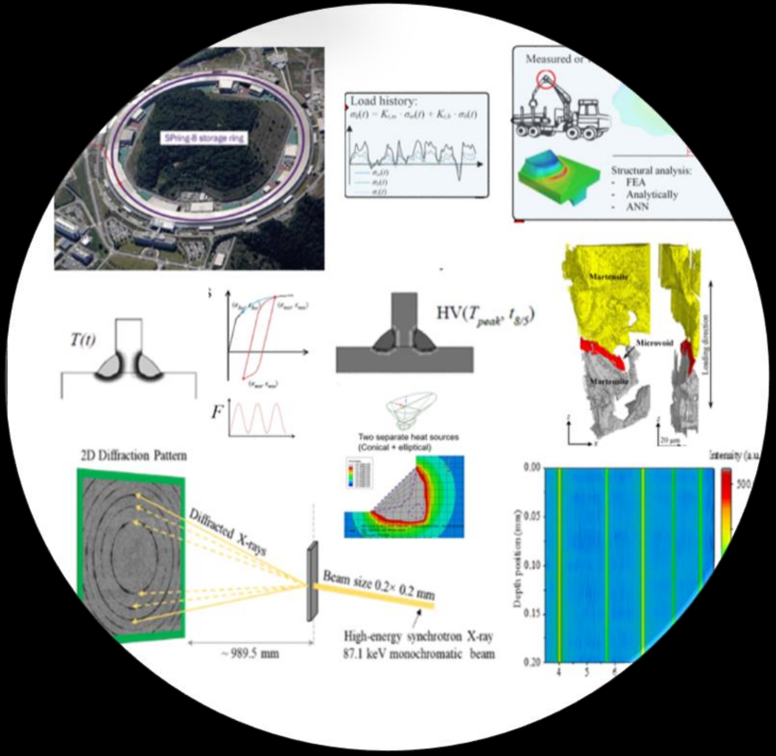
LUT University

LAND OF THE CURIOUS

Prospects of H2Pipeline projects in Austria
What is done so far? What is understood?



Masoud Moshtaghi
Tenure Track Assistant Professor
Head of Steel Structures Research Group
LUT University
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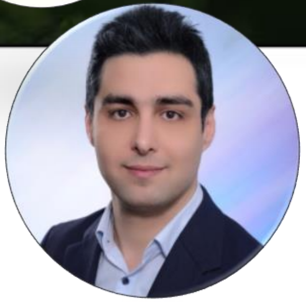
A trailblazer in the field of design and strength analysis of metallic parts and components in Finland since 1974; towards testing and designing novel alloys and structures for energy and other structural applications.


SYSTEM
EARTH
AIR
From emissions to opportunities
BUSINESS AND SOCIETY
Sustainable renewal of business, industry and society
WATER
Complex water adequacy and water treatment needs
ENERGY
Transition to carbon neutrality
TRAILBLAZERS – Science with a Purpose
LUT UNIVERSITY STRATEGY 2030



Masoud Moshtaghi
Tenure Track Assistant Professor
Head of Steel Structures Research Group

+ 8 master students

+ 10 Bachelor students

+ 3 technicians

Mahdieh Safyari
Post-doctoral researcher
Hydrogen embrittlement and additive manufacturing

Kalle Lipiäinen
Post-doctoral researcher
Mechanics of materials

Jani Riski
PhD student
Residual stress

Matti Koskimäki
Research Engineer

Hamidreza Rouhani
Post-doctoral researcher
Finite element and machine learning, hydrogen-assisted fatigue

Donát Horváth
PhD Student
Hydrogen embrittlement

Aleksi Härkönen
PhD student
Real-time fatigue monitoring

Pasi Tanskanen
Lecturer

Antti Ahola
Post-doctoral researcher
Fatigue and stress analysis

Kiia Grönlund
PhD student
Fatigue in variable amplitudes conditions

Dilip Neupane
PhD student
Weld geometry simulation and fatigue

Sami Heinilä
Lecturer

Shahriar Afkhami
Post-doctoral researcher
Microstructure-mechanical properties relationships

Juho Havia
PhD student
Fatigue of welded aluminium

Tero Pesonen
PhD student
Finite element methods for fatigue assessment

Edris Dabiri
Lecturer
(Metso)

Visiting Professor:

Prof. Martin Leitner
From **Technical University of Graz, Austria**

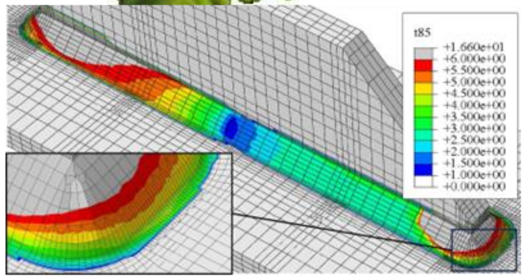
Future new member:

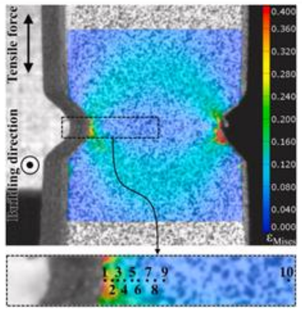
Dr. Digvijay Singh (Starting from Jan. 2025)
From **National Insitute of Materials Science (NIMS), Japan**

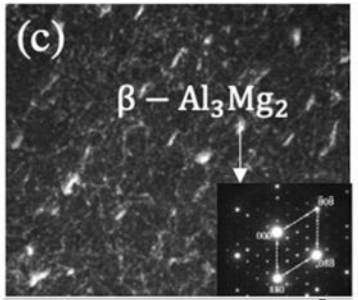
Overview of activities of LUT Steel Structures

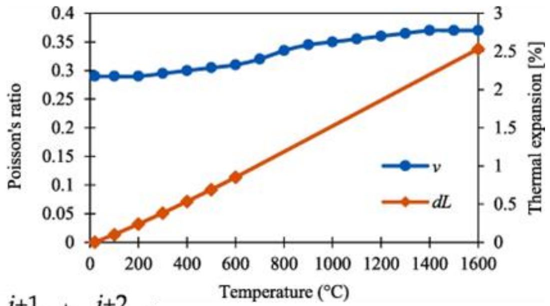
LUT University

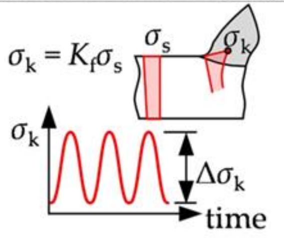
- Design and testing hydrogen storage tanks, pipelines, etc.
- Hydrogen embrittlement and its mechanisms
- Steel structures for hydrogen energy
- Fatigue assessment methods and life prediction
- Static and fatigue strength of welded joints and components
- High Strength steels (HSS) and Ultra High Strength Steel (UHSS)
- High-cycle and low-cycle fatigue behaviour of components in view of their microstructure
- Microstructure-mechanical properties relationships
- Structural performance and quality of high-strength steels
- Enhancement of fatigue strength of welded joints by welding techniques and post-weld treatments
- Numerical methods and analysis of welded structures, incl. stress analysis and welding simulations
- Stability and distortion phenomena of thin-walled products
- Performance of steel structure at subzero temperatures
- Structural performance of AM components
- Failure analysis of structural components
- Environmental effect on mechanical response of components

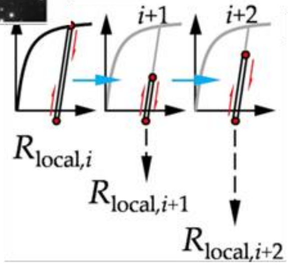


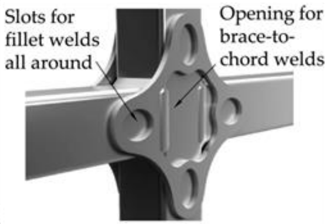


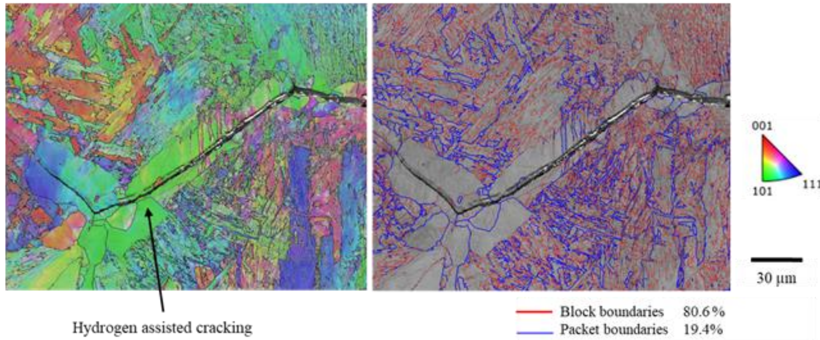






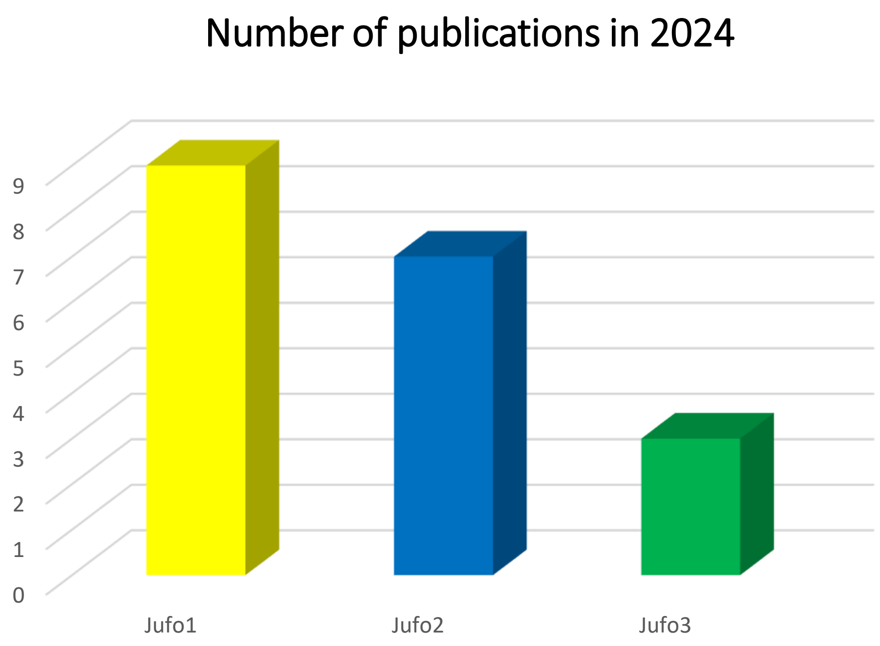


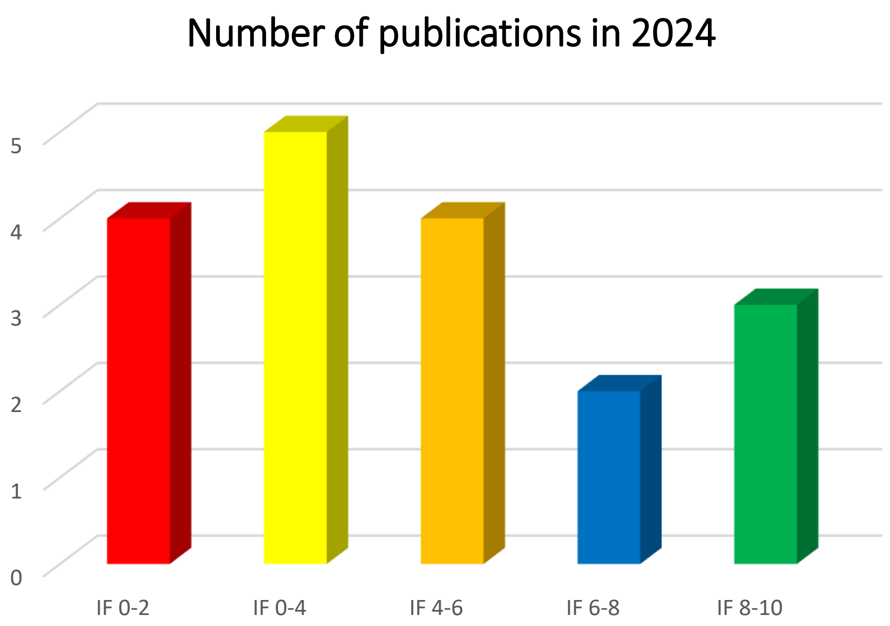




Paper publication status

Paper contributions:

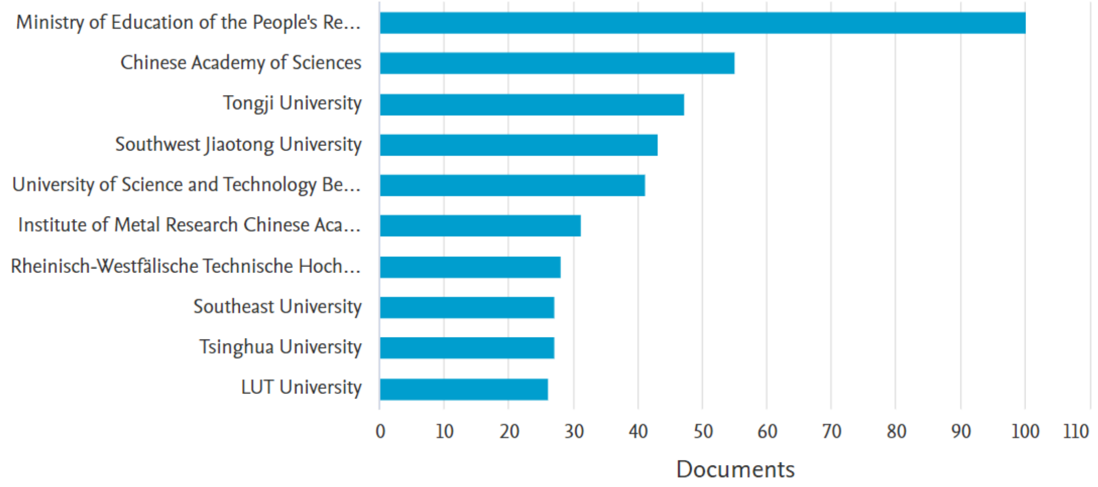




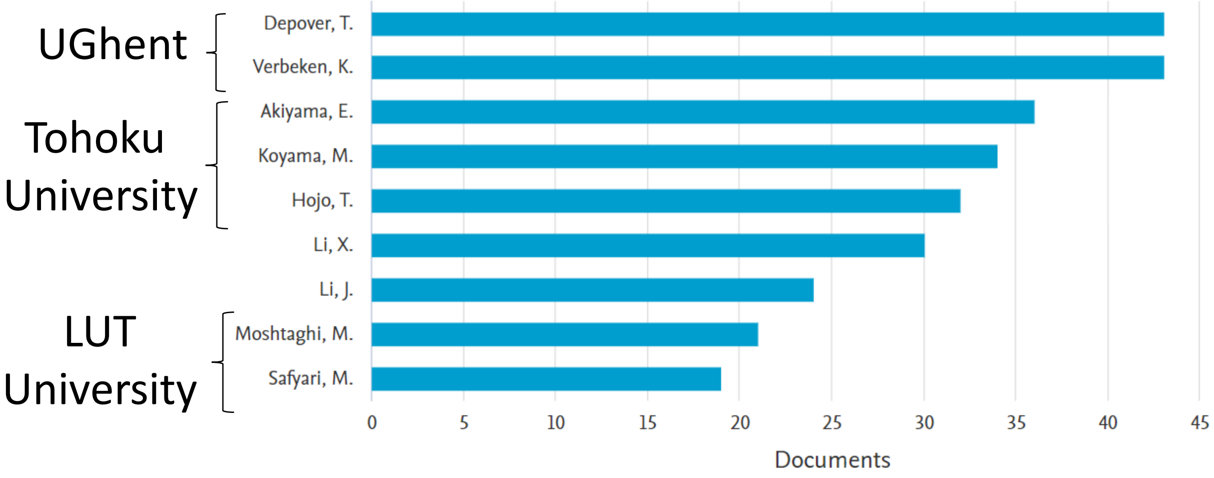
LUT Steel Structures in Scopus (2021-2024)

LUT Steel Structures in top 10 of the world:

Fatigue of high-strength steels



Hydrogen embrittlement



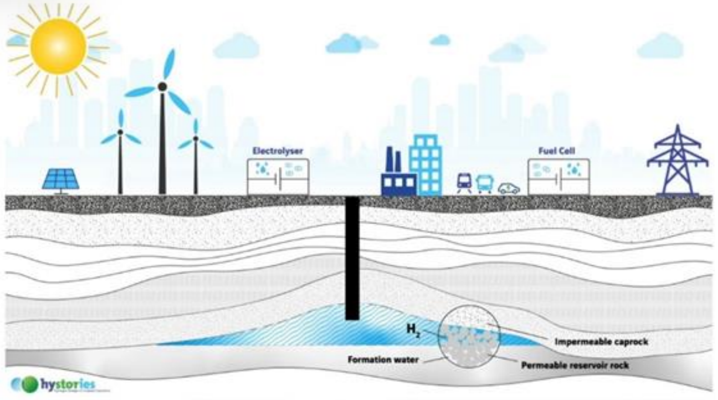
Projects

Key active projects:

