EUROMAT 2015

Warsaw, 2015 September 23th

Influence of stress concentrator on hydrogen embrittlement susceptibility of a X70 weld simulated coarse grained heat affected zone

A. Alvaro[*], V. Olden[*], B. Nyhus[*]

*: SINTEF Material and Chemistry, Dept. Material Integrity and Welding, Trondheim, Norway

The Norwegian "Hydrogen Embrittlement" team


A. Barnoush


Z. Zhang


R. Johnsen


N. Kheradmand


O.M. Akselsen


A. Alvaro


Ole M. Løvvik


I. Thue Jensen


S. Dumoulin


A. Thøgersen


B. Nyhus


V. Olden

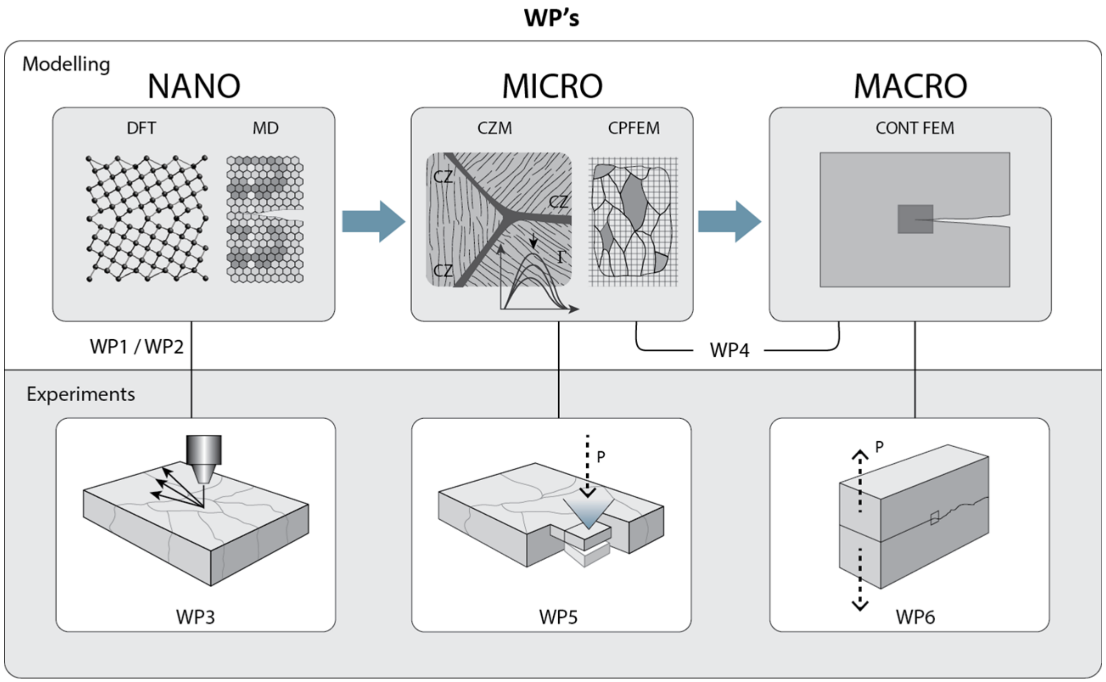
11 PhDs and about 30 master student projects

HIPP, 2014-2017 (Research Project)

Hydrogen-induced degradation of offshore steels in ageing infrastructure – models for prevention and prediction.

Main goal: To develop a model framework which describes and couples environment-assisted hydrogen degradation mechanisms at different length and time scales towards a predictive mechanism-based integrity assessment approach.

National research partners:
SINTEF, NTNU, UiO
International research partners:
I^2CNER, Bochum University
Industrial Advisory group:
Statoil, Aker Solutions, DNV GL



Poster by:
Domas Birenis (PhD):
Novel TEM based approach for H content measurement in Fe on atomistic scale

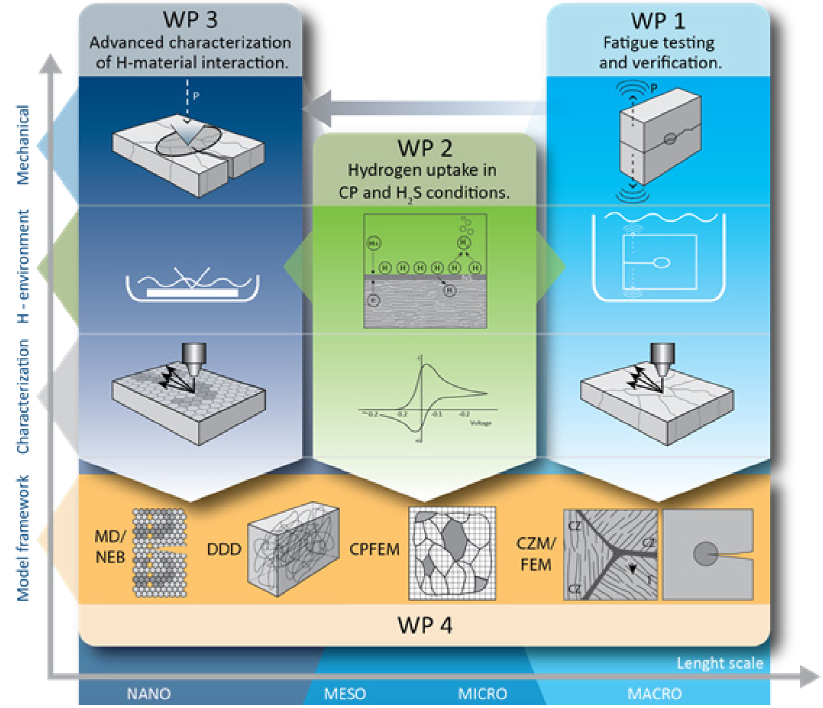
The Research Council of Norway

HyF-Lex, 2015-2018 (Research Project)

Field life extension through controlling the combined material degradation of fatigue and hydrogen

Main goal: *Increase the fundamental understanding of the mechanisms inherent to hydrogen assisted fatigue crack growth in steels, as well as contributing to a model framework for assessment of hydrogen assisted fatigue.*

National research partners:
SINTEF, NTNU
International research partners:
Politecnico di Milano, Université de la Rochelle, Universität des Saarlandes
Industrial Advisory group:
Statoil, Aker Solutions, DNV GL, Norske Shell, FMC Technologies



The Research Council of Norway

ROP, 2014-2018 (Knowledge Building Project)

Knowledge basis for Repair cOntingency of Pipelines

Main goal: To establish basic knowledge on subsea hyperbaric repair welding and degradation of clad and lined pipes, as well as C-Mn steel

Separate work package on hydrogen assisted cracking:

Specifically addressing resistance towards cracking of the joint between clad and the pipeline steel/weld metal. 1 PhD on modelling.

