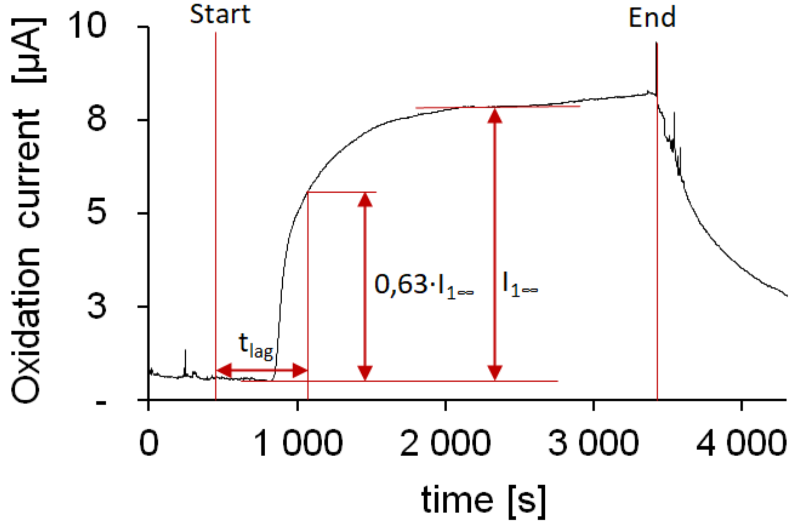
tensile specimen: 90% of Yield Strength



3. Methodology Permeation Testing

Schematic representation of the double cell according to Devanathan and Stachurski [1,2]





evaluation [3]:

$$D_{eff} = \frac{L^2}{6 \cdot tLag}$$

D_{eff}	effective diffusion coefficient
t_{Lag}	time to 63% of the plateau value
L	Membrane thickness

[1] W. Siegl, Hydrogen trapping in heat treated and deformed Armco iron, NACE International (2019)
[2] M. A. V. Devanathan, Z. Stachurski, The adsorption and diffusion of electrolytic hydrogen in palladium, Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences 270 (1962) 90–102
[3] ÖNORM EN ISO 17081-2014-10-01 EN ISO 17081, Elektrochemisches Verfahren zur Messung der Wasserstoffpermeation und zur Bestimmung von Wasserstoffaufnahme und -transport in Metallen, 2014

4 Results

4. Hydrogen uptake and layer formation at welded J55

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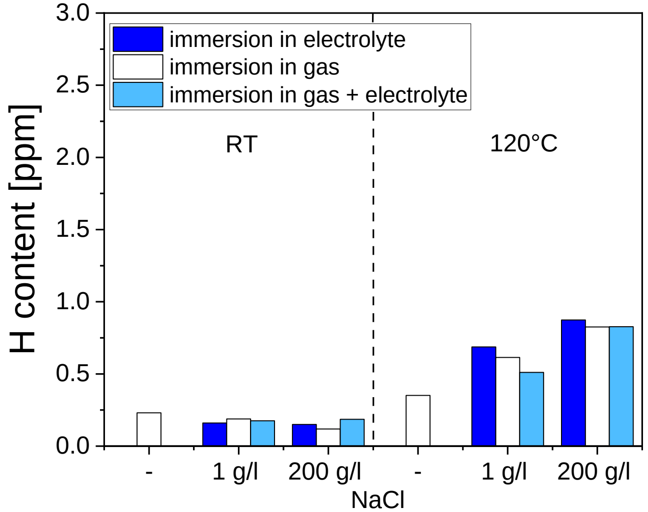
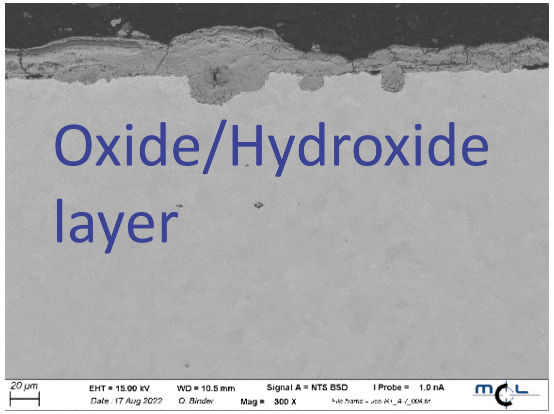
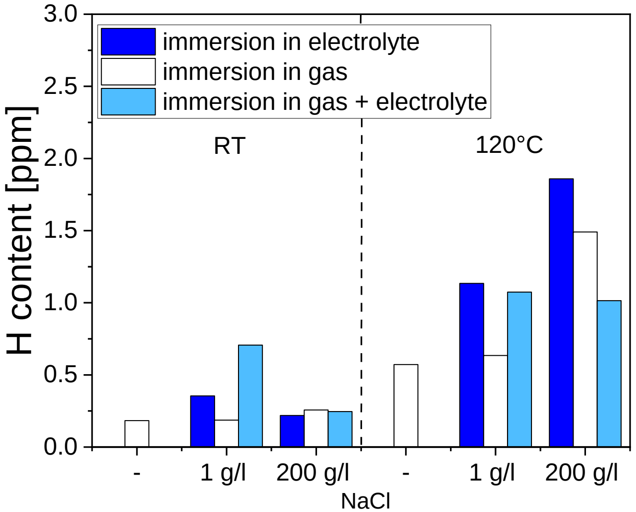
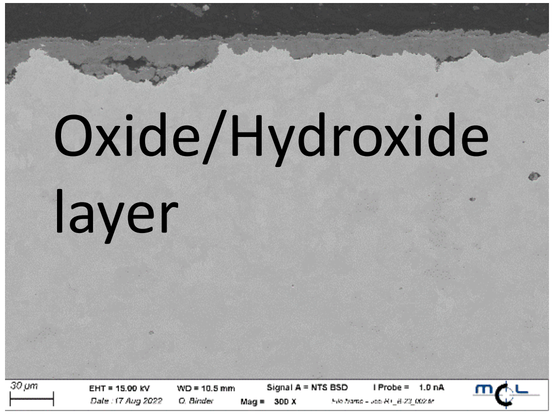
120 bar H_2