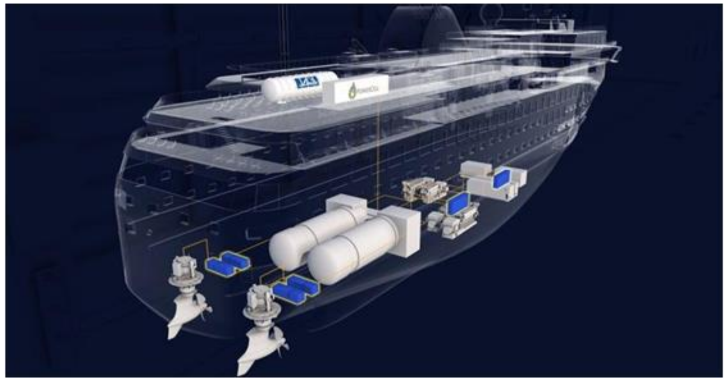
- **Business Finland: FOSSA II – Fossil-free Steel Applications II**
- **Business Finland: CaNeLis - Carbon-neutral lightweight ship structures using advanced design, production, and life-cycle services**
- **Business Finland: AluWeld, Fatigue studies of welded aluminium structures**
- **Business Finland: Dreams, Database for Radically Enhancing Additive Manufacturing and Standardization**
- **Business Finland: Viima, Real-time fatigue studies of the machines**
- **FWF, Austrian Science Fund – ESPRIT Development of hydrogen-resistant high-strength steels**
- **HyGCEL project: Hydrogen and Carbon Value Chain in Finland**

+ more than 50 small-scale projects with national and international companies

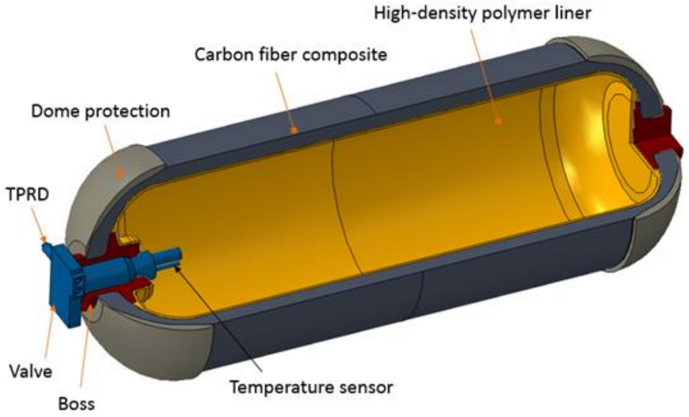
Hydrogen embrittlement



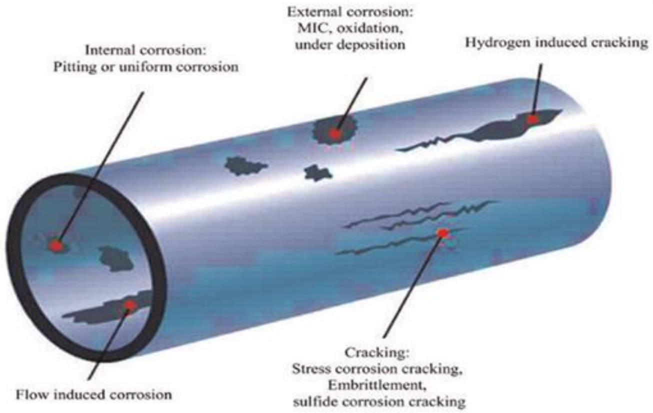
Steel design for underground storage



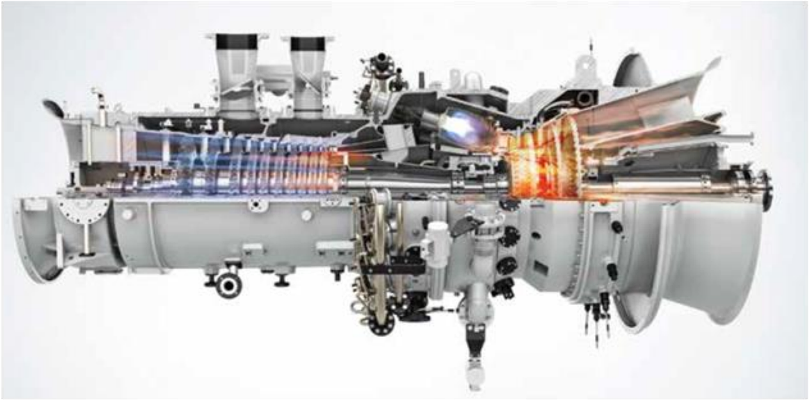
Ship design and fatigue design



Design of hydrogen storage tanks under fatigue and vibration condition

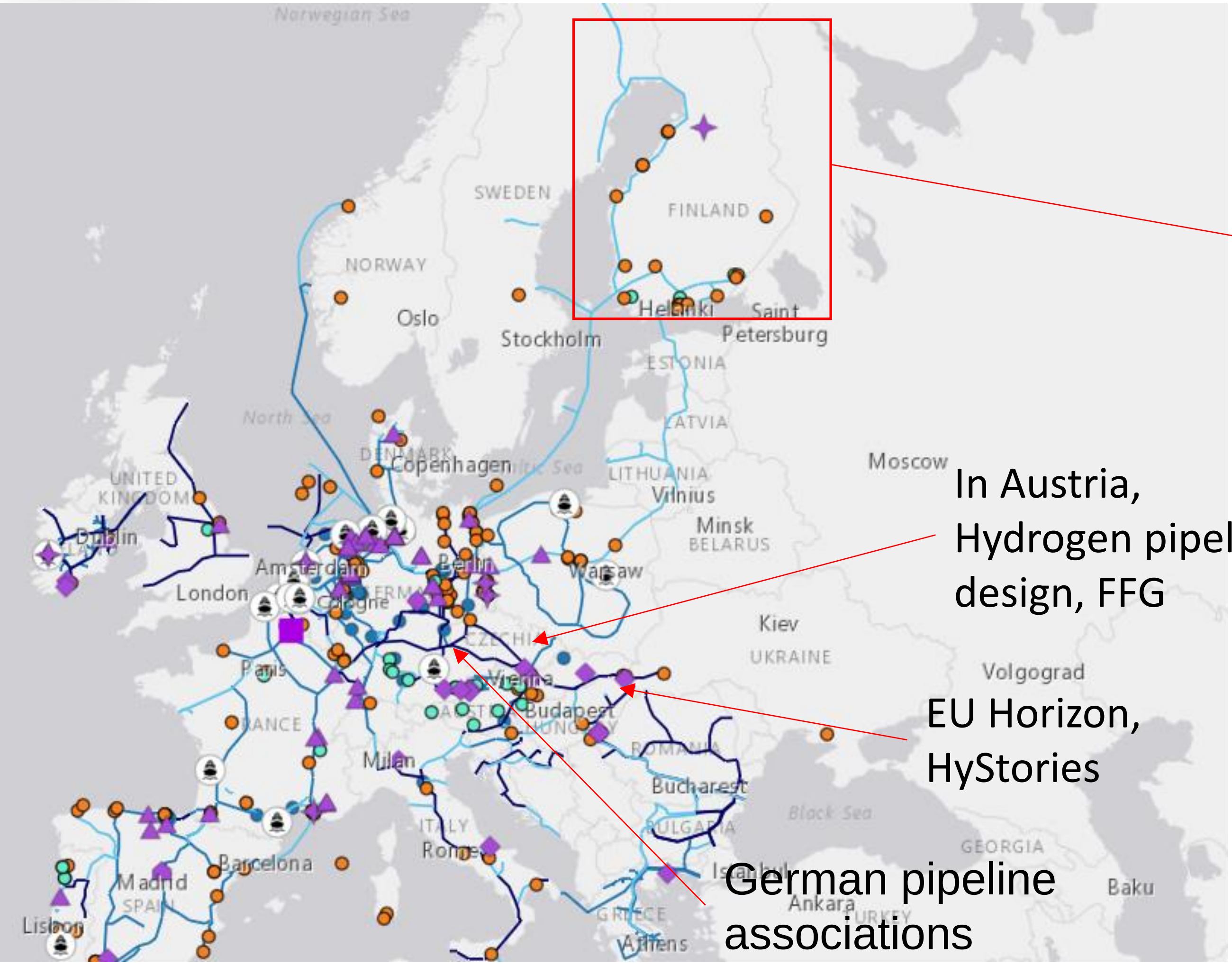


Design of welded pipeline steels



Compressors and gas turbines

Hydrogen pipeline projects lead by me in Austria



In Austria, Hydrogen pipeline design, FFG

EU Horizon, HyStories

German pipeline associations

HyGCEL, Hydrogen and Carbon Value Chain (HyGCEL) project, LUT

Stress intensity factor

A different approach to estimate whether an existing crack/flaw will grow is by looking at the stress intensity factor (**SIF**) at the crack tip. In your design classes you have already encountered the concept of stress rise due to stress concentrators.

Under the assumptions of LEFM we can derive the stress field in a cracked body, leading to :

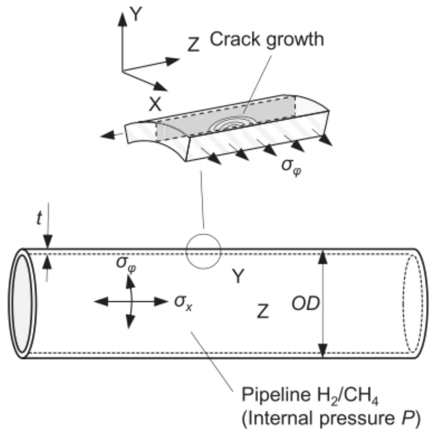
$$\sigma_{ij} = \left(\frac{k}{\sqrt{r}}\right) f_{ij}(\theta) + \sum_{m=0}^{\infty} A_M r^{m/2} g_{ij}^{(m)}(\theta) \qquad (5)$$

with r and θ being define at the orifin of the crack tip and counter-clockwise respectively. close to the crack tip, where $r \to 0$ the second term on the RHS of (8.1) vanishes. As a results, the $\sigma \propto r^{-1/2}$ relation holds in general for any cracked elastic body.

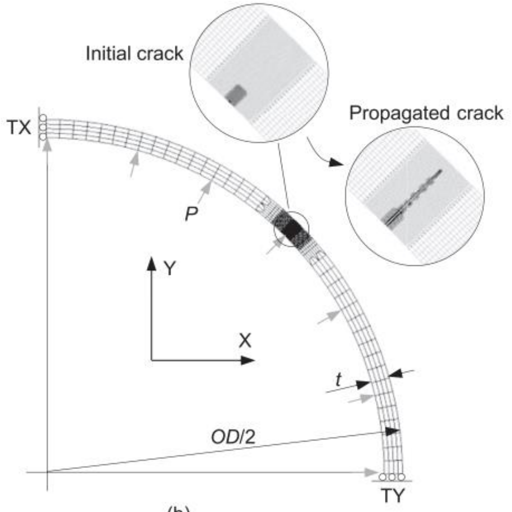
As you recall we can obtain the displacement directly from the stress field using the elastic constitutive equation to obtain the strains and then integrating them to obtain displacements. This implies that the displacements at the crack tip will be proportional to $\sqrt{r}$.

As we will see later, when deriving the crack tip fields, it is useful to replace k in (8.1) with $K = k\sqrt{2\pi}$.

Moreover, we will add a subscript to K to differentiate between the different crack opening modes: $K_I; K_{II}; K_{III}$.



(a)



(b)

Stress intensity factor

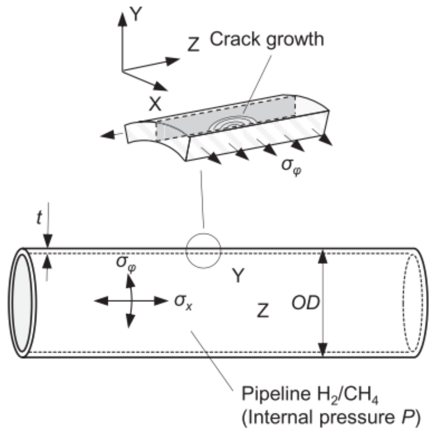
$$\lim_{r \to 0} \sigma_{ij}^{(I)} = \frac{K_I}{\sqrt{2\pi r}} f_{ij}(\theta)$$

$$\lim_{r \to 0} \sigma_{ij}^{(II)} = \frac{K_{II}}{\sqrt{2\pi r}} f_{ij}(\theta)$$

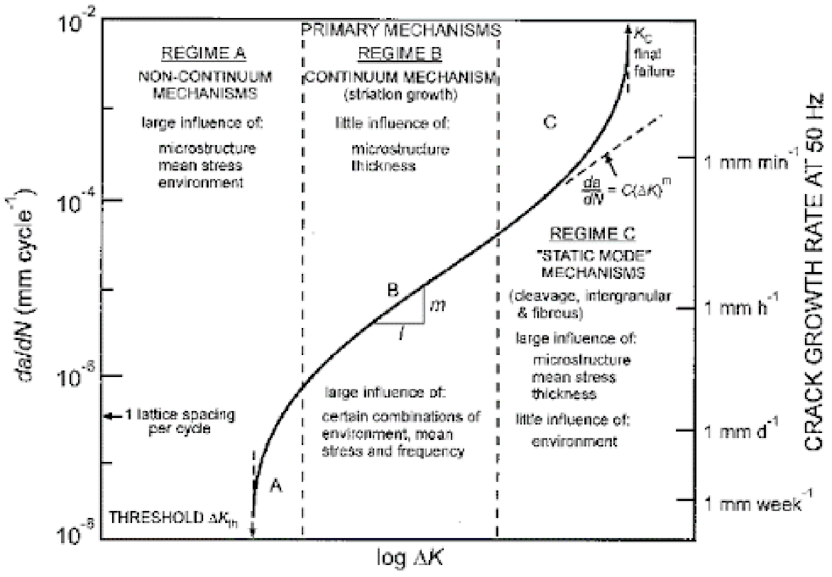
$$\lim_{r \to 0} \sigma_{ij}^{(III)} = \frac{K_{III}}{\sqrt{2\pi r}} f_{ij}(\theta)$$

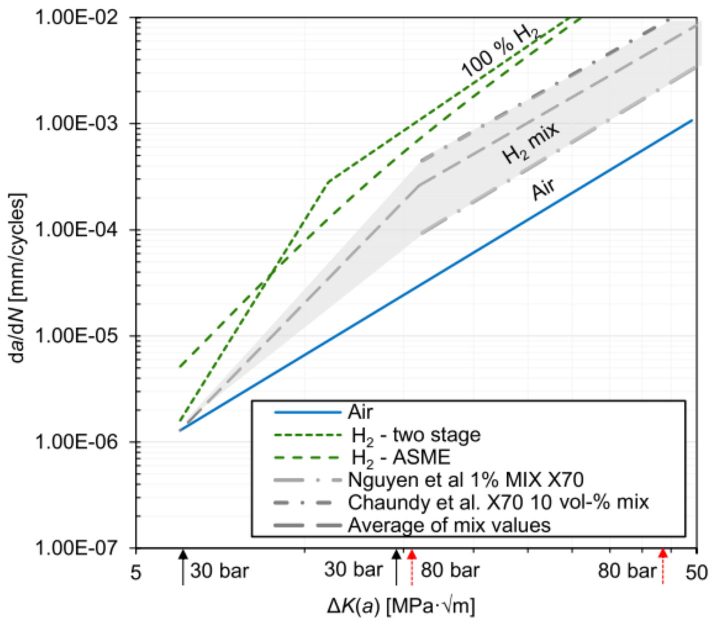
When encountering a problem of mixed-mode, we can use superposition to find the stresses at the crack tip such that :

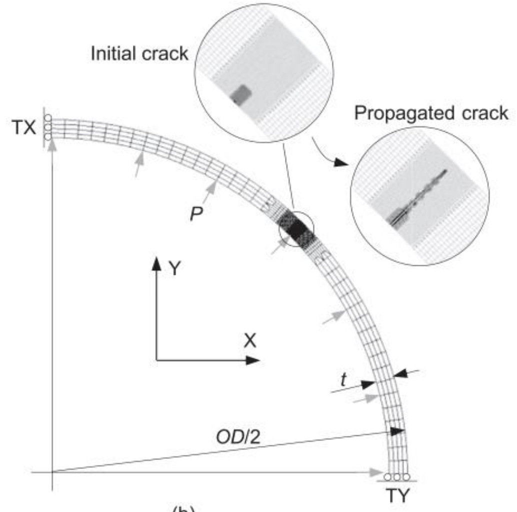
$$\sigma_{ij}^{mixed} = \sigma_{ij}^{I} + \sigma_{ij}^{II} + \sigma_{ij}^{III}$$



(a)







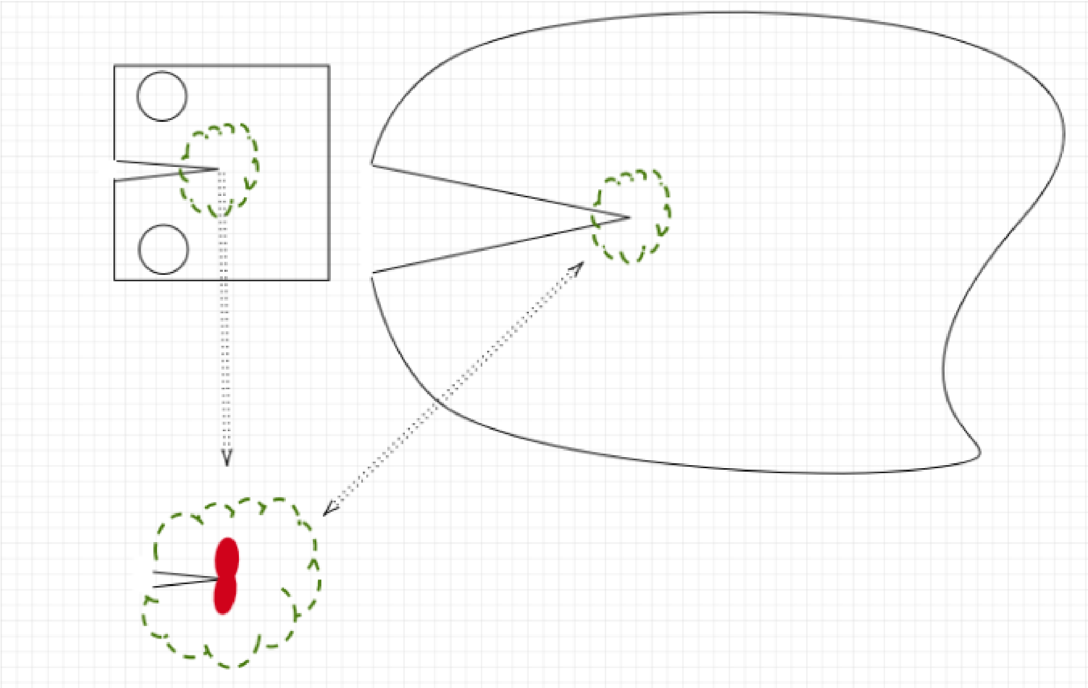
(b)

Plain strain fracture

When we started discussing how to characterize a cracked structure we introduced the concept of a **singularity** dominated region and extracted a single parameter from it K which we claimed can fully characterize the crack tip fields.