Research partners: SINTEF, NTNU, IFE

Industry partners: Statoil, Gassco, Technip, EDF Induction, POSCO

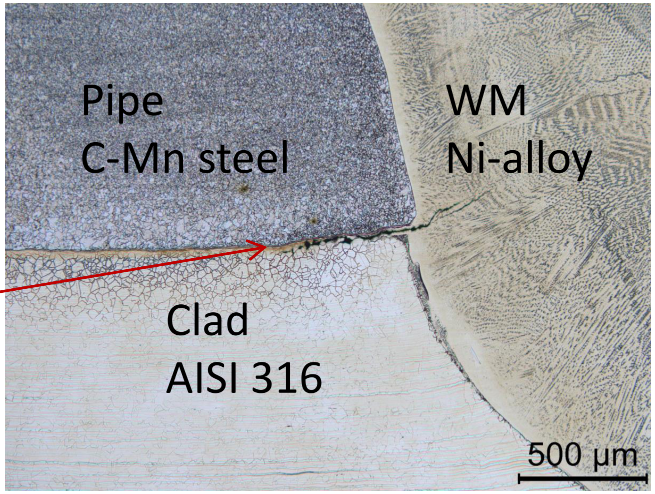
International collaboration: I^{2}CNER

Posters by:

Dag Lindhom (IFE): numerical case study of H-diffusion model including effect of trapping and temperature dependency (welding of clad)

Lise Jemblie (PhD): CZM and fracture mechanical testing of H-cracking at clad pipes interface

H



Materials

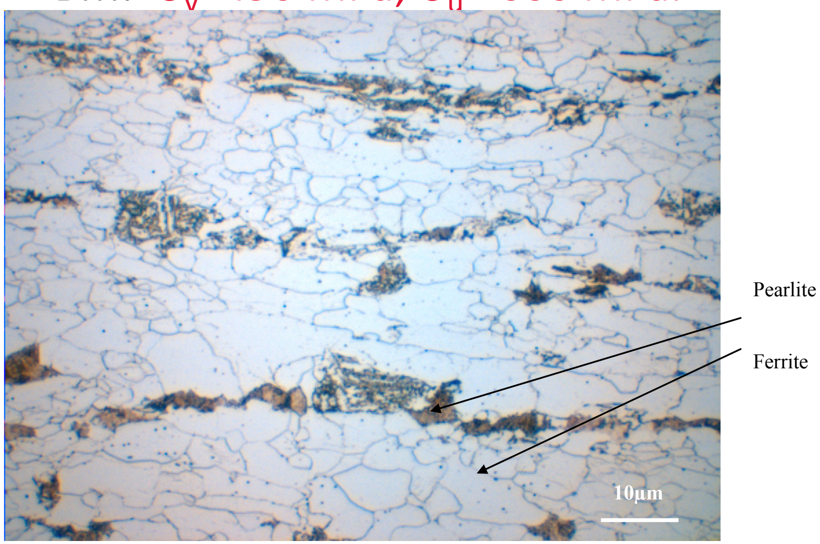
X70: BM and weld simulated CGHAZ

Chemical composition (%w)

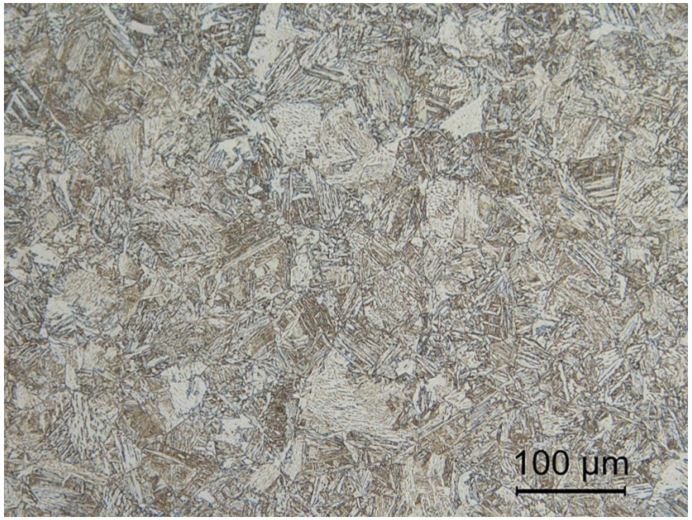
	C	Mn	Si	P	S	Cu	Ni
X70	0.047	1.74	0.1	0.01	7 ppm	0.3	0.25

Heat Treatment for CGHAZ (SMITWELD 1405): T_p= 1280 ˚C, no holding time, $\Delta t_{8/5}$=6 sec;

BM: σ_y=490 MPa; σ_u= 600 MPa.



CGHAZ: σ_y=628 MPa; σ_u= 764 MPa.