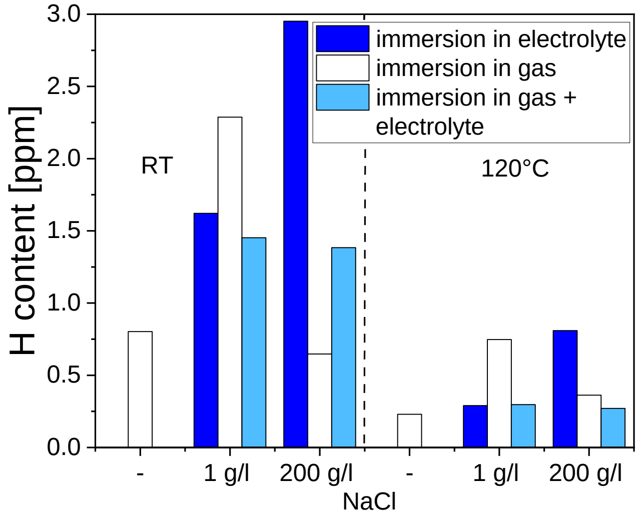


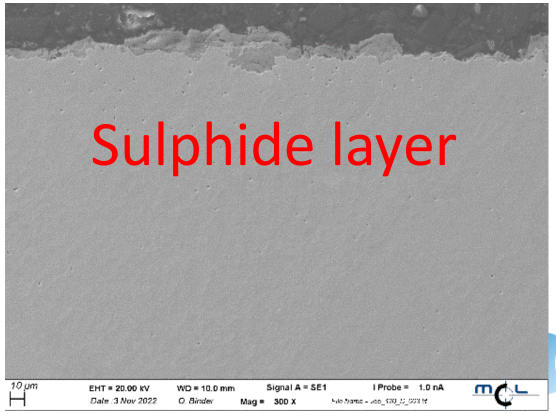
120 bar H_2 + 15 bar CO_2



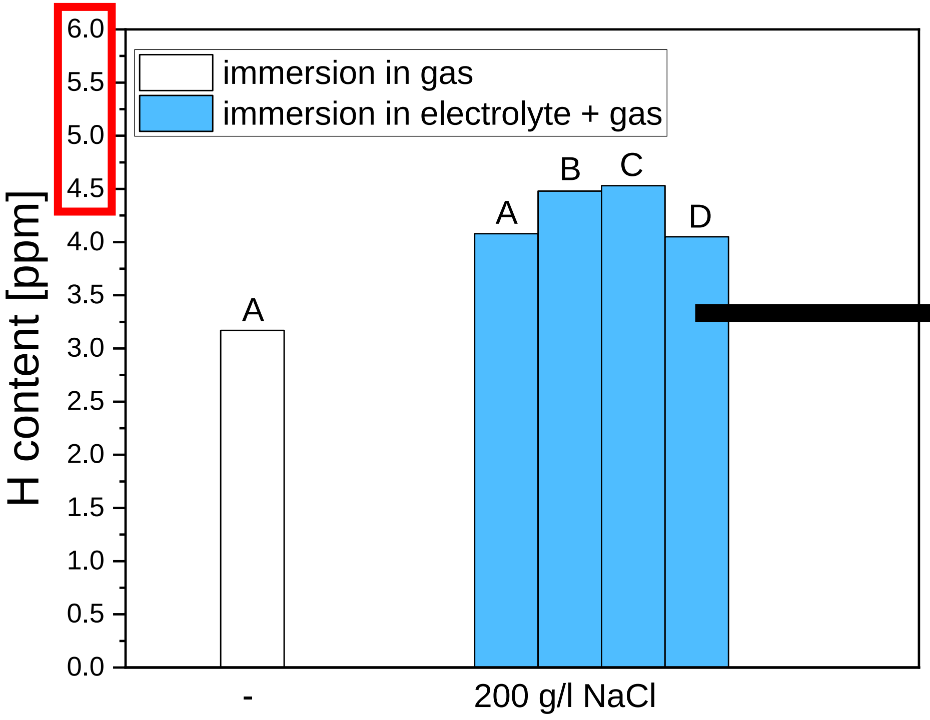


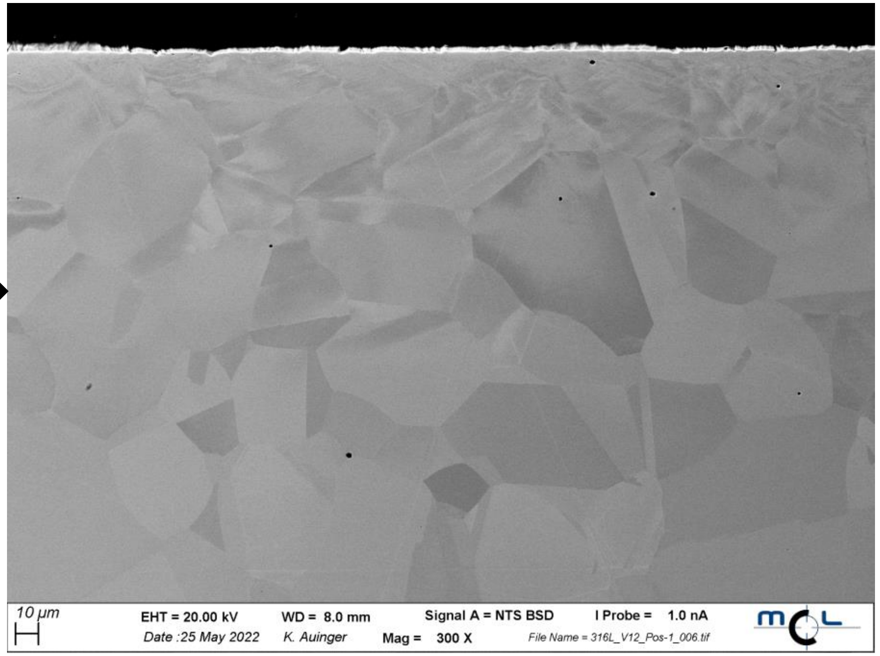