The value of K at which a test specimen fails is denoted K_c and is a material parameter (i.e. independent on geometry).

- How can be concile the K approach to fracture arising from LEFM with the presence of plasticity at the crack tip we discussed last week?
- What are the conditions for which the K approach still holds?



Plain strain fracture

Cracks and flaws cause **stress concentration**

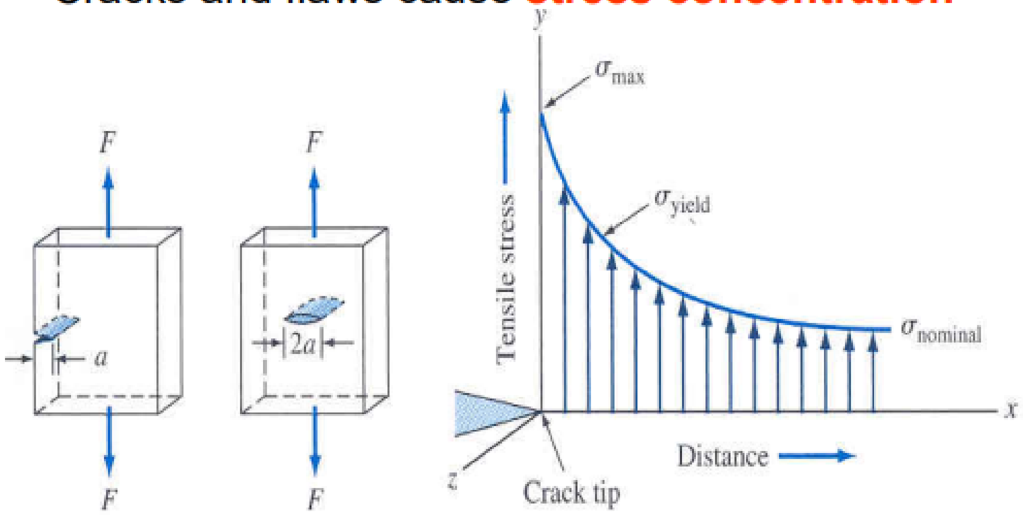
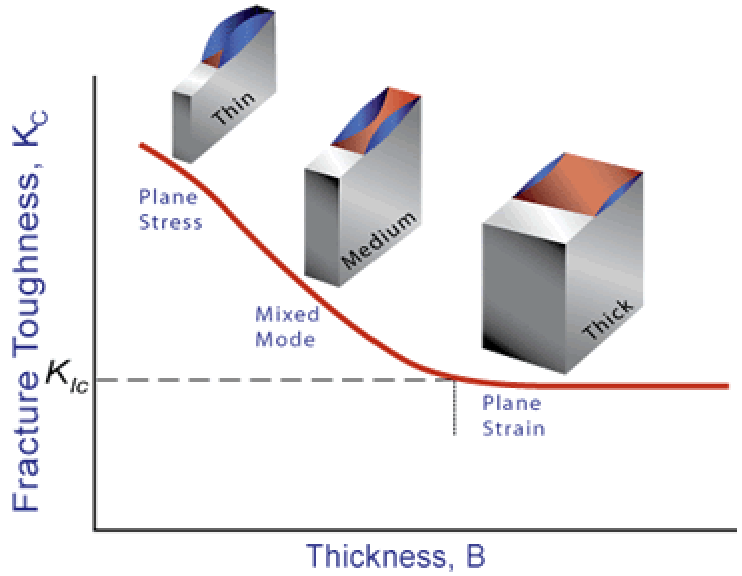


Figure 6.17

$$K_1 = Y\sigma\sqrt{\pi a}$$

K_1 - Stress intensity factor
σ - Applied stress
a - edge crack length
Y - geometric constant



K_{Ic} - critical value of stress intensity factor (fracture toughness)

$$= Y\sigma_f\sqrt{\pi a}$$

Measuring Fracture Toughness: notch is machined in a specimen of thickness B
B >> a plain strain condition.
B = 2.5(K_{Ic}/Yield strength)^2
Specimen is tensile tested
Higher the K_{Ic} value, more ductile the metal is

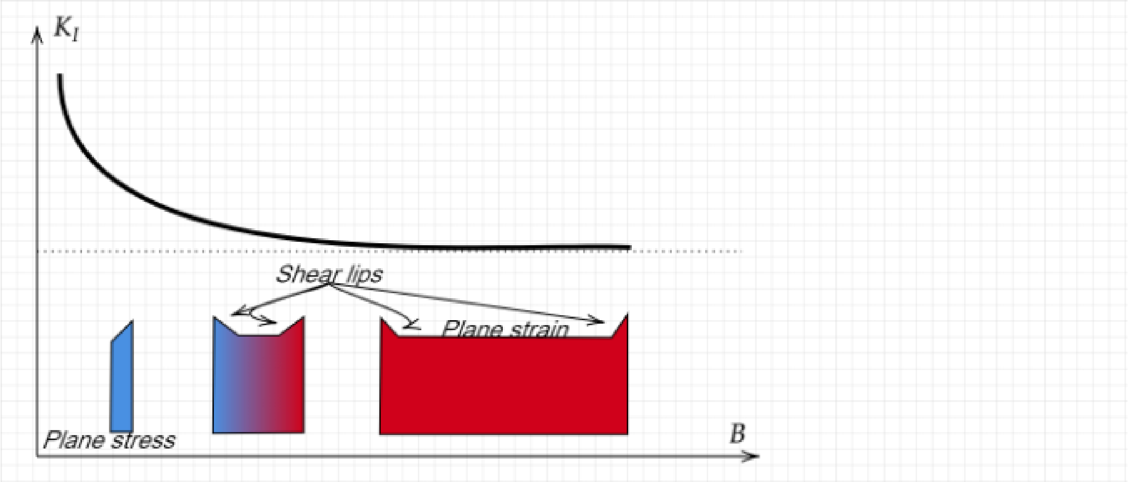
Plain strain fracture

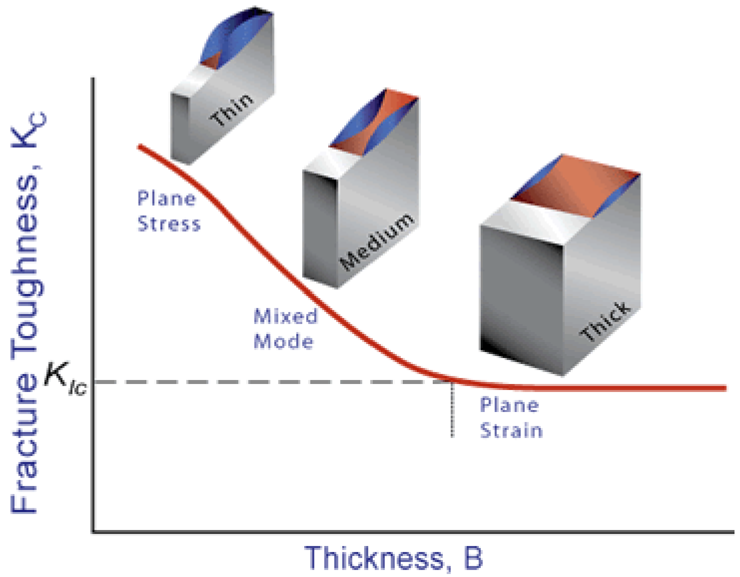
The plastic zone estimates we dealt with beofre are used in teh ASTM standards (e.e. ASTM E399) as a criteria for the validity of a K_I measurment.

Knowing the σ_y of our material, and after measuring the K_{Ic} from an experiment, we will use

$$a, B, (W-a) \geq 2.5\left(\frac{K_{IC}}{\sigma_y}\right)$$

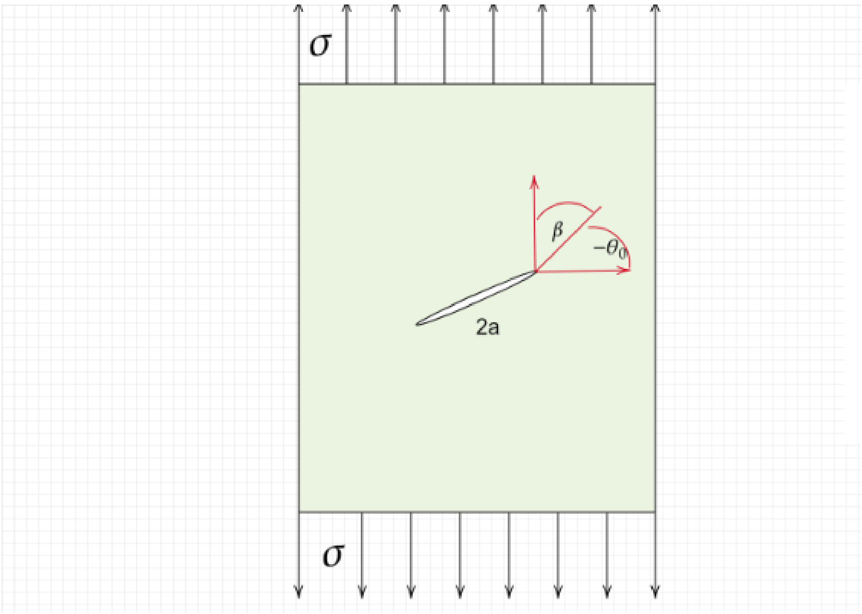
as a criteria for accepting our test result.





Mixed mode fracture

Mixed-mode scenarios will often be found in heterogenous structures (multi-phase materials, weldements, coatings, composites etc.).



And the displacements:

$$u_1 = \frac{K_I}{2\mu}\sqrt{\frac{r}{2\pi}}\left[\cos\frac{\theta}{2}(\kappa - \cos\theta)\right] + \frac{K_{II}}{2\mu}\sqrt{\frac{r}{2\pi}}\left[\sin\frac{\theta}{2}(\kappa - + \cos\theta)\right]$$

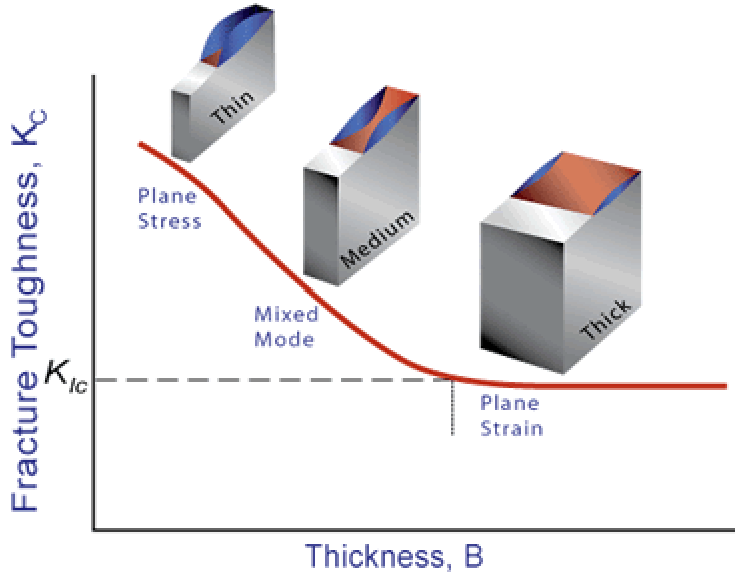
$$u_2 = \frac{K_I}{2\mu}\sqrt{\frac{r}{2\pi}}\left[\sin\frac{\theta}{2}(\kappa - \cos\theta)\right] + \frac{K_{II}}{2\mu}\sqrt{\frac{r}{2\pi}}\left[-\cos\frac{\theta}{2}(\kappa - 2 + \cos\theta)\right]$$

We can use superposition and obtain the crack tip fields as

$$\sigma_{11} = \frac{K_I}{\sqrt{2\pi r}}\left[\cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{2\theta}{2}\right)\right] + \frac{K_{II}}{\sqrt{2\pi r}}\left[-\sin\frac{\theta}{2}\left(2 + \cos\frac{\theta}{2}\cos\frac{2\theta}{2}\right)\right]$$

$$\sigma_{22} = \frac{K_I}{\sqrt{2\pi r}}\left[\cos\frac{\theta}{2}\left(1 + \sin\frac{\theta}{2}\sin\frac{2\theta}{2}\right)\right] + \frac{K_{II}}{\sqrt{2\pi r}}\left[\sin\frac{\theta}{2}\cos\frac{\theta}{2}\cos\frac{2\theta}{2}\right]$$

$$\sigma_{12} = \frac{K_I}{\sqrt{2\pi r}}\left[\cos\frac{\theta}{2}\sin\frac{\theta}{2}\sin\frac{2\theta}{2}\right] + \frac{K_{II}}{\sqrt{2\pi r}}\left[\cos\frac{\theta}{2}\left(1 - \sin\frac{\theta}{2}\sin\frac{2\theta}{2}\right)\right]$$



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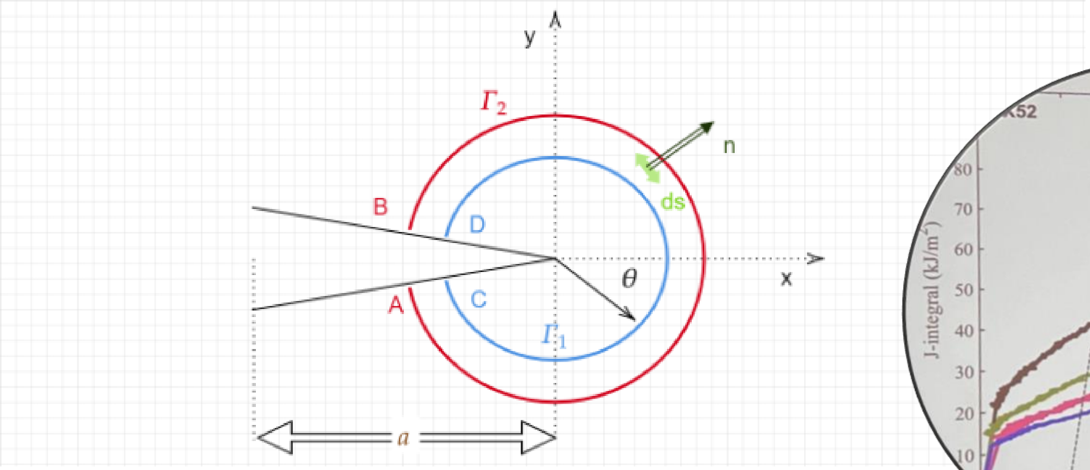
J Integral

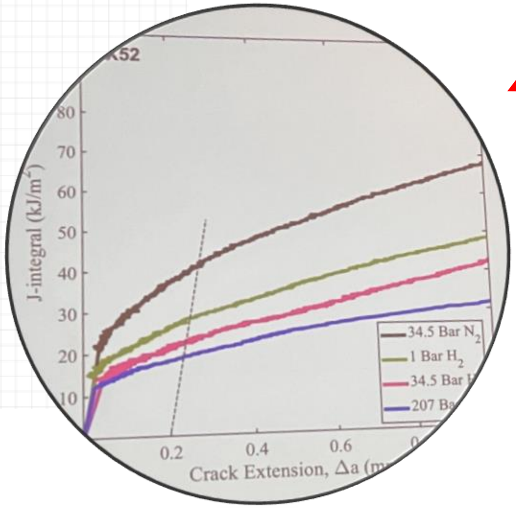
As you all remember we previously discussed energy methods in the context of fracture mechanics.