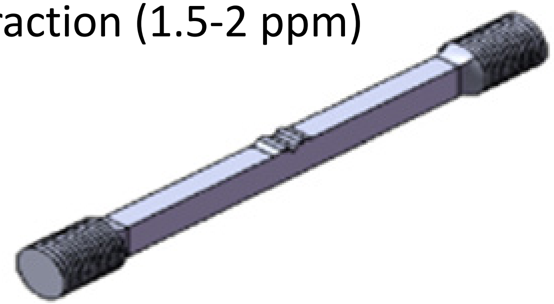


Experimental procedure

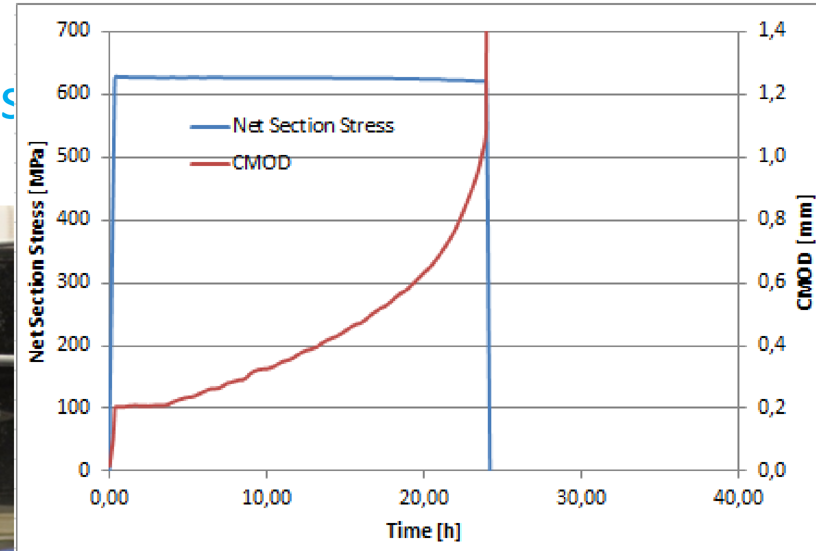
In-situ charging fracture mechanics tes

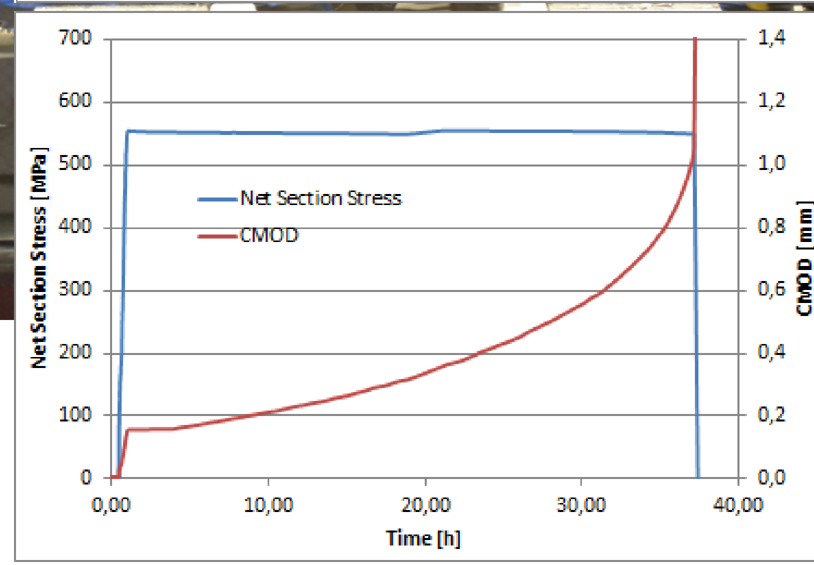
Constant load SENT testing procedure:

- Clamped specimens
- Hydrogen pre-charging at 80 ˚C and -1050 mV_{SCE} for one week
- Melt extraction (1.5-2 ppm)



- Constant load testing at 4 ˚C and in-situ charging (-1050 mV_{SCE}) submerged in circulating sea water.
- CMOD and stress vs time curves recorded.





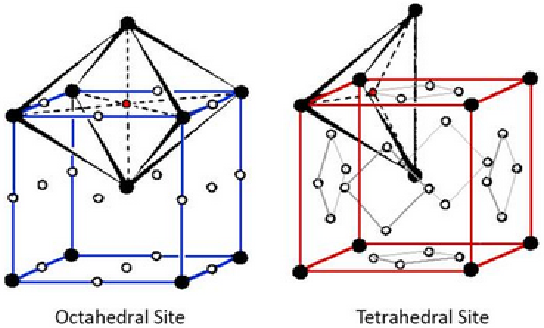
Modeling procedure

Modelling of hydrogen distribution in the material

Total distribution C_H : diffusible hydrogen C_L + hydrogen in traps C_T

1. Hydrogen in Normal Interstitial Lattice Sites (NILS)

Modified Fick's law: Concentration and hydrostatic stress gradients:



Interstitial sites in bcc unit cell

$$\frac{\partial C_L}{\partial t} = D\nabla^2 C_L + D \cdot \frac{V_H}{R \cdot (T - T^Z)} \nabla C_L \nabla \sigma_h + D \cdot \frac{V_H}{R \cdot (T - T^Z)} C_L \nabla^2 \sigma_h$$

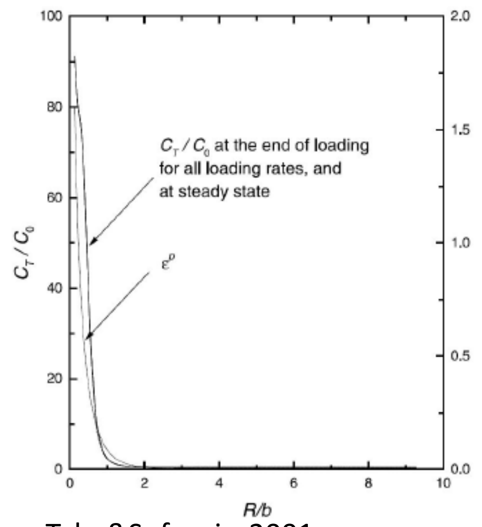
Li and Oriani, 1966

2. Hydrogen in traps

Local perturbation of lattice structure (dislocations, grain boun precipitates… E_b).

$$C_T = (49 \cdot \varepsilon_p + 0.1) \cdot C_L$$

Olden, 2010



Taha&Sofronis, 2001

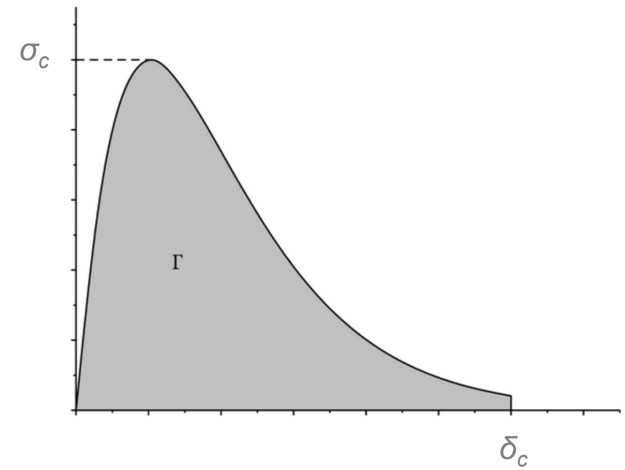
Modeling procedure

Modelling of hydrogen induced degradation through CZM

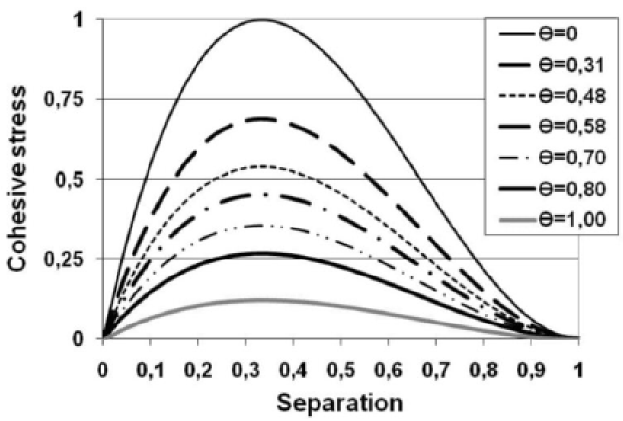
Traction Separation Law

Two independent parameters among:

- Cohesive strength σ_c : maximum value of the TSL
- Critical distance δ_c : maximum separation distance
- Cohesive energy Γ_c : area embedded by the TSL



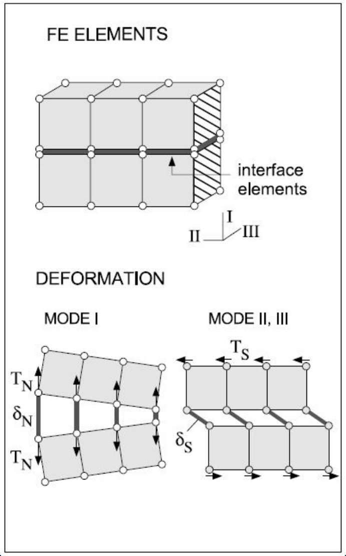
H reduces the max cohesive strength for separation of cohesive interfaces.