120 bar H_2 + 15 bar CO_2 + 1 bar H_2S





4. Results on Stainless Steel - 316L





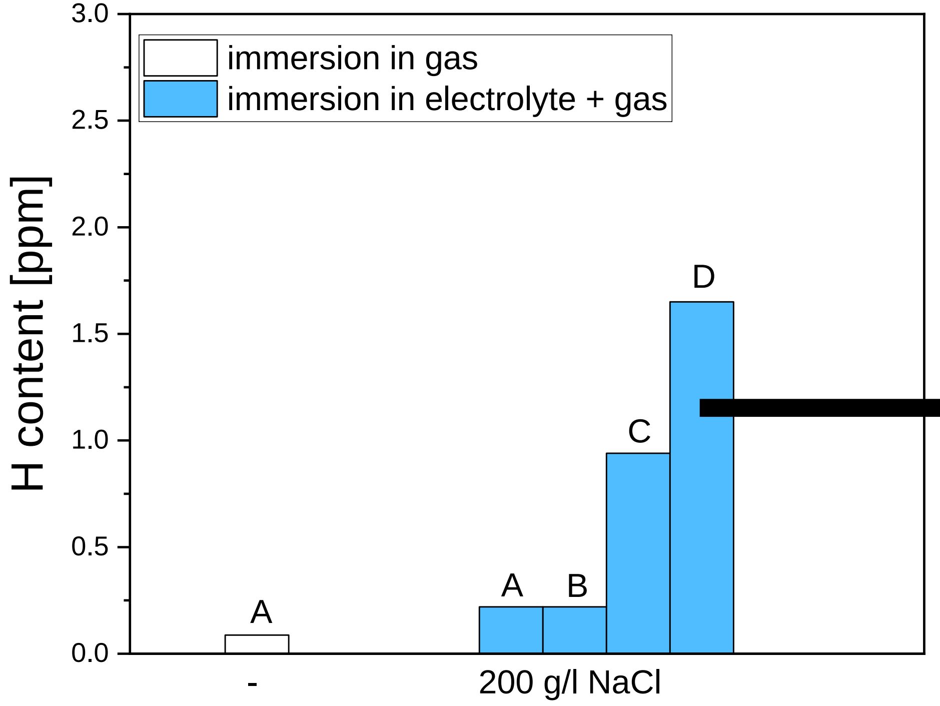
Gas D,
200 g/l NaCl,
1 rpm,
RT.

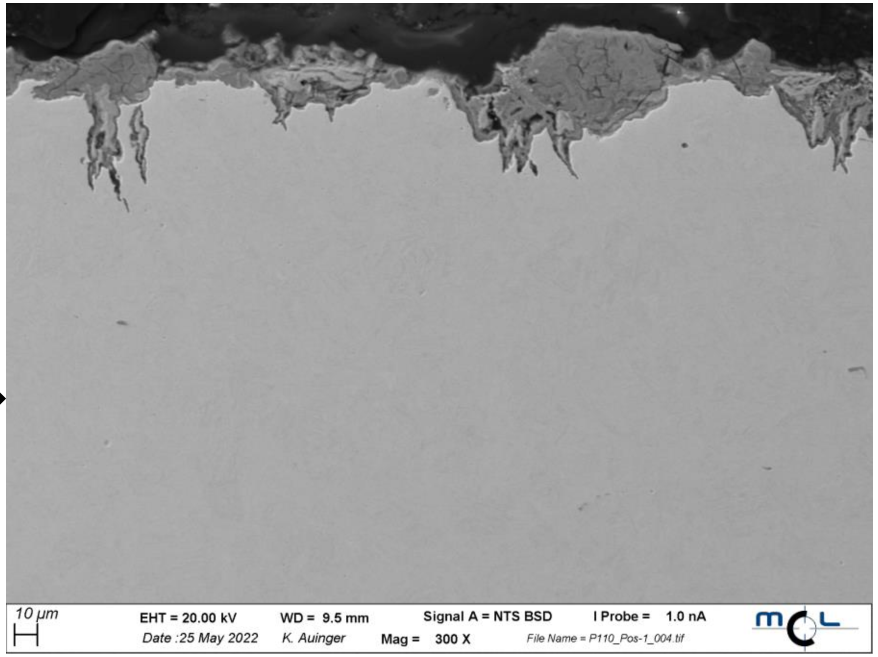
Conditions:

RT
200 g/l NaCl, 1 rpm
without electrolyte

A: 120 bar H_2
B: 120 bar H_2 + 15 bar CO_2
C: 120 bar H_2 + 1 bar H_2S
D: 120 bar H_2 + 15 bar CO_2 + 1 bar H_2S