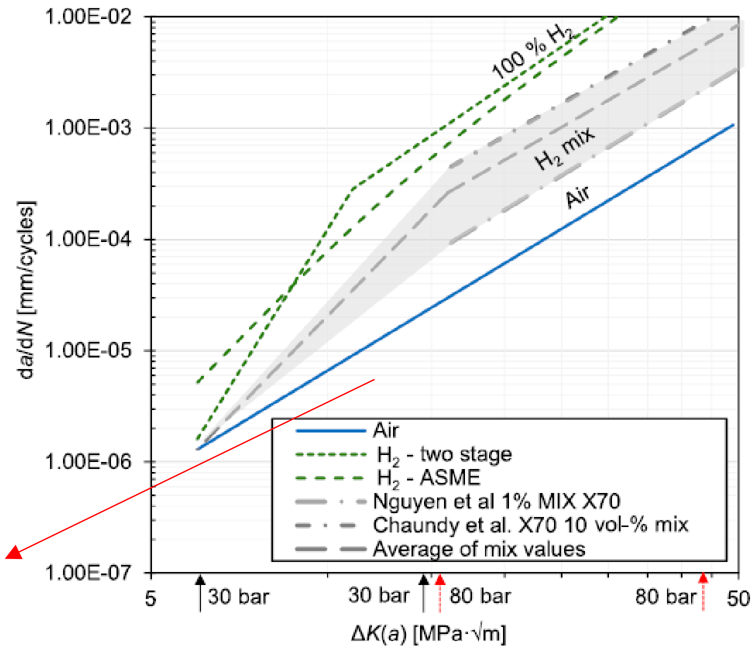
G , the energy release rate was used when we discussed the stability of growing cracks.

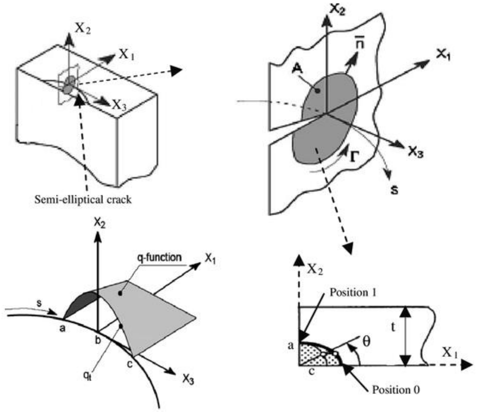
The strain energy concept, proposed by Shih was used for defining the crack growth direction under mixed-mode conditions.

We will now introduce another energy related concept which will allow us to estimate the fracture toughness and resistance curves of cracks, while avoiding some of the limitations we discussed previously, resulting from the plastic zone size.









The J integral is defined as :

$$J = \int_{\Gamma} \left(W\,dy - \vec{T}\frac{\partial \vec{u}}{\partial x} ds \right)$$

Elastic-Plastic Fracture Mechanics

CTOD - Crack Tip Opening Displacement

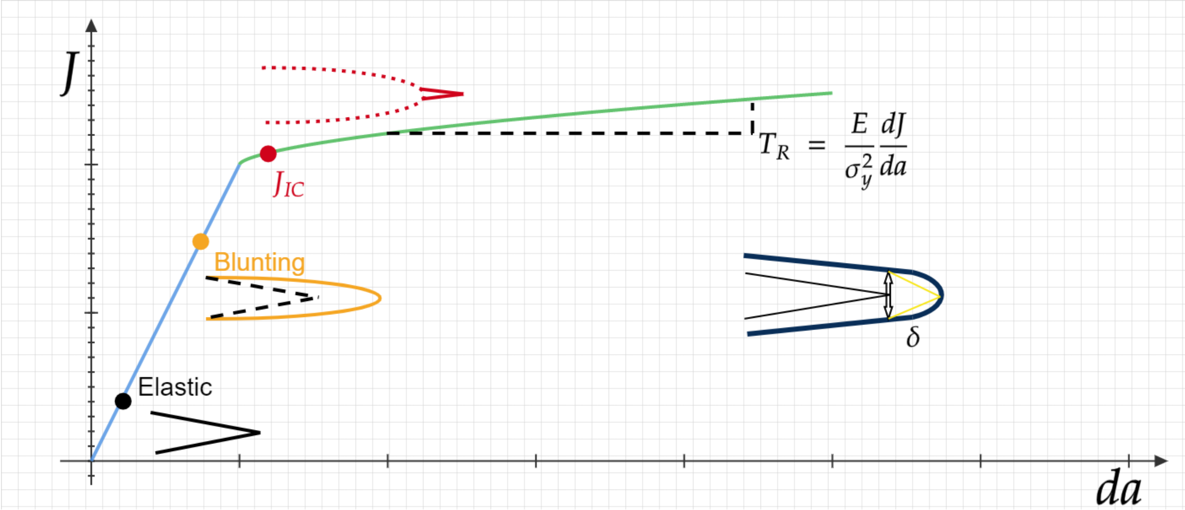
Using *Irwin's* crack-tip plasticity model, Wells was able to show that the CTOD (δ) follows:

$$\delta = \frac{4}{\pi}\frac{G}{\sigma_y}$$

A similar result is obtained following the strip model:

$$\delta = \frac{G}{m\sigma_y}$$

and m assumes a value of 1 for plane stress and 2 for plane strain.



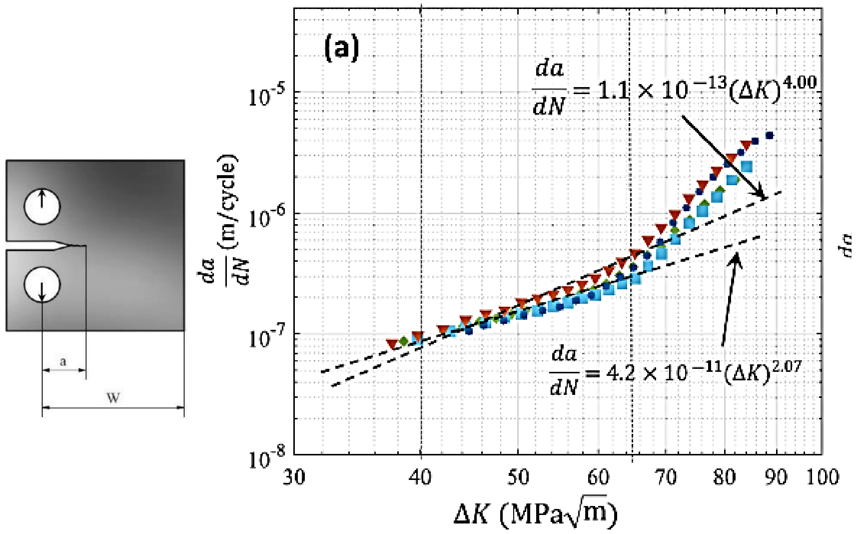
While not entirely accurate, this assumption allows us to measure the **Crack Mouth Opening Displacement (CMOD)** and using similarity of triangles obtain the **CTOD**.

$$\delta_{CTOD} = \frac{r(W-a)}{r(W-a)+a}\delta_{CMOD}$$

The experimentaly measured **CMOD** is decomposed into an elastic and plastic part (similar to the way you would for a stress strain curve) and thus:

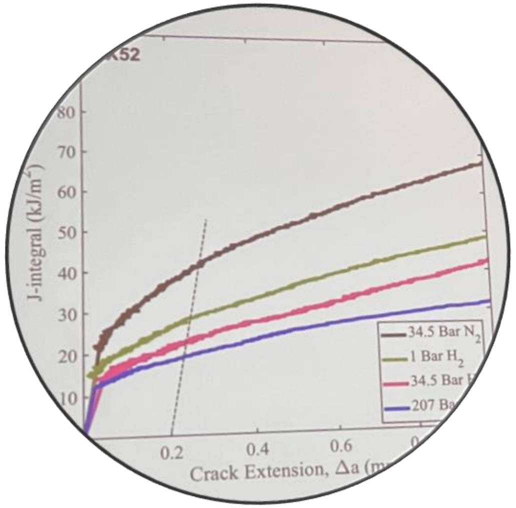
$$\delta_{CTOD} = \delta_e + \delta_p = \frac{K_I^2}{m\sigma_y E'} + \frac{r(W-a)}{r(W-a)+a}\delta_{CMOD}$$

Hydrogen pipeline test in Austria: measurement of toughness



LEFM approach

J-Integral Approach



ASME B31.12 features a nonlinear correlation (in log-scale) between crack growth rate and SIF range. ASME B31.12 suggests a characteristic design da/dN curve for hydrogen pressure under 20 MPa (200 bar).

FEM and Machine Learning

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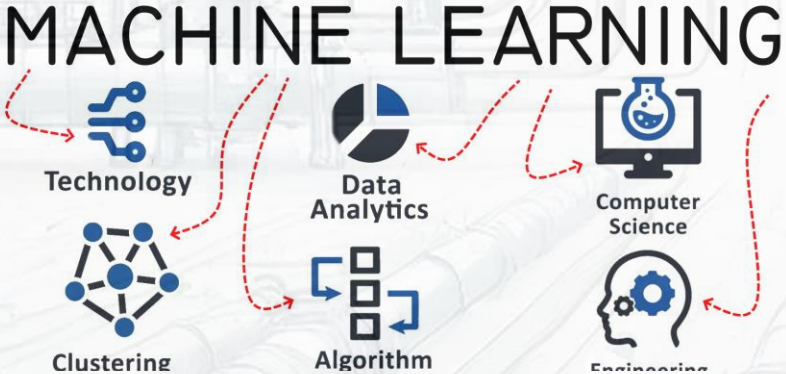
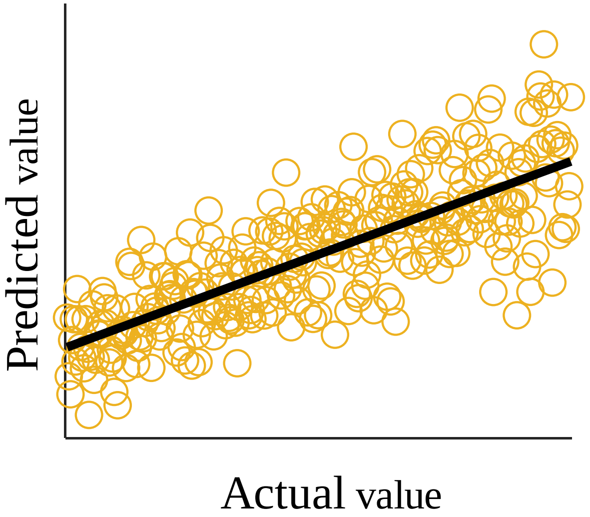
Methodology

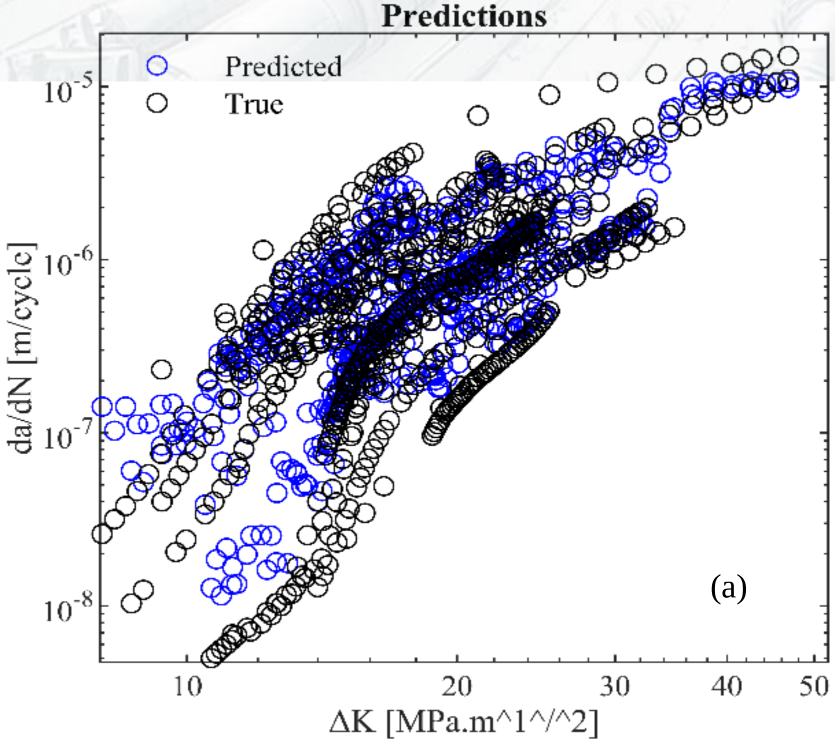
Data Analytics

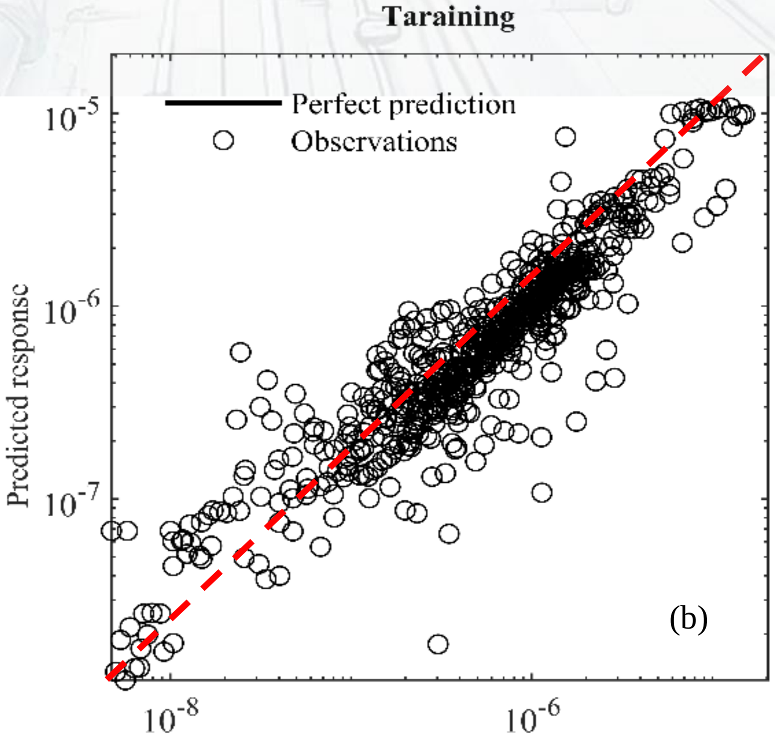


Application of Machine Learning

- Development of predictive models
- Assessment of various models
- Verification of developed model







LUT Steel Structures, Member of Standard Committee

LUT University

❖ Prof. Masoud Moshtaghi is a member of the Standard Committee at NACE and API for hydrogen pipeline testing procedures.