Reduction of cohesive strength:

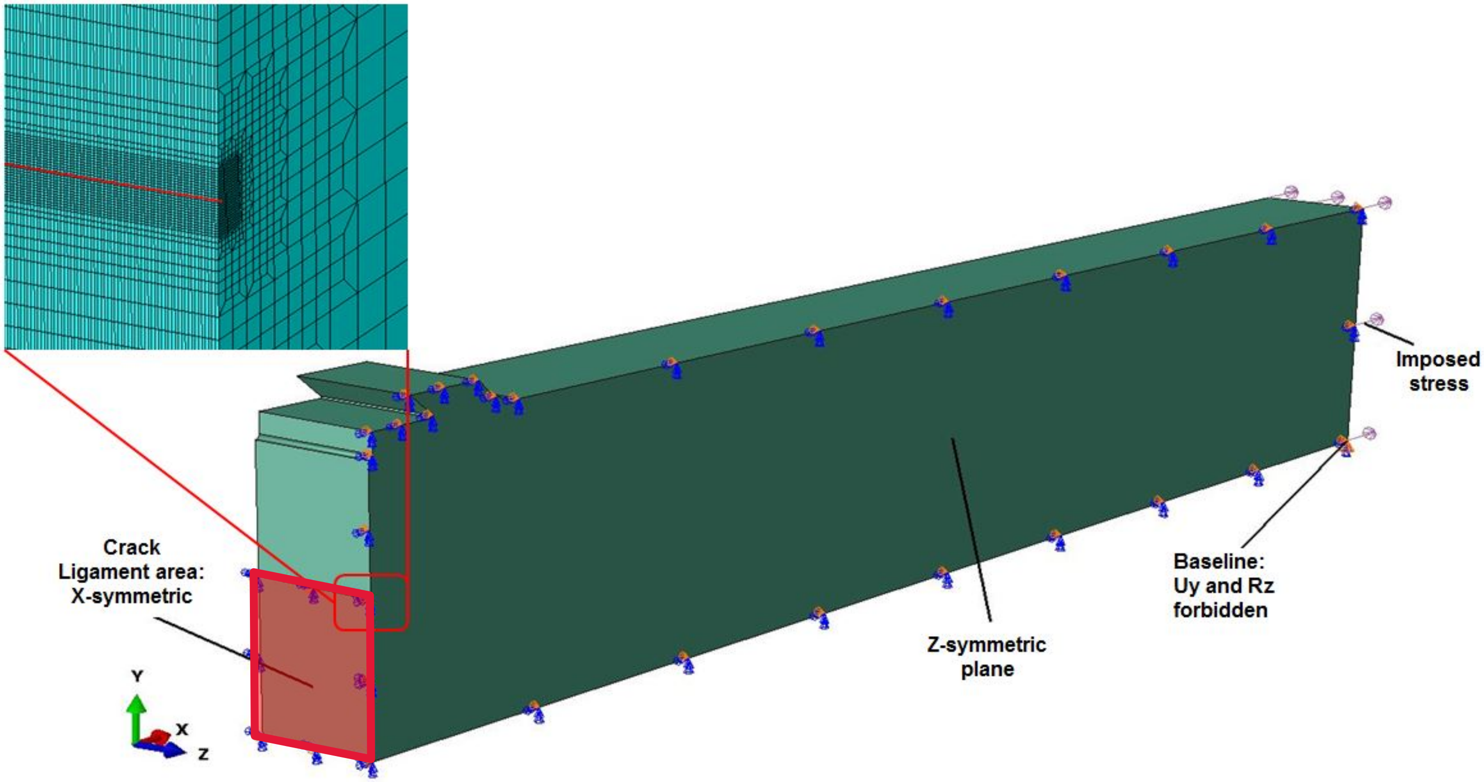
$$\frac{\sigma_c(\theta)}{\sigma_c(0)} = 1 - 1.0467\theta + 0.1687\theta^2$$

Serebrinsky, 2004



Motivations

Modelling of hydrogen induced degradation through CZM

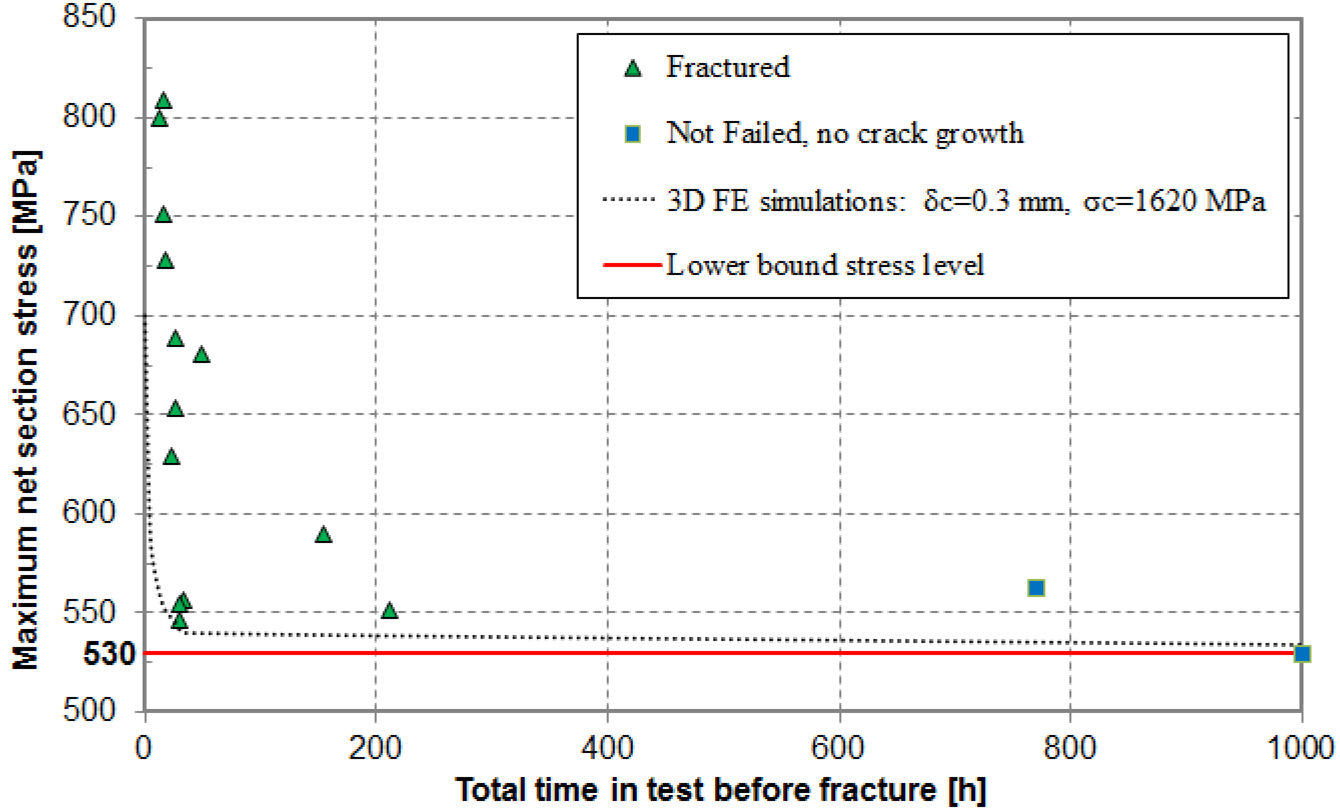


Hydrogen-related boundary conditions

CP: 1.5 ppm (melt extr.)