4. Results on Carbon Steel - P110





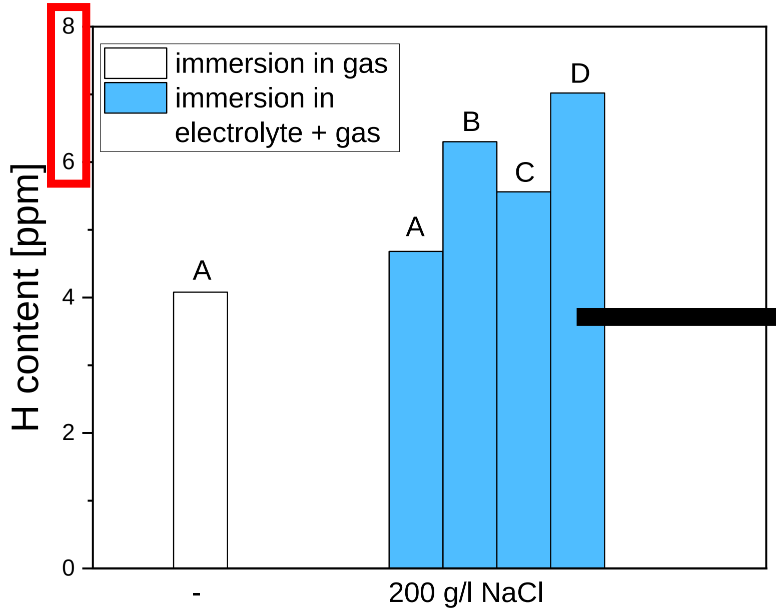
Gas D,
200 g/l NaCl,
1 rpm,
RT.

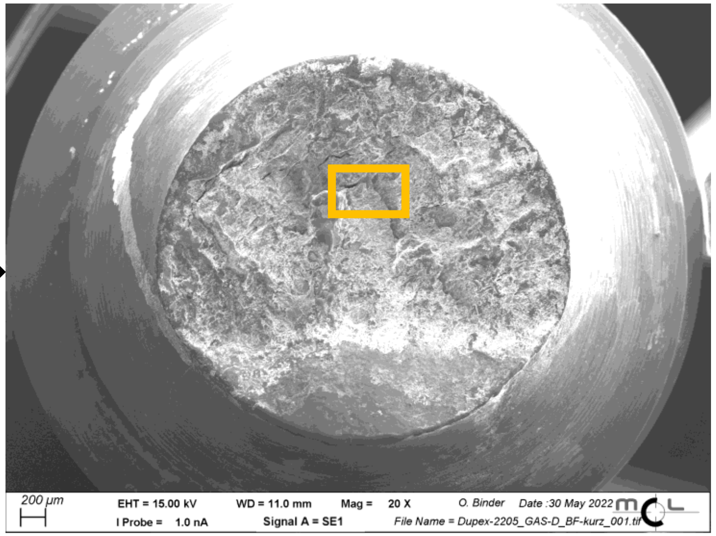
Conditions:

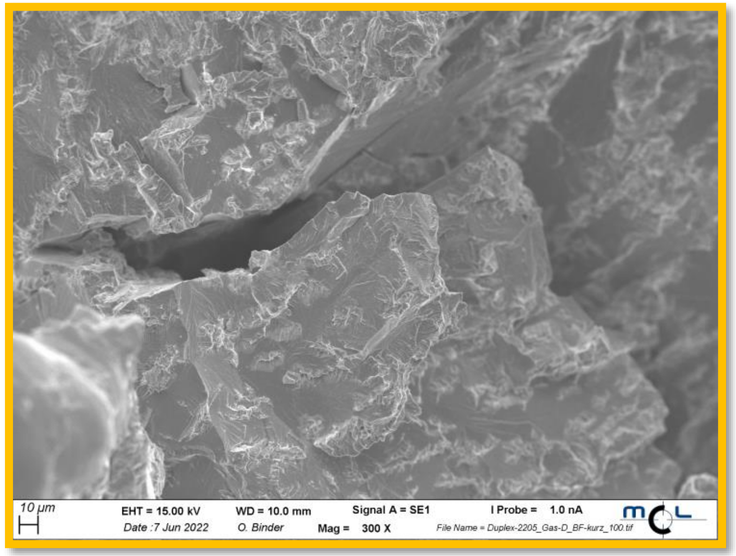
RT
200 g/l NaCl, 1 rpm
without electrolyte

A: 120 bar H_2
B: 120 bar H_2 + 15 bar CO_2
C: 120 bar H_2 + 1 bar H_2S
D: 120 bar H_2 + 15 bar CO_2 + 1 bar H_2S

4. Results on Duplex Steel 2205







Gas D, 200 g/l NaCl, 1 rpm, RT

Conditions:

RT
200 g/l NaCl, 1 rpm
without electrolyte

A: 120 bar H_2
B: 120 bar H_2 + 15 bar CO_2
C: 120 bar H_2 + 1 bar H_2S
D: 120 bar H_2 + 15 bar CO_2 + 1 bar H_2S