API

GUIDE 21586 - Guidelines For Laboratory Testing For Hydrogen

Discussions 3 | Libraries 0 | Members 24

GUIDE 21586 - Guidelines For Laboratory Corrosion Testing For Hydrogen

member last person joined 4 months ago

NACE INTERNATIONAL

SC 26 - Carbon Capture, Alternative Fuels, and Energy Storage

Discussions 42 | Libraries 7 | Members 290

SC 26 - Carbon Capture, Alternative Fuels, and Energy Storage

member last person joined yesterday

Hydrogen embrittlement in martensitic steels

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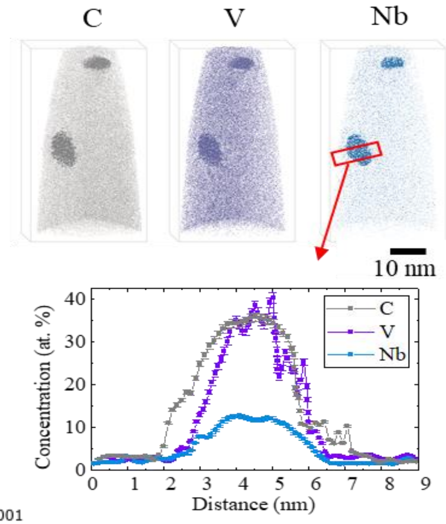
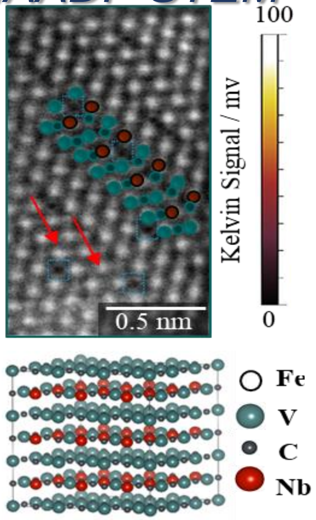
❶ Multiscale microstructural characterisations

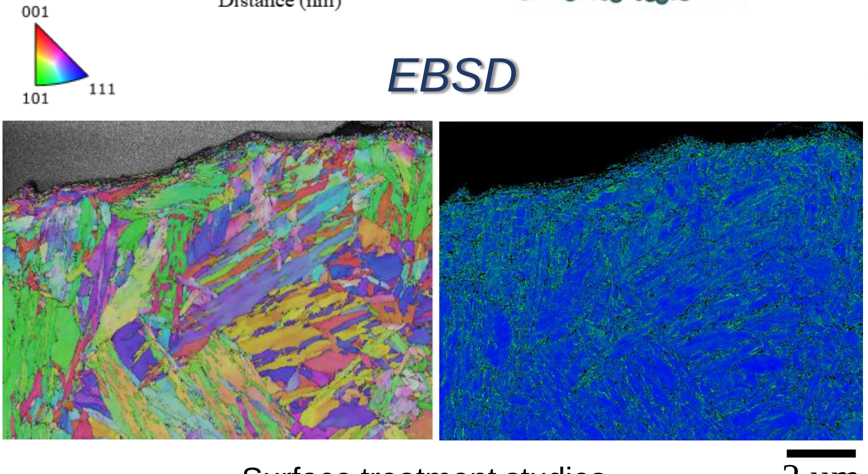
APT



HAADF-STEM

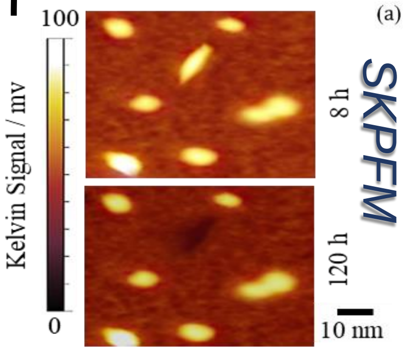


EBSD

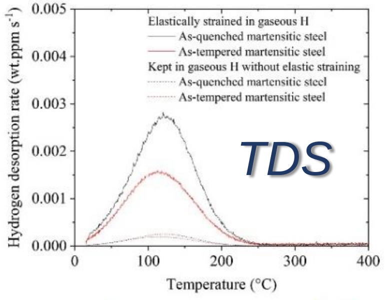


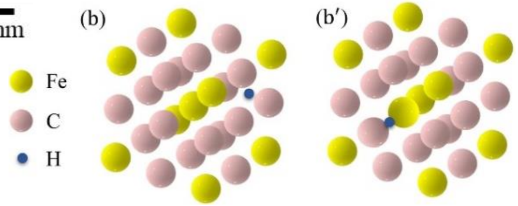
Surface treatment studies

❷ Multiscale hydrogen mapping & simulation (Gaseous and electrochemical hydrogen)

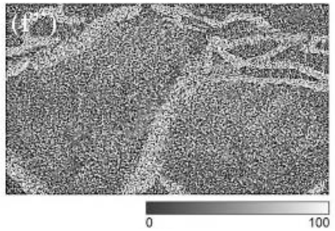


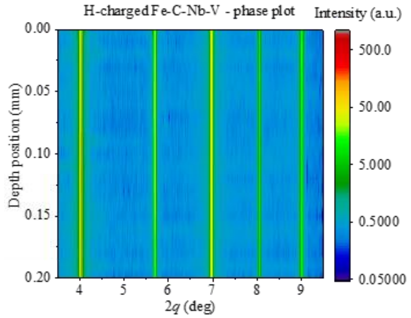
Irreversible H trapping by carbon vacancies accessed from broad face of precipitates

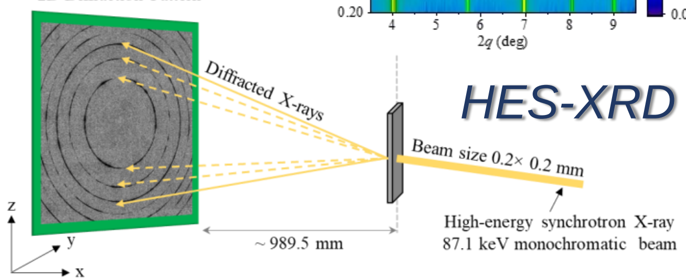




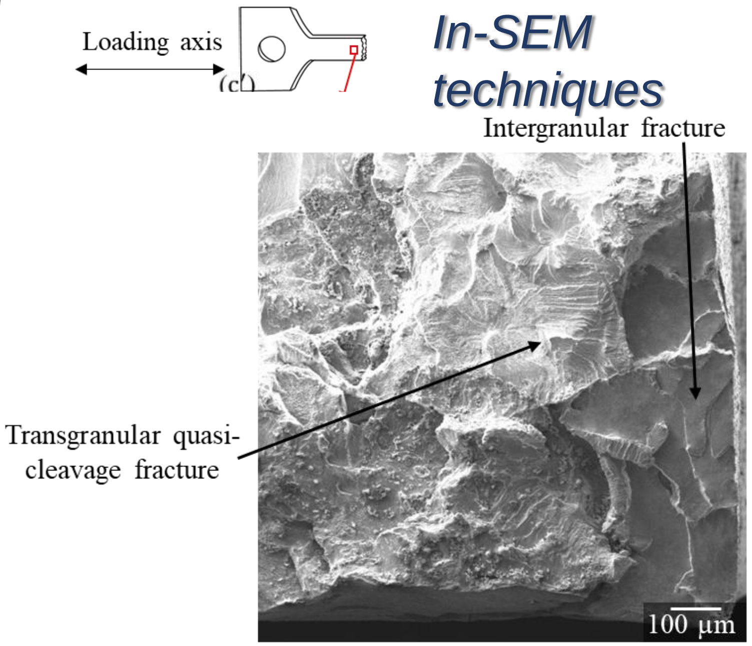
NanoSIMS



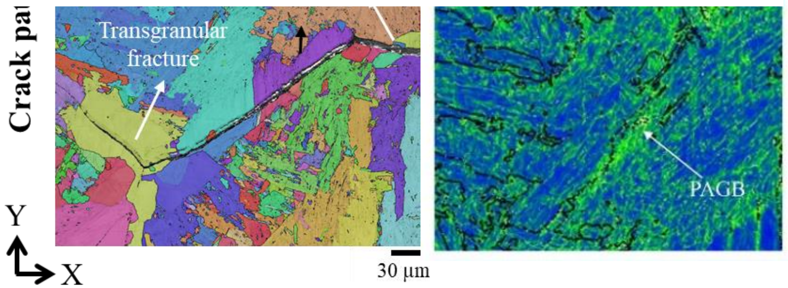




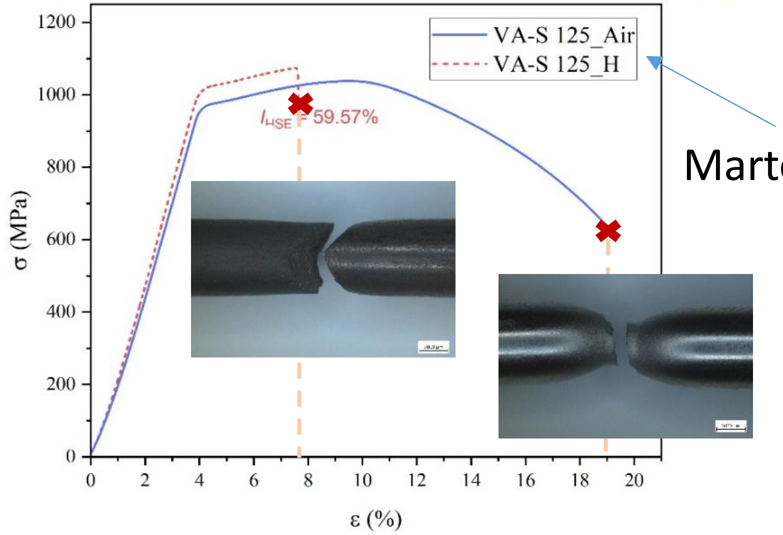
❸ H-assisted crack path and fracture studies



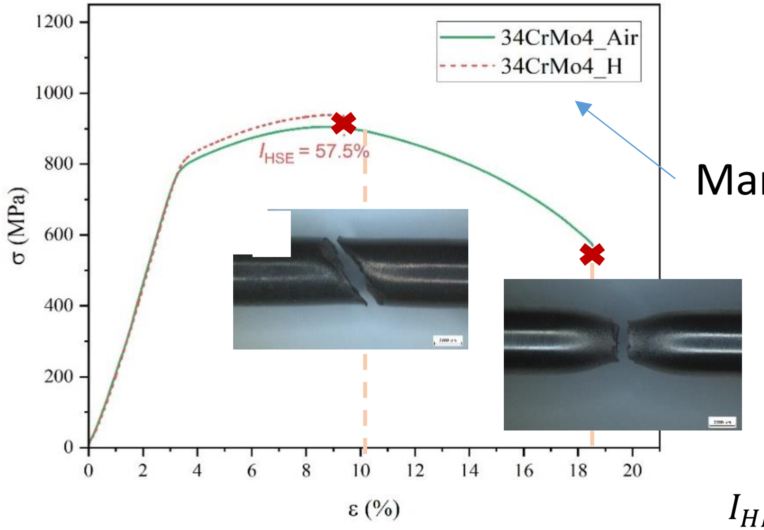
HEDE + HELP



Hydrogen embrittlement in steels



Martensitic steel

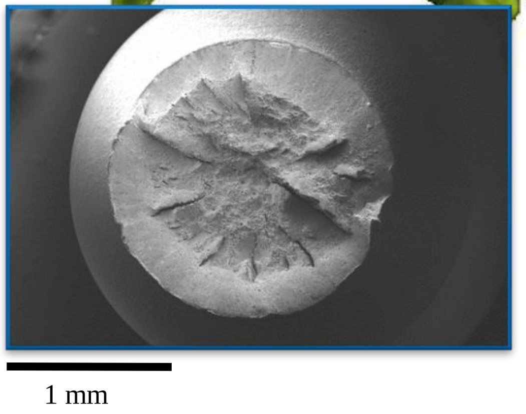


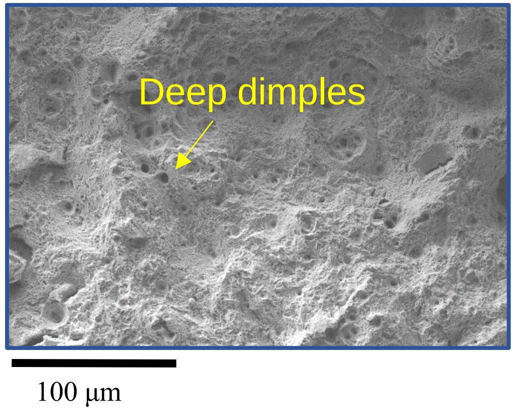
Martensitic steel

$$I_{HES} = \frac{\delta_{air} - \delta_H}{\delta_{air}}$$

Fracture surface

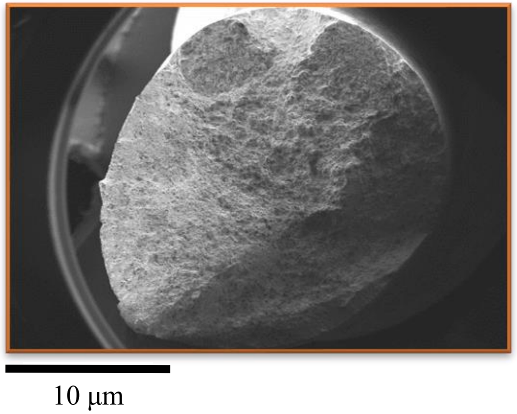
Air

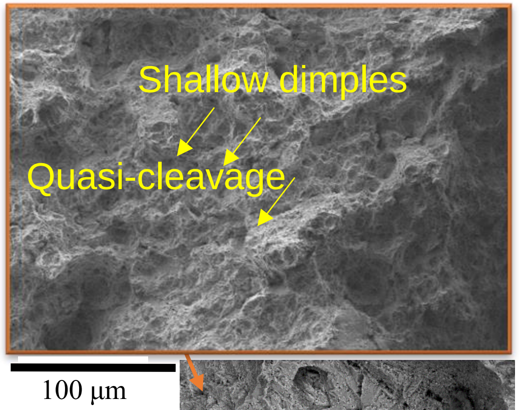


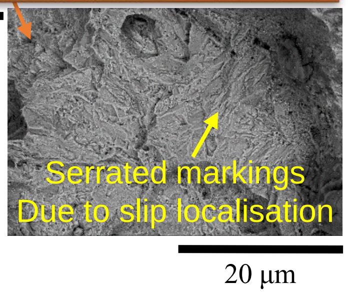


- Ductile fracture

H







- Brittle fracture

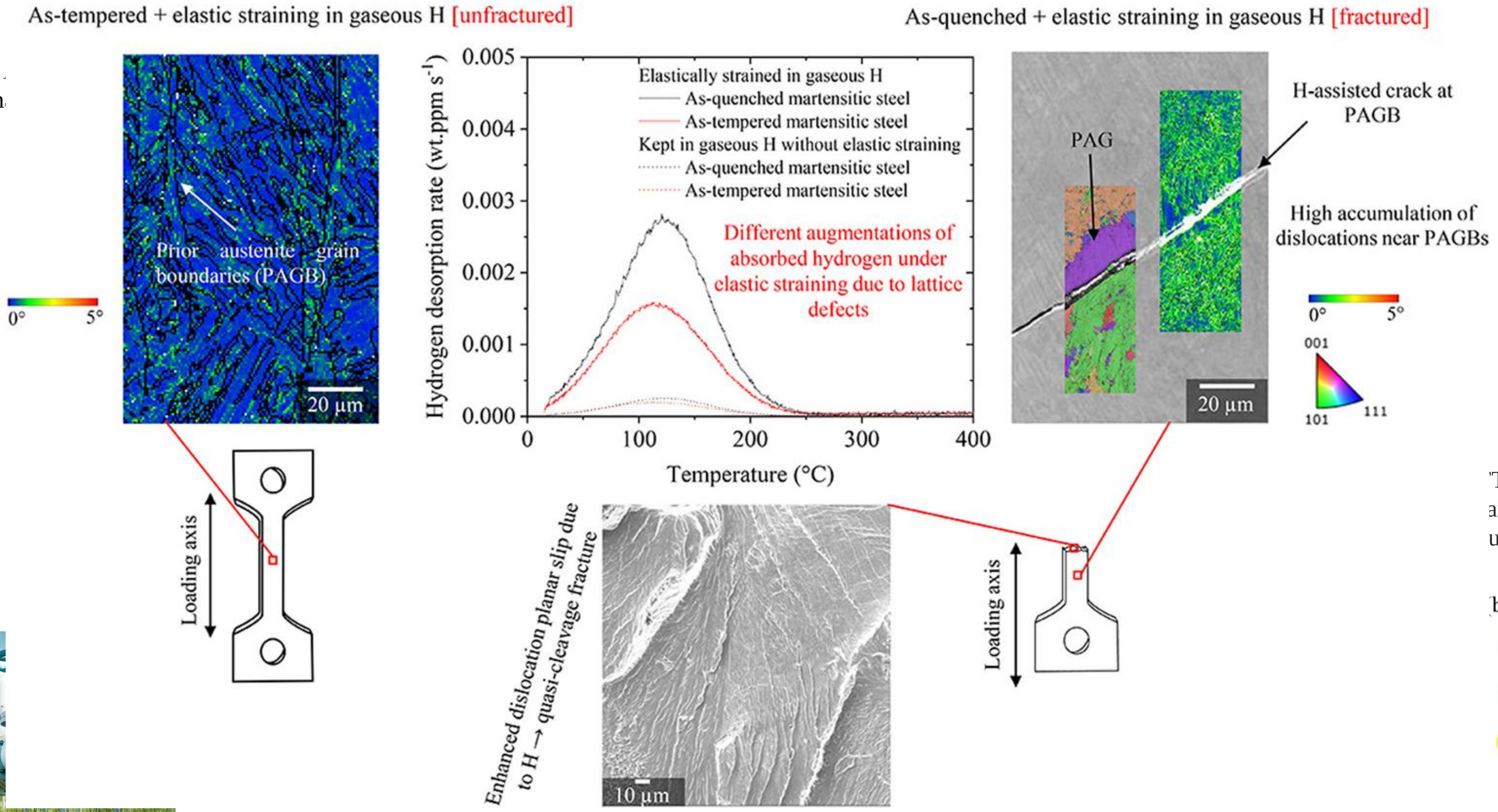
voestalpine ONE STEP AHEAD.

FFG Promoting Innovation.