Motivations

Modelling of hydrogen induced degradation through CZM



Is this cohesive zone modelling approach ROBUST enough? Is it able to account for different stress concentration configurations? (horizontal validity?)

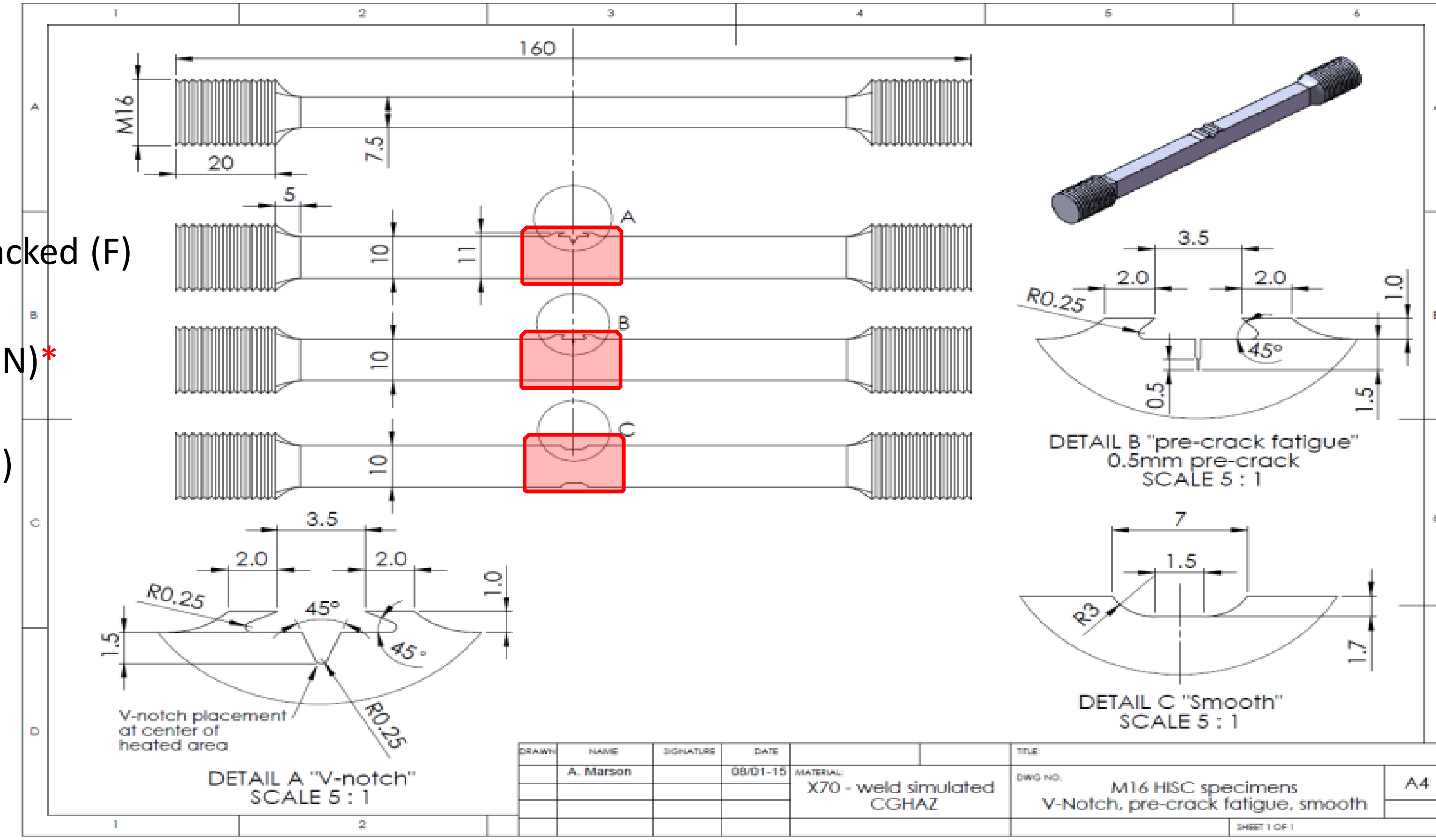
Experimental procedure

Specimens

Fatigue pre-cracked (F)

V-Notched (N)*

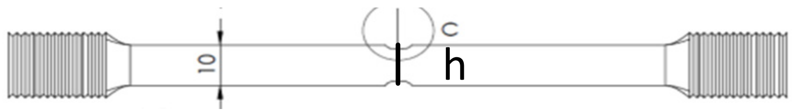
Smooth (S)