5

Summary & Conclusions

5. Summary

increasing yield strength ↓ / increasing alloy content ↓

Material	max H-uptake / blank value	Depth of localized corrosion attack*	cracking (no/yes)
20MnV5	2.71 / 0.11	≤ 5 µm	no
welded J55	2.95 / 0.65	≤ 5 µm	no
welded J55 pre-corroded	3.32 / 0.65	≤ 5 µm	no
welded J55 with notch	-	≤ 5 µm	no
K55	2.33 / 0.22	15 µm	no
K55 pre-corroded	3.64 / 0.22	≤ 5 µm	no
K55 notched	-	30 µm	no
welded K55	2.69 / 0.49	≤ 5 µm	no
L80	1.03 / 0.21	68 µm	no
L80 pre-corroded	3.55 / 0.21	15 µm	no
L80 notched	-	35 µm	no
P110	1.65 / 0.23	55 µm	no
quenched material	0.86 / 0.20	fracture	yes, in gas A and gas D
13%Cr	7.02 / 0.52	≤ 5 µm	no
316L supplier 1	2.04 / 1.94	no attack	no
316L supplier 2	4.53 / 3.20	no attack	no
Duplex 2205	7.02 / 4.72	fracture	yes, in gas D
Alloy 625	6.86 / 0.78	no attack	no

* low...≤ 5 µm/mt * medium...5 – 30 µm/mt * high...≥ 30 µm/mt

Material	Damage	Application with H_2S based on ISO 15156	Applicability in H_2 environment
20MnV5	no damage	Not specified	well applicable
welded J55	no damage	Acceptable for H_2S application for all temperatures	well applicable
welded J55 pre-corroded	no damage		
welded J55 with notch	no damage		
K55	no damage	Acceptable for H_2S application for all temperatures	well applicable when localized corrosion is not an issue
K55 pre-corroded	no damage		
K55 with notch	some localized damage		
welded K55	no damage	Acceptable for H_2S application if hardness ≤ 22 HRC	well applicable
L80	deep localized damage	Acceptable for H_2S application for all temperatures provided that it is type 1	applicable when localized corrosion is not an issue
L80 pre-corroded	some localized damage		
L80 with notch	some localized damage		
P110	deep localized damage	Acceptable for H_2S application only if T° > 80°C	applicable at RT when no H_2S is present
quenched material	failure in H_2	Not applicable	not applicable
13%Cr	no damage	Acceptable if pH_2S < 10.2 kPA	well applicable
316L supplier 1	no damage	Acceptable if pH_2S < 10.2 kPA	well applicable
316L supplier 2	no damage		well applicable
Duplex 2205	failure in ($H_2 + CO_2 + H_2S$)	Acceptable if pH_2S < 2 kPA	not applicable
Alloy 625	no damage	Acceptable for H_2S application for all temperatures	well applicable

**no damage **localized damage **failure

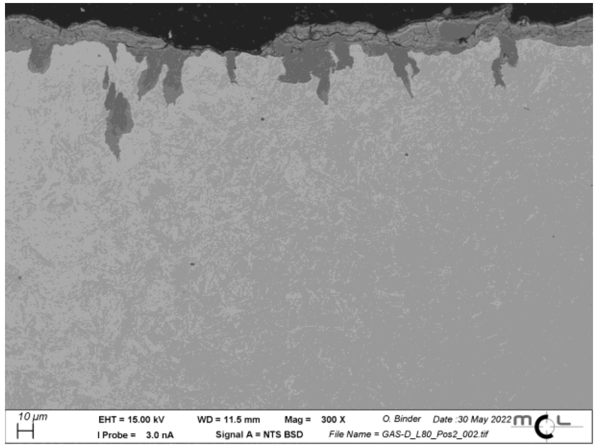
**well applicable in hydrogen environment **applicable in hydrogen environment when localized corrosion is not an issue **not applicable in hydrogen environment

5. Conclusions

→ **Steels K55, welded J55, 20MnV5 & welded K55 are applicable for hydrogen storage**

→ **Steel L80 is applicable with limits of H_2S**

→ **Steel P110 is applicable with strong limits of H_2S**



Conditions:

- L80
- 120°C
- 200 g/l NaCl,
- 1 rpm
- Gas D

→ **Stainless steels 13%Cr, 316L & Alloy 625 are well applicable for hydrogen storage**

→ **Duplex 2205 steel is not applicable for hydrogen storage**

Hystories project consortium

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GEOSTOCK GREEN STORAGE

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The Project is co-founded by European Union

Clean Hydrogen Partnership

Thank you for your attention

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