M. Eskinja, G. Winter, J. Klarner, H. Schnideritsch, G. Mori, M. Moshtaghi, Procedia Structural Integrity, 2024.
M. Eskinja, G. Winter, J. Klarner, H. Schnideritsch, V. Razumovsky,M. Moshtaghi, G. Mori, Engineering Failure Analysis, 2024

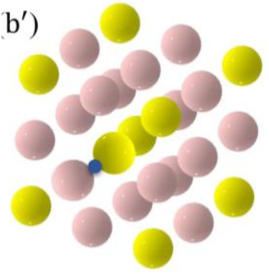
Martensitic steel design for steel pipelines in elastic loading regime in the high-pressure gaseous hydrogen condition

Strain
m.



T) results of the
and octahedral
ures.

b′)

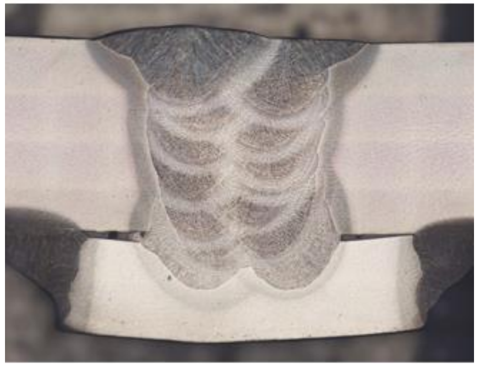


Masoud Moshtaghi’s Google Scholar: https://scholar.google.com/citations?user=UgjW2j8AAAAJ&hl=en

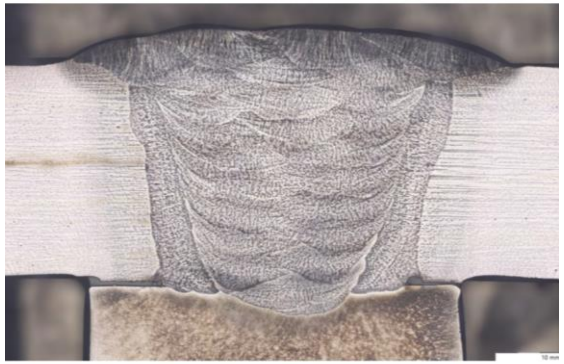
Weld joints (SAW, FCAW and SMAW) of pipelines: towards hydrogen-resistant steel pipelines

Residual stress/strain measurements

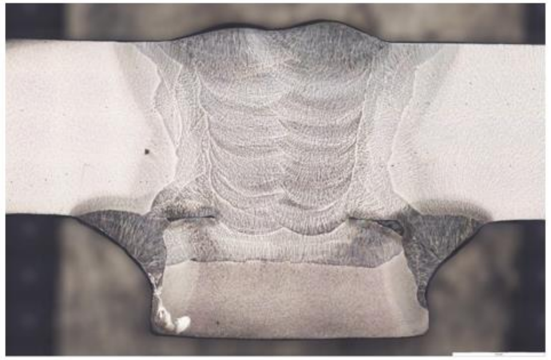
Submerged arc welding (SAW)



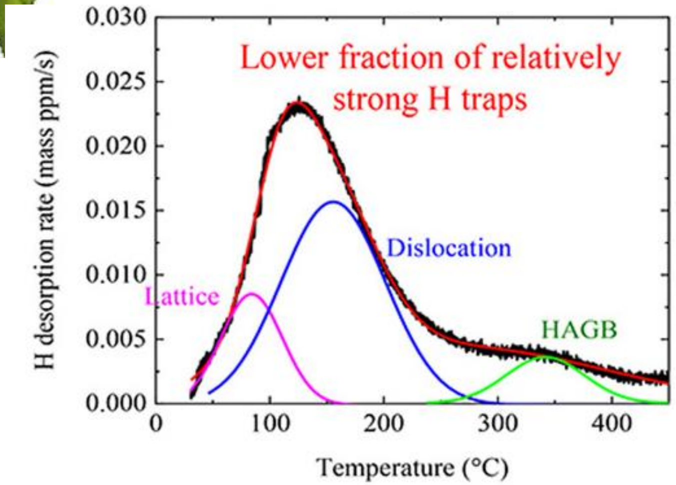
Flux-cored arc welding (FCAW)

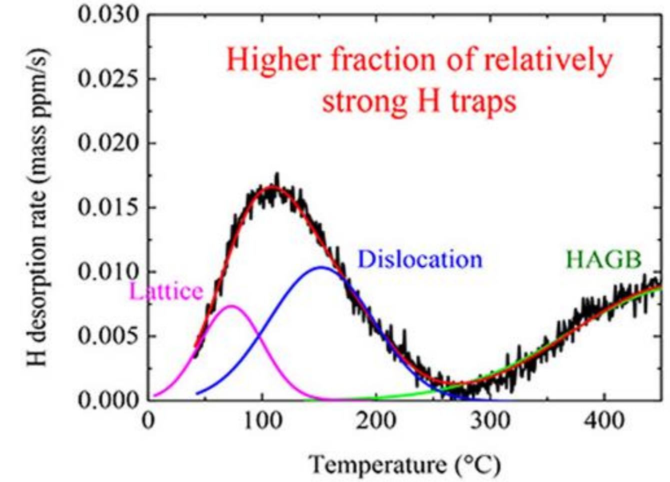


Shielded metal arc welding (SMAW)

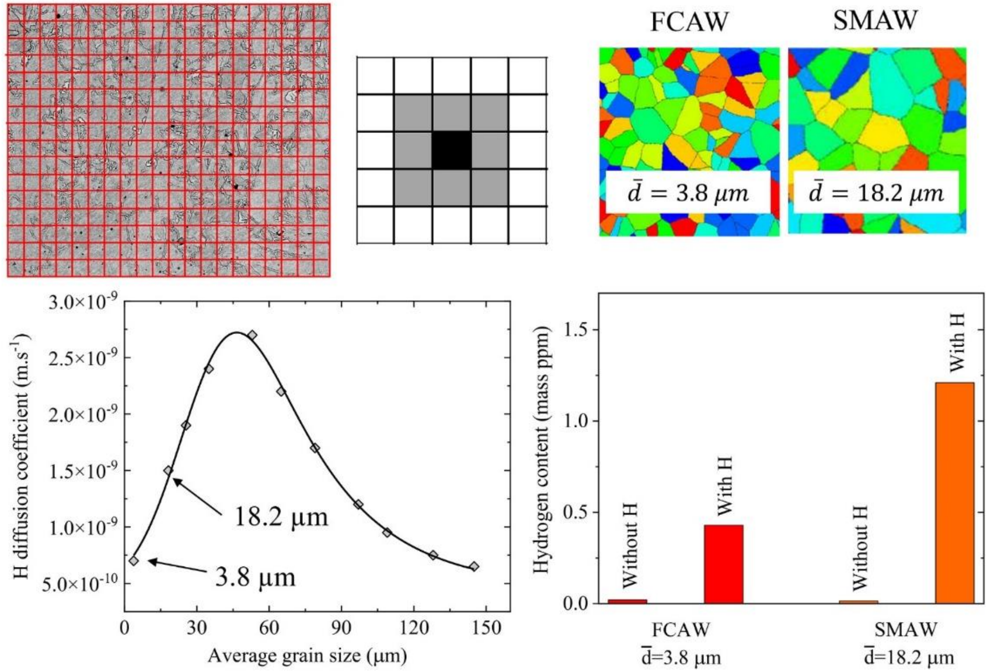


TDS

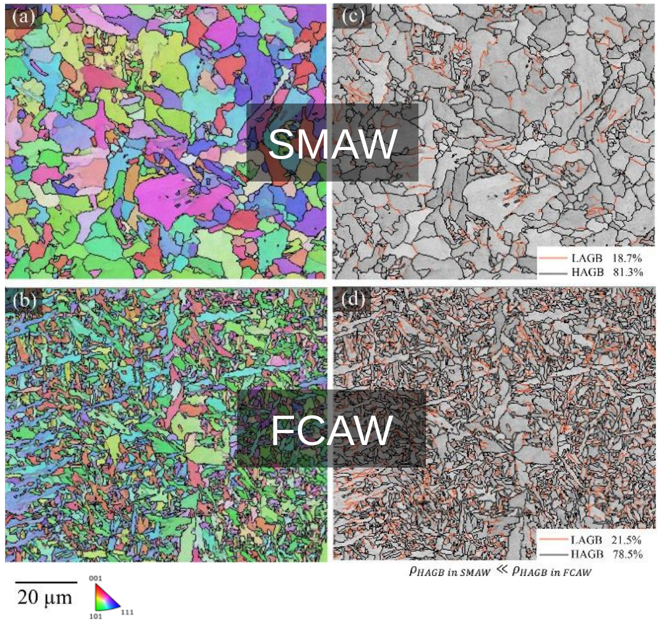




Numerical simulation results



Grain observations



* M. Moshtaghi*, B. Loder, M. Safyari, T. Willidal, T. Hojo, G. Mori, “Hydrogen trapping and desorption affected by ferrite grain boundary types in shielded metal and flux-cored arc weldments with Ni addition” International Journal of Hydrogen Energy, Vol. 47, 2022, 20676-20683.

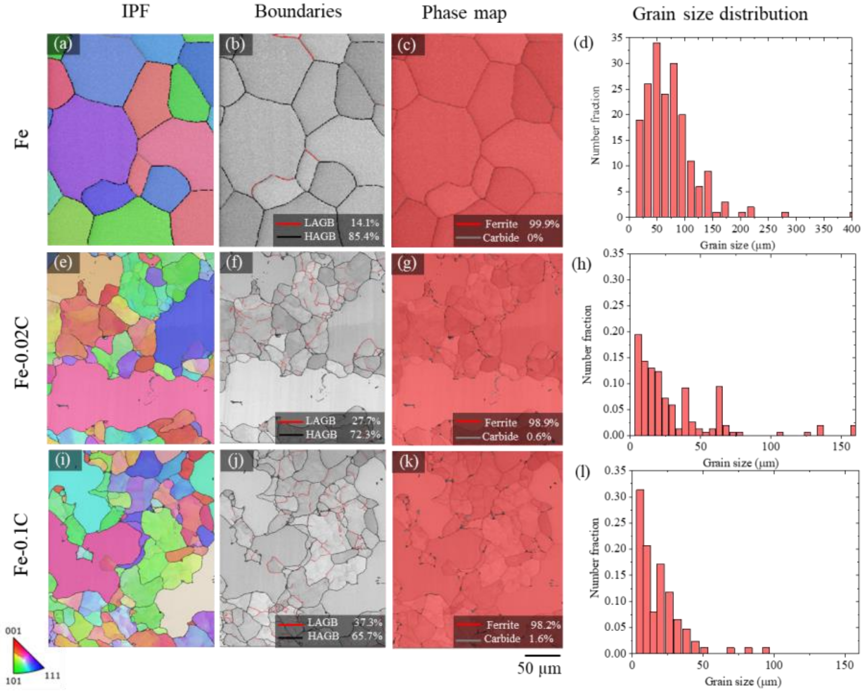
Hydrogen embrittlement in **ferritic and F/P steels**

❶ Multiscale microstructural characterisations

❷ Multiscale hydrogen mapping & simulation

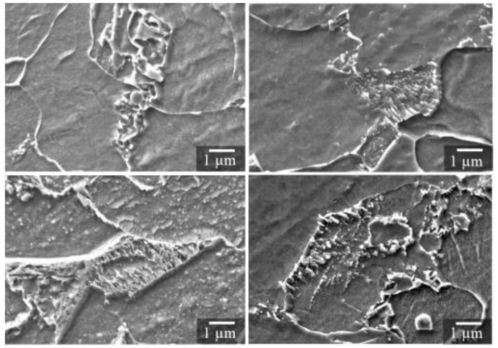
❸ H-assisted crack path and fracture studies