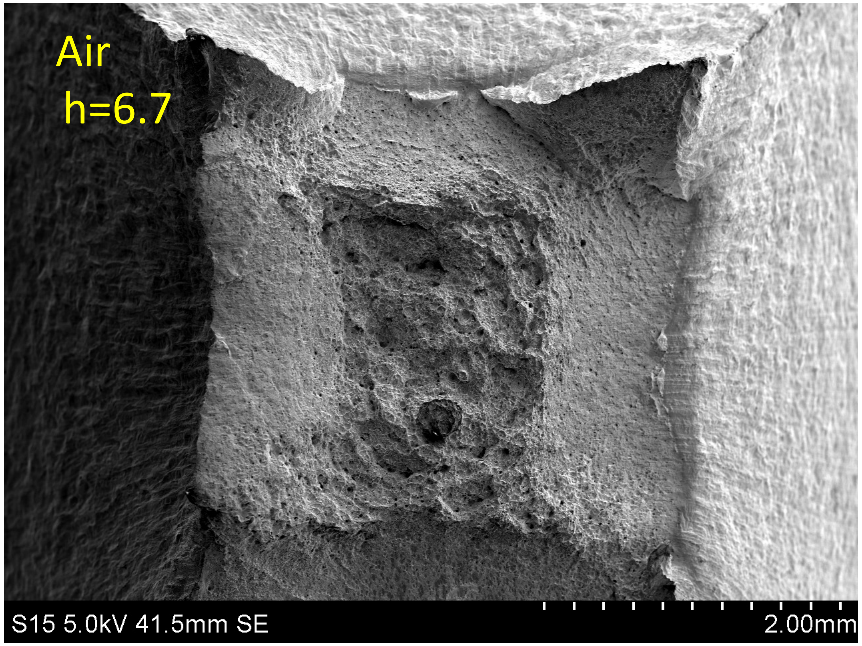


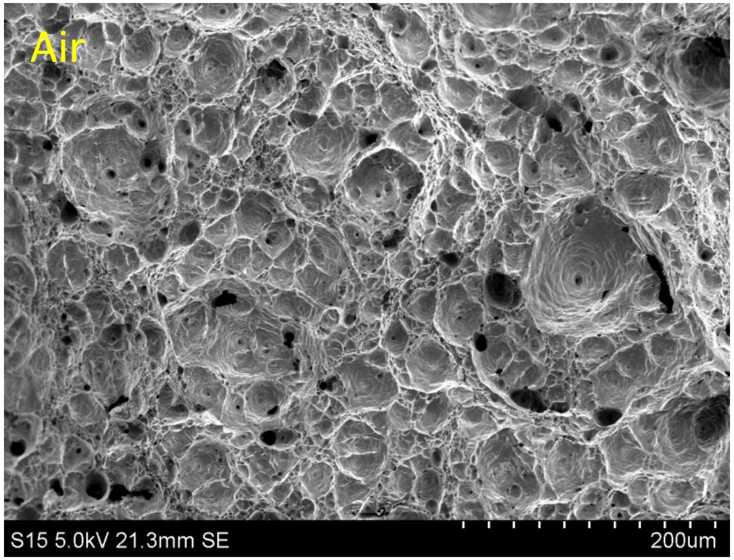
*: worst case undercut in the weld toe, SCF=6.4, (HISC project)