EBSD



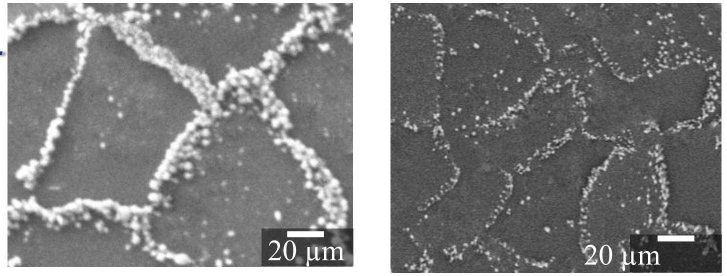
Fe-0.02C

Fe-0.1C

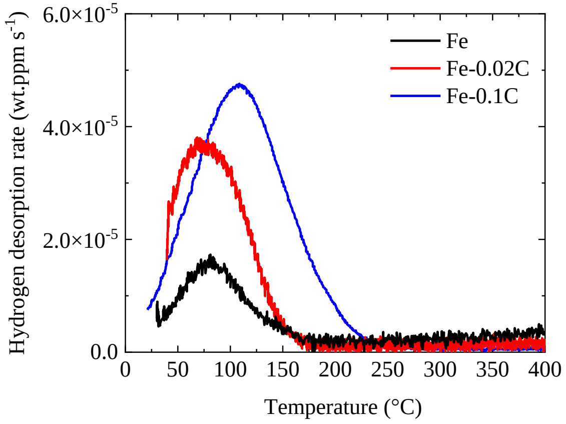


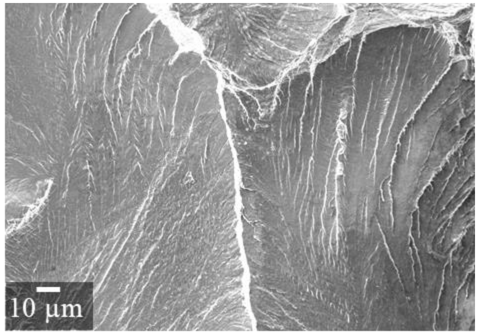
Fe-0.02C Fe-0.1C

HMPT



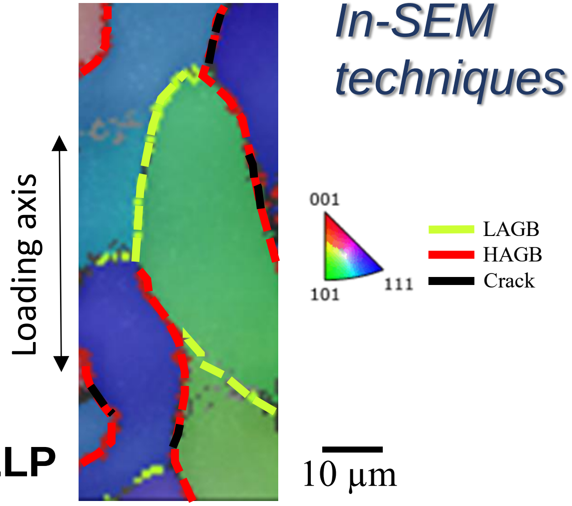
TDS



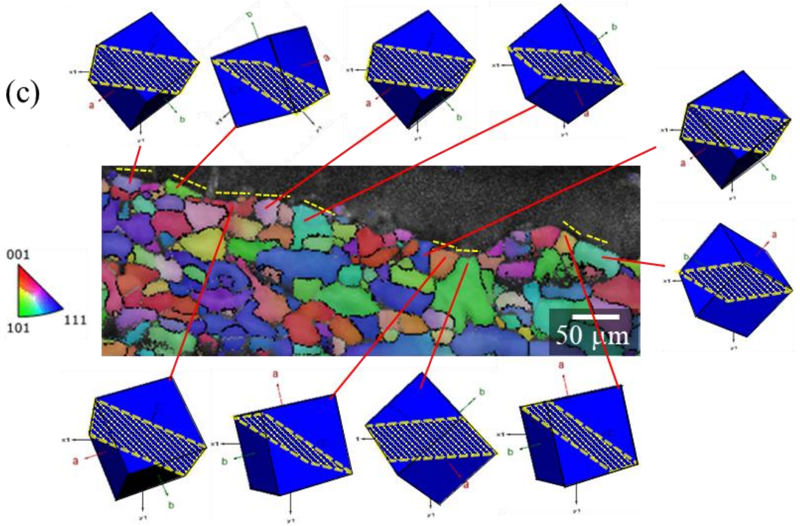


Fe-0.02C

In-SEM techniques



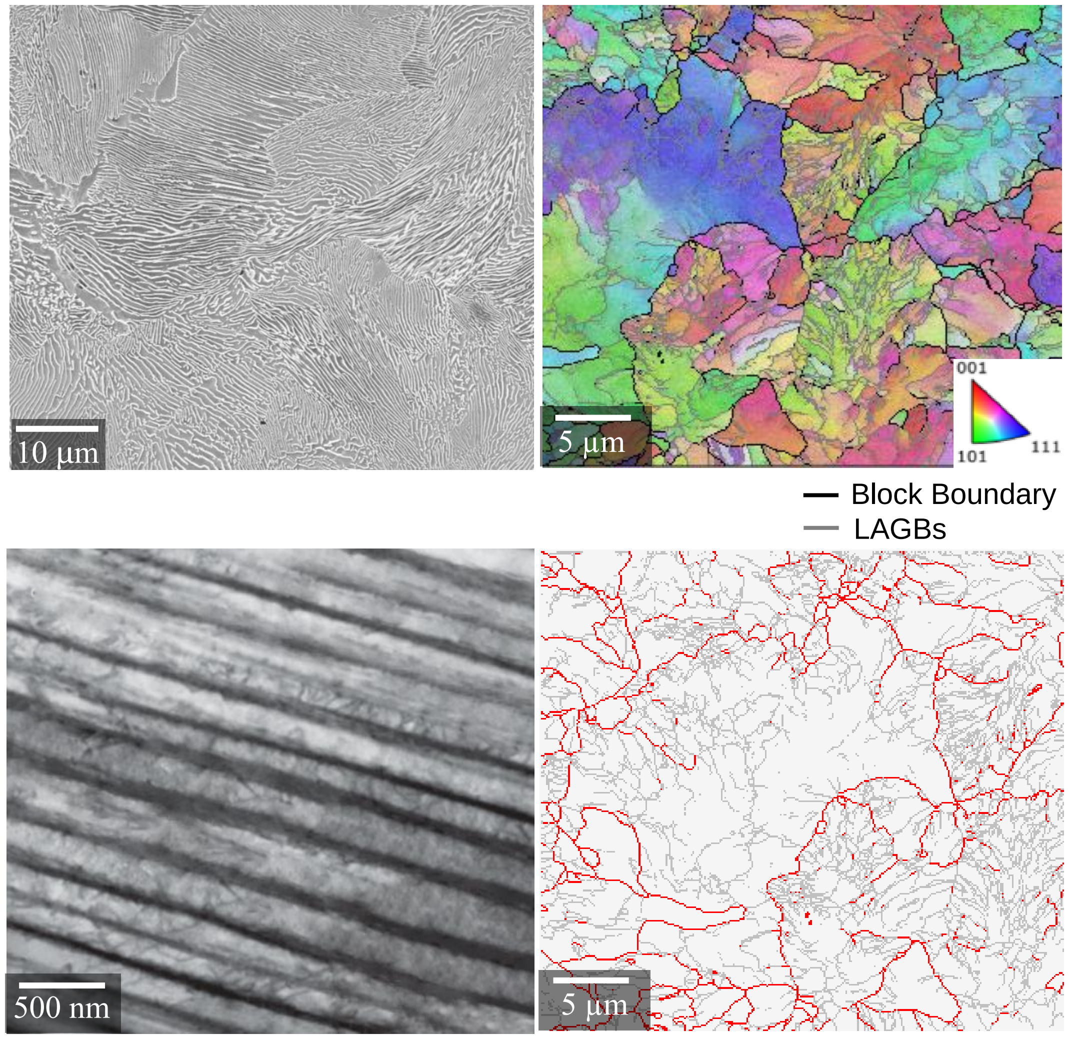
HEDE + HELP



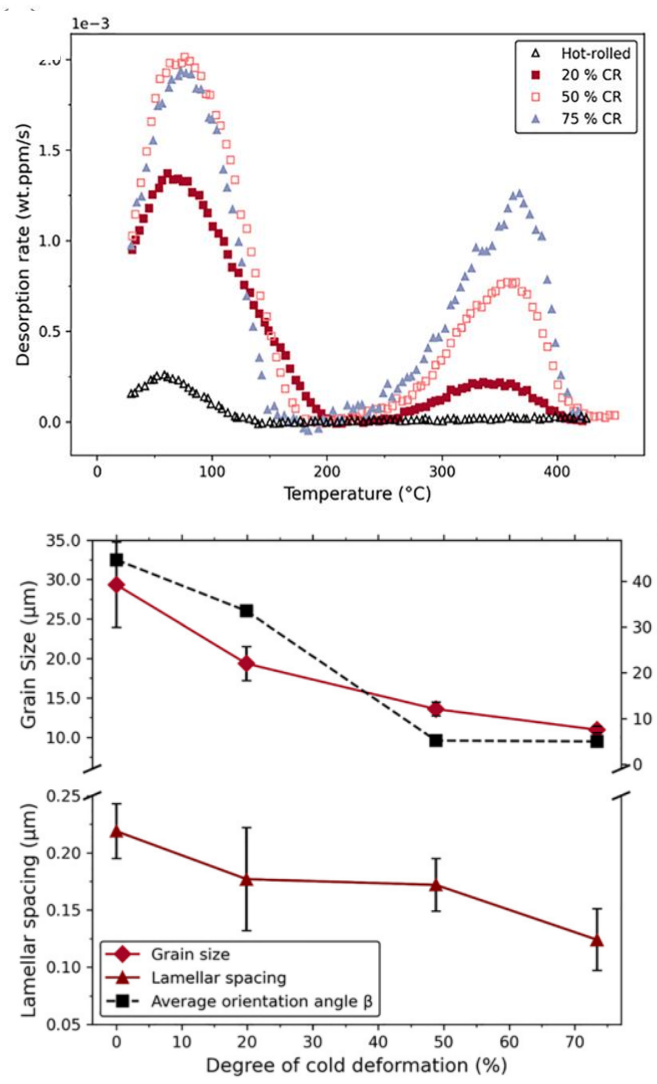
Masoud Moshtaghi's Google Scholar: https://scholar.google.com/citations?user=UgjW2j8AAAAJ&hl=en

Activities and current projects: Hydrogen embrittlement in **pearlitic steels**

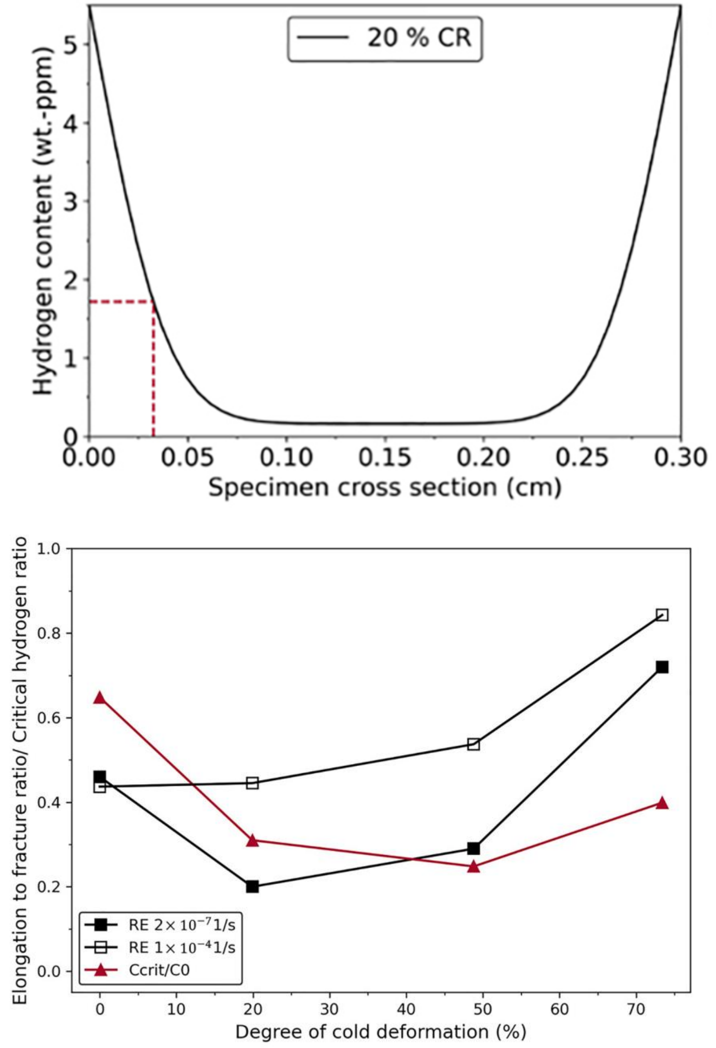
❶ Multiscale microstructural characterisations



❷ Multiscale hydrogen mapping & simulation



❸ H-assisted fracture evaluation



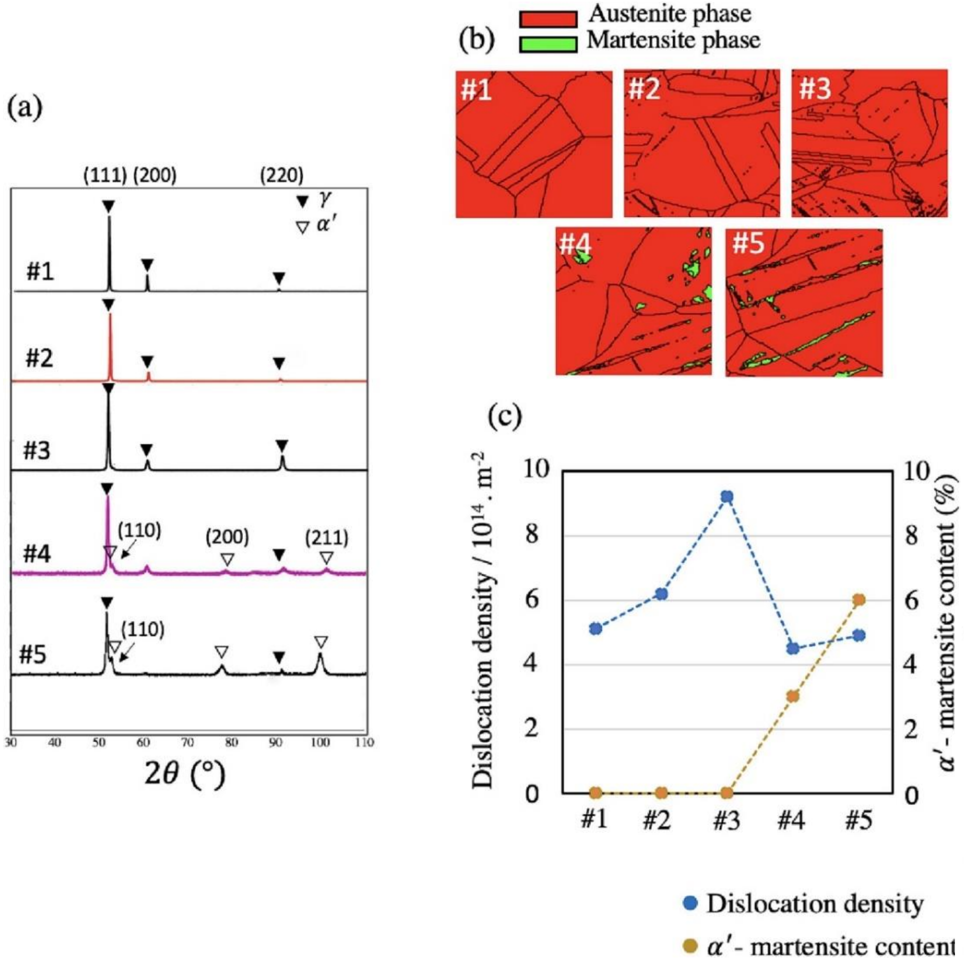
Masoud Moshtaghi's Google Scholar: https://scholar.google.com/citations?user=UgjW2j8AAAAJ&hl=en

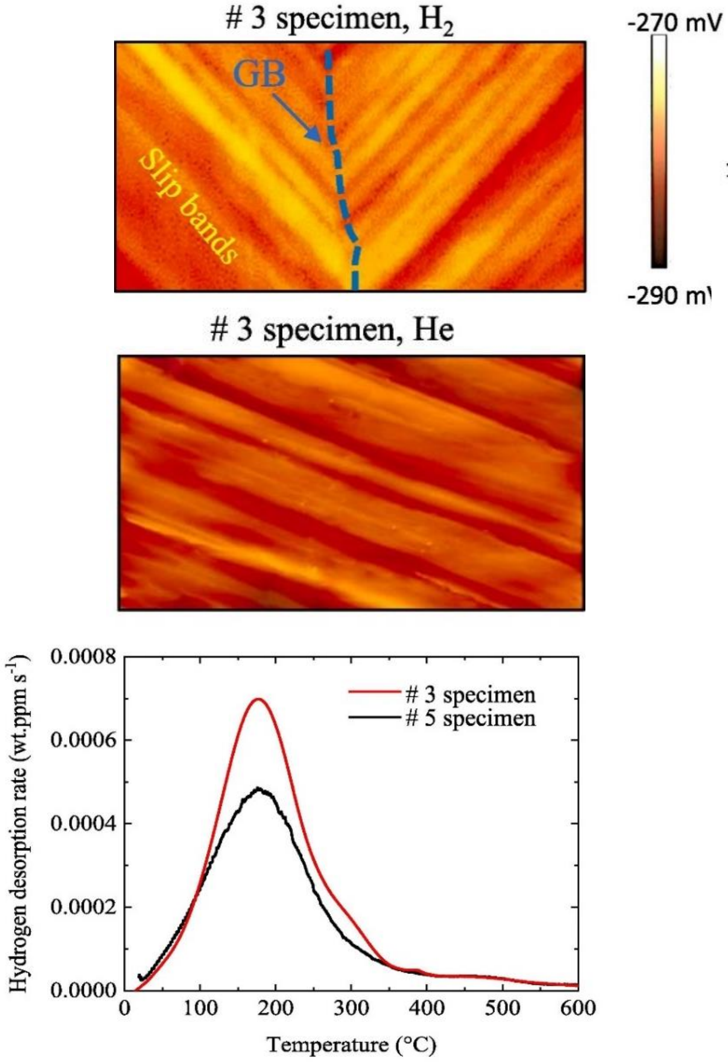
Activities and current projects: Hydrogen embrittlement in **austenitic steels**

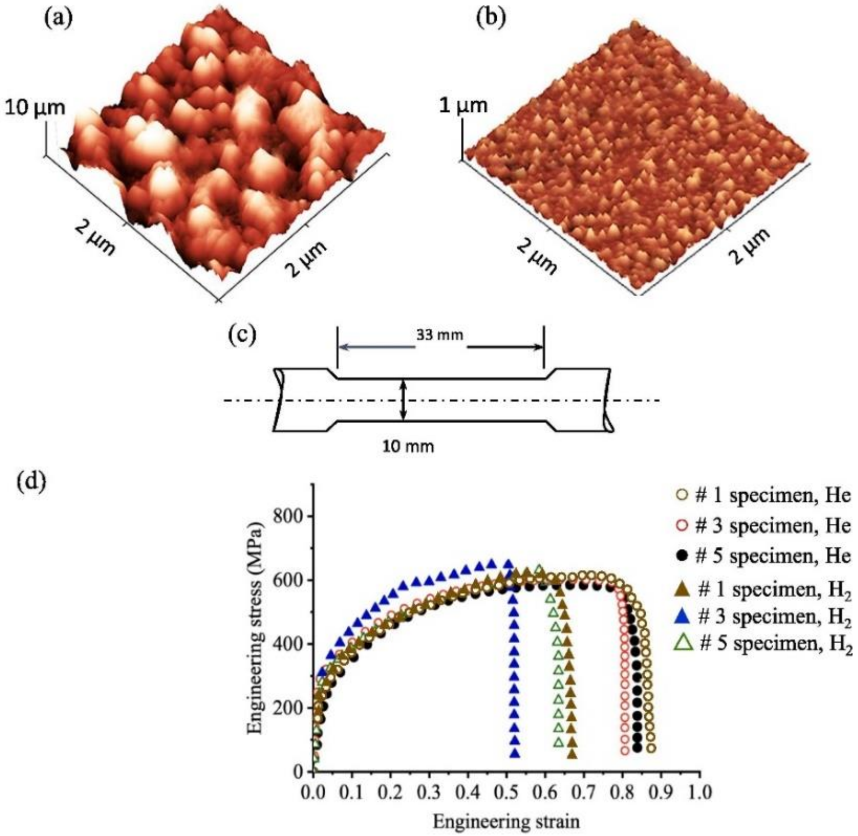
❶ Multiscale microstructural characterisations

❷ Multiscale hydrogen mapping & simulation

❸ H-assisted fracture studies







Masoud Moshtaghi's Google Scholar: https://scholar.google.com/citations?user=UgjW2j8AAAAJ&hl=en

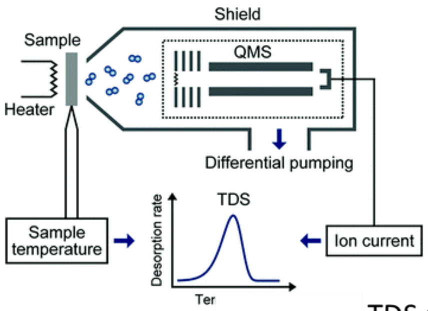
Design and testing hydrogen pipelines with SSAB Tubulars

Fossil Free Steel Application (FOSSA) – Hydrogen-assisted fatigue in pipelines

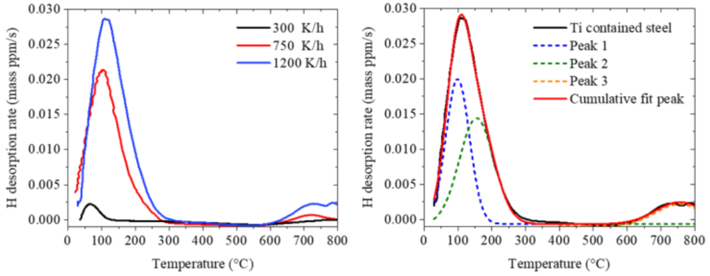
Goal: Consideration of the effect of hydrogen exposure on fatigue design of Finnish pipelines
Fatigue of a weld joint / welded component
Construction of a hydrogen exposure test device as part of the loading rig
Testing the steels and welded steels under the fatigue conditions in the presence of hydrogen.
Analytical approach to the performance of the steels in fatigue conditions
Ranking the materials based on their applicability in hydrogen-assisted fatigue applications.
Studying the root cause failure of the specimens in the hydrogen-assisted fatigue condition.