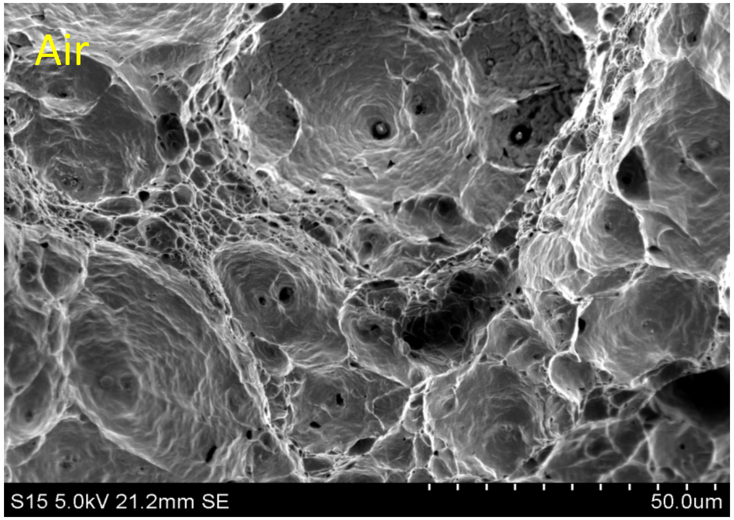
Experimental: Results

Smooth specimens



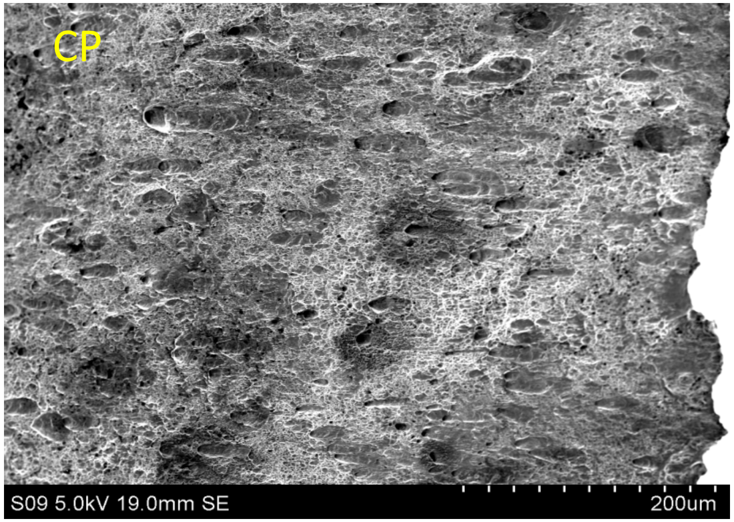


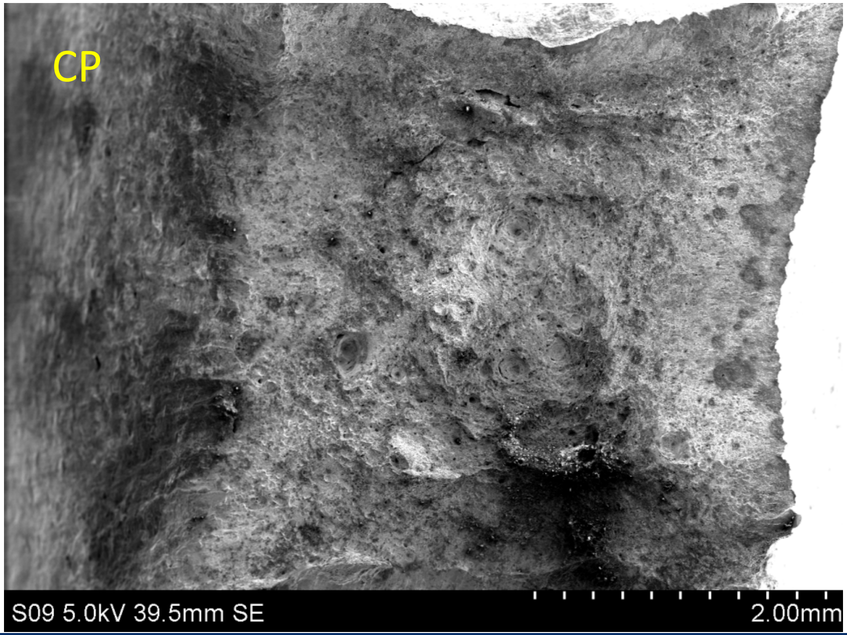


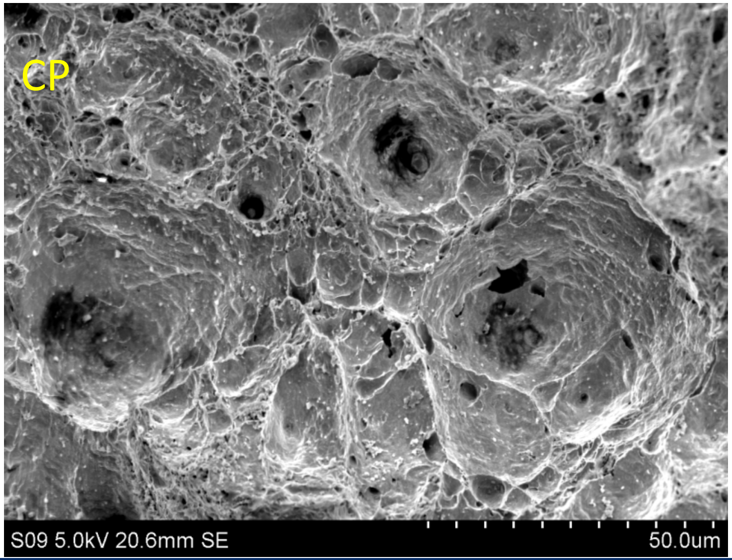


Experimental: Results

Smooth specimens

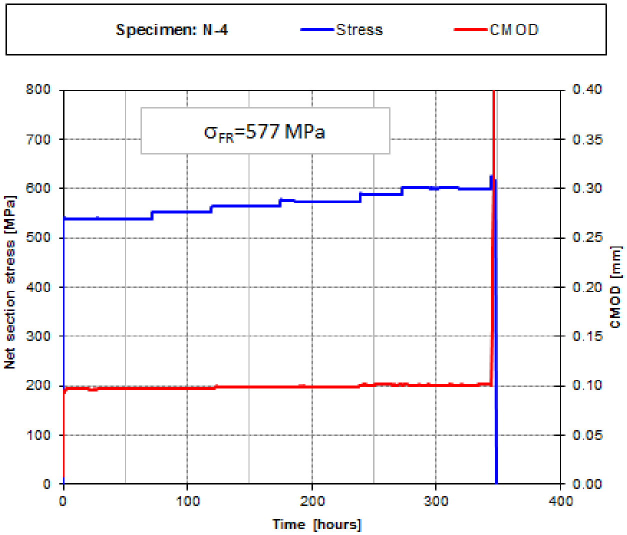


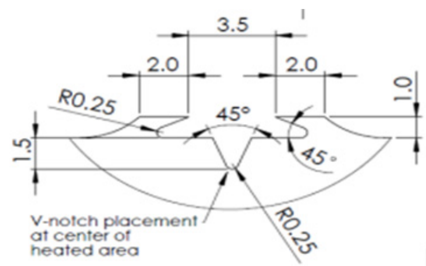


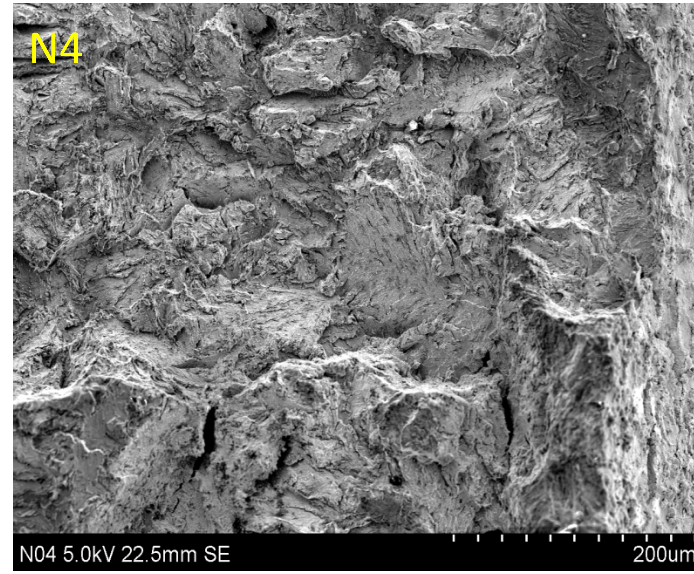


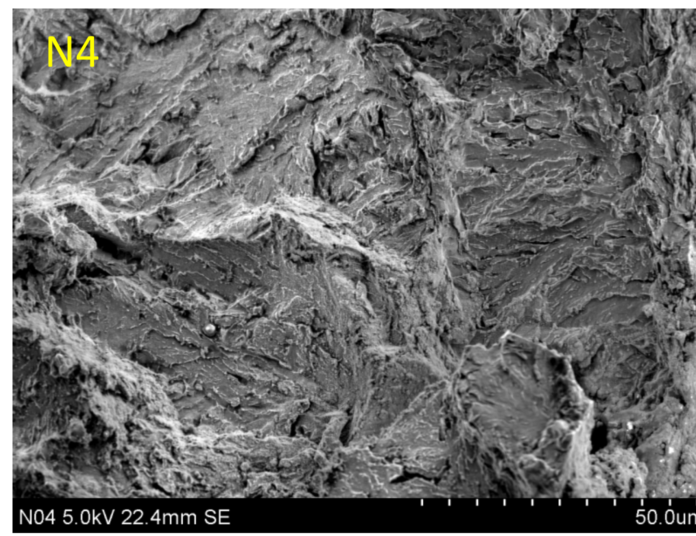
Experimental: Results

V-Notched specimens



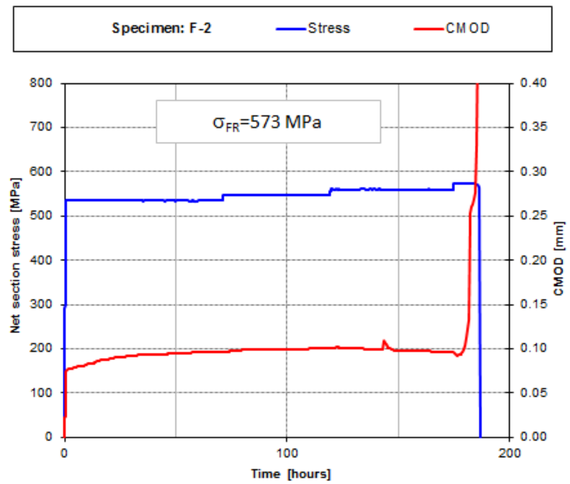


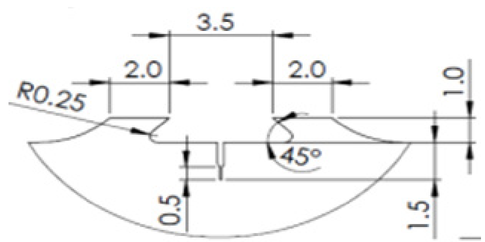


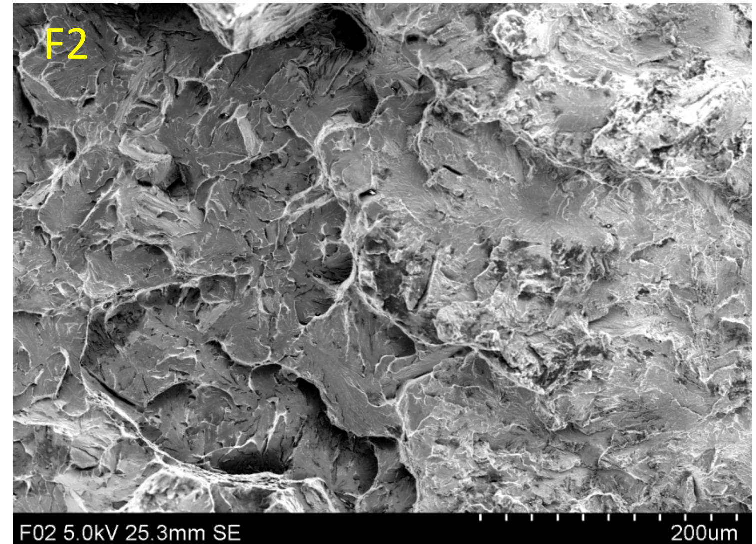


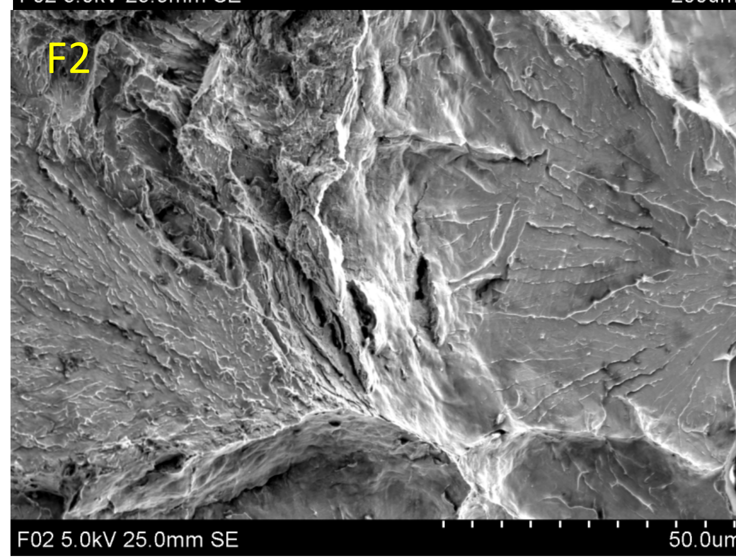
Experimental: Results

Fatigue pre-cracked specimens (F)



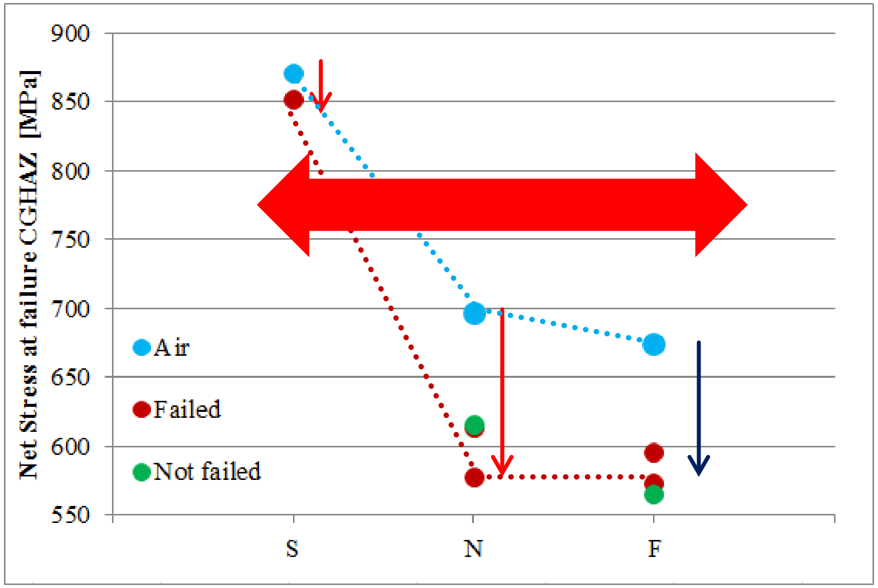


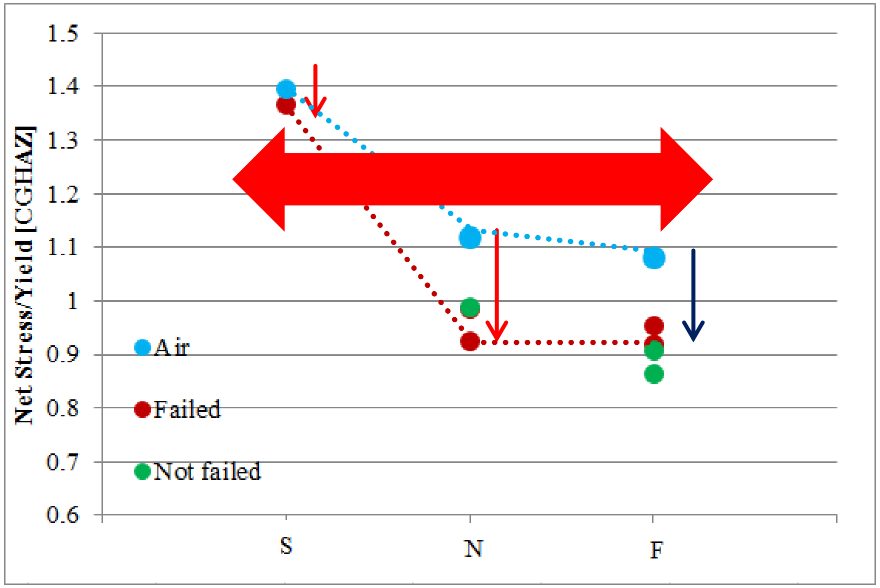


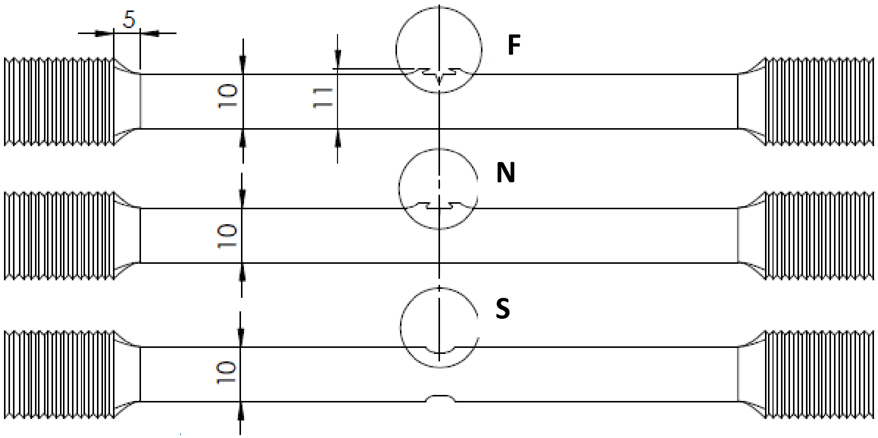


Experimental: Results

Summary







Transferability between different testing geometry? (Horizontal validity)

Conclusion

- X70 CGHAZ shows very little hydrogen embrittlement susceptibility when there is not presence of stress concentrator
- Increase of notch severity increases the material susceptibility to hydrogen
- Despite some differences in fracture surface appearances between notched and fatigue pre-cracked specimens, they feature almost equal low bound fracture stresses in cathodically charged hydrogen

Further work

- Verification of the "horizontal" robustness of the model will be performed based on these experimental results
- Further testing of specimen with notches featuring SCF < 6.4 will be performed in order to get a more complete overview of the influence of the notch sensitivity on hydrogen embrittlement material susceptibility

THANK YOU FOR ATTENTION!