$$a_{\mathrm{f}} < a_{\mathrm{cr}} = \frac{K_{\mathrm{IC}}^{2}}{\pi\left(\sigma_{\max} Y(a)\right)}$$

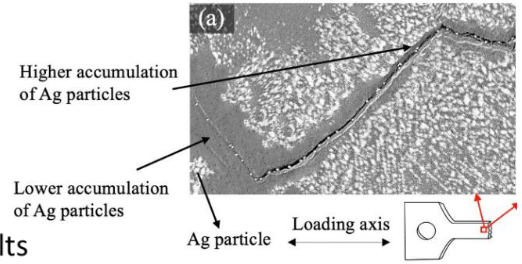
$$N_{\mathrm{f}} = N_{\mathrm{i}} + N_{\mathrm{cp}} = N_{\mathrm{i}} \int_{a_{\mathrm{i}}}^{a_{\mathrm{f}}} \frac{da}{C \Delta K(a)^{m}}$$

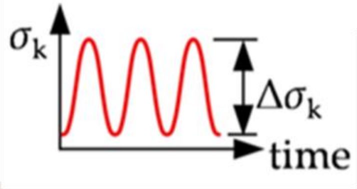


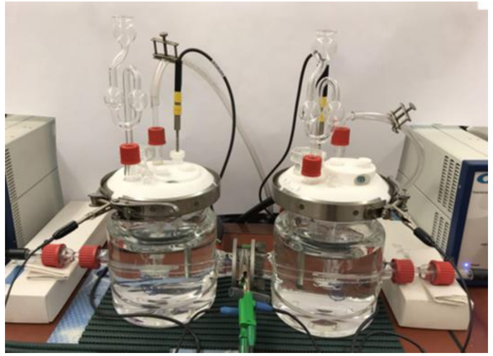
TDS results



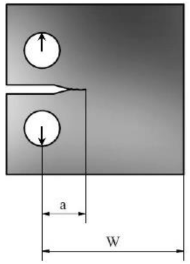
Hydrogen Microprint Technique



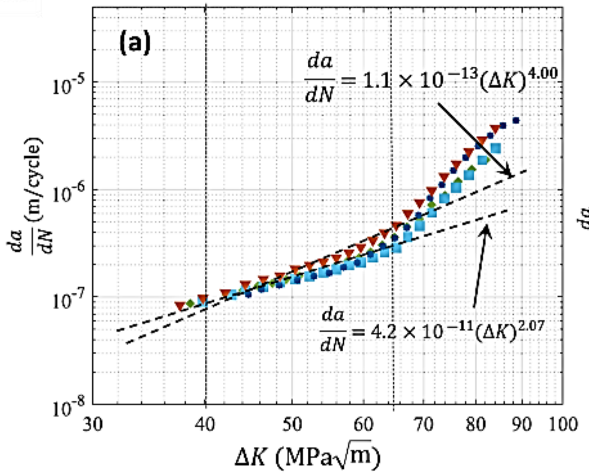




Hydrogen Permeation Tests

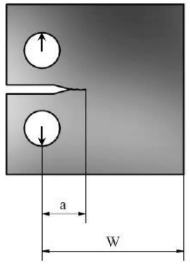


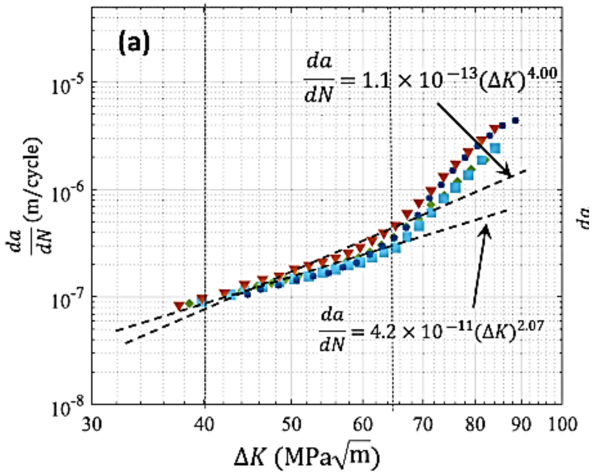
Fatigue crack growth behaviour by linear elastic fracture mechanics (LEFM)

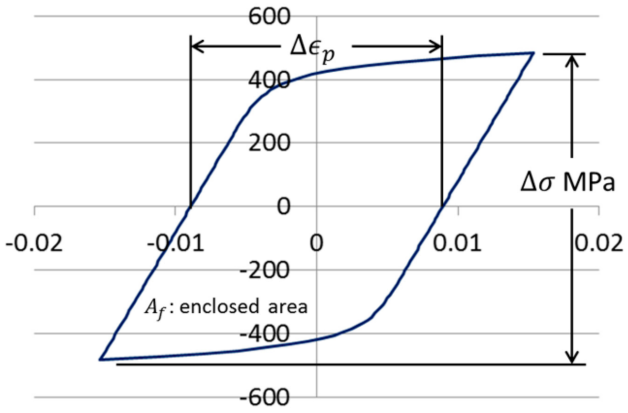


Hydrogen-enhanced entropy (HEENT): a newly proposed mechanism for hydrogen embrittlement

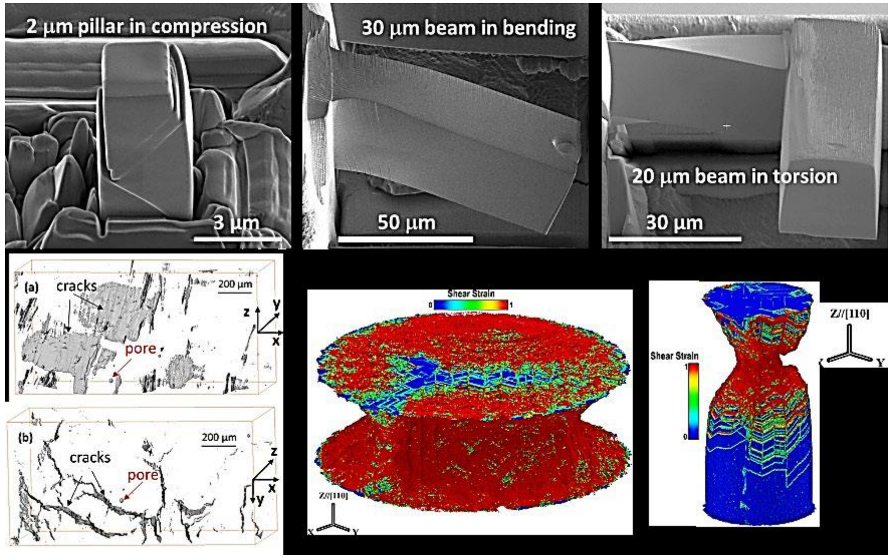
Fatigue crack growth behaviour by linear elastic fracture mechanics (LEFM)





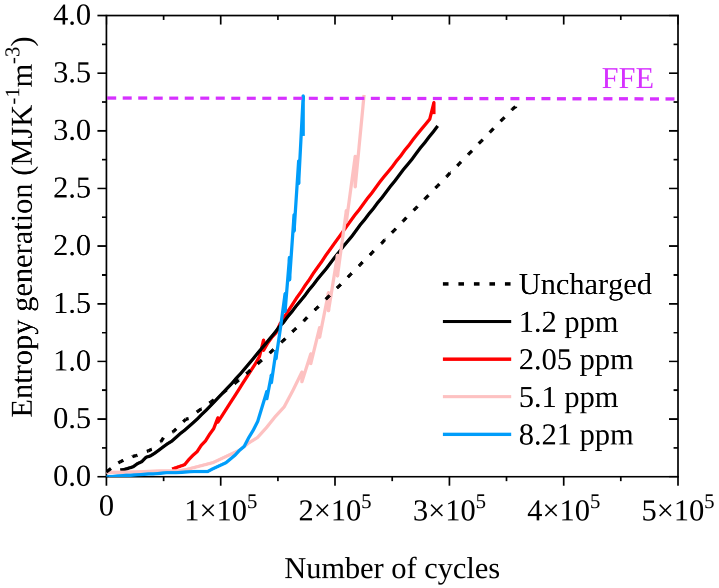


Synchrotron computed tomography and micromechanical tests at LSU, USA



$$\eta = \int_0^{t_f} \frac{W_p}{T} dt$$

Total entropy calculation
via **inelastic dissipation** (W_p)

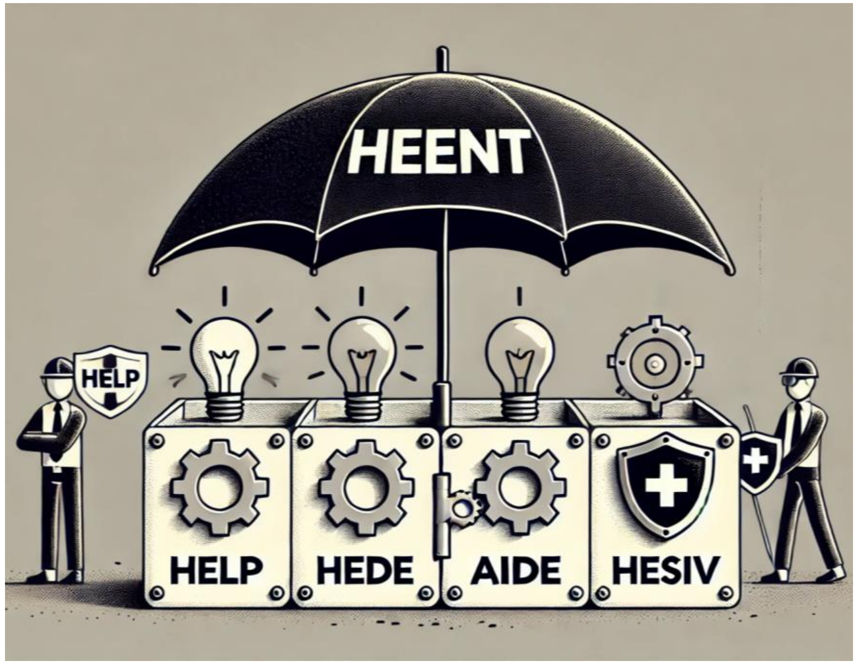


Hydrogen-enhanced entropy (HEENT): A concept for hydrogen embrittlement prediction, International Journal of Hydrogen Energy, Volume 53, 2024, Pages 434-440.

HEENT mechanism: Makes the mechanism-based HE-resistance alloy design and monitoring possible.

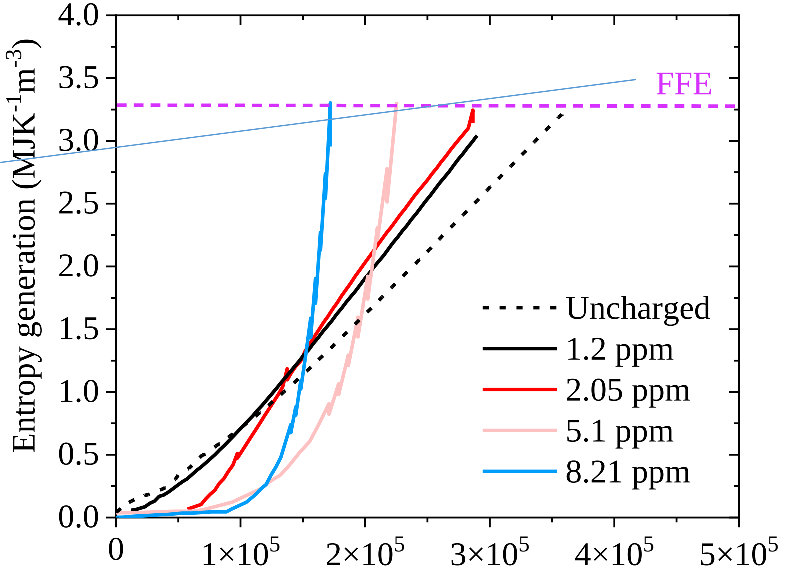
LUT University

- The concept of hydrogen-enhanced entropy (HEENT) for hydrogen embrittlement prediction was introduced and discussed. The contribution of the different mechanisms to the total entropy, i.e. HEENT effect compensates for the total entropy reduction generated due to reduced fatigue life. This is applicable to the other types of hydrogen-assisted fracture, based on HEDE, and HESIV, HELP, HELP+HEDE, etc.



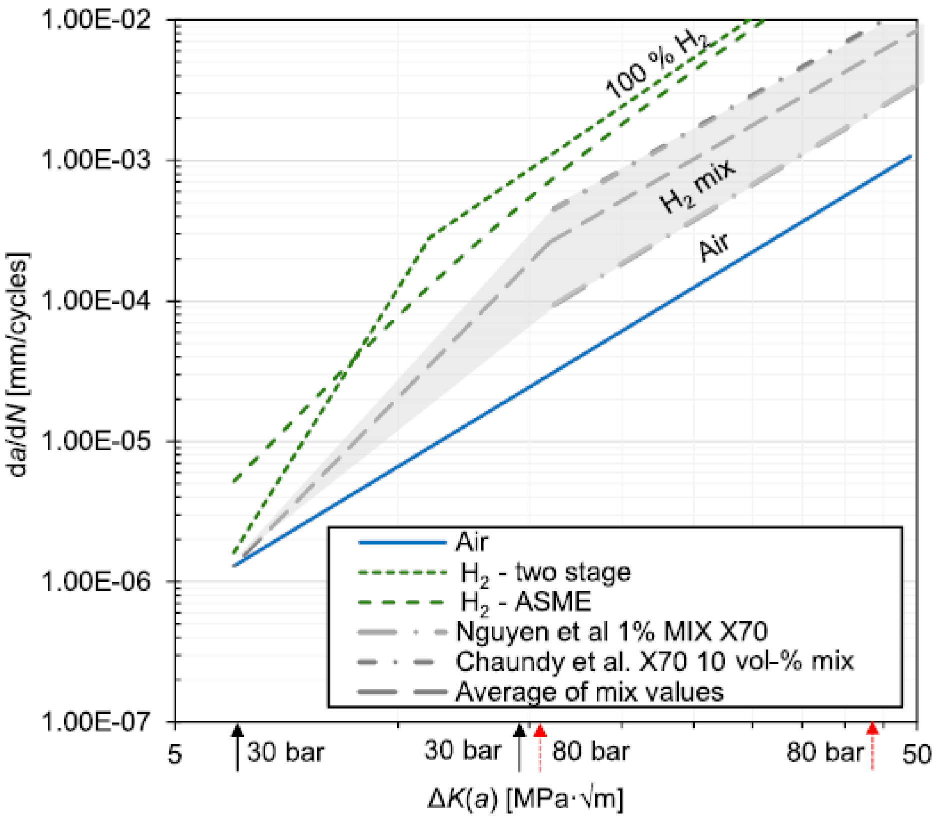
- This makes feasible the mechanism-based design of HE resistant alloys and structures.
- With the monitoring the evolution of entropy and estimation of the generated entropy, one can reach to viable approach to estimate the efficiency of the different preventive actions for mitigating HE and also, indexing them.

A value that is the property of the material irrespective of the hydrogen amount. This makes the prediction of the failure possible.



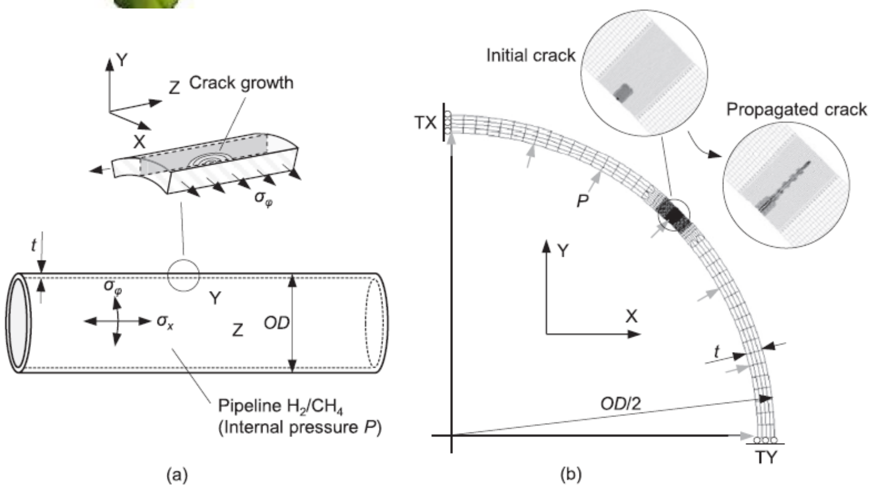
Hydrogen-enhanced entropy (HEENT): A concept for hydrogen embrittlement prediction, International Journal of Hydrogen Energy, Volume 53, 2024, Pages 434-440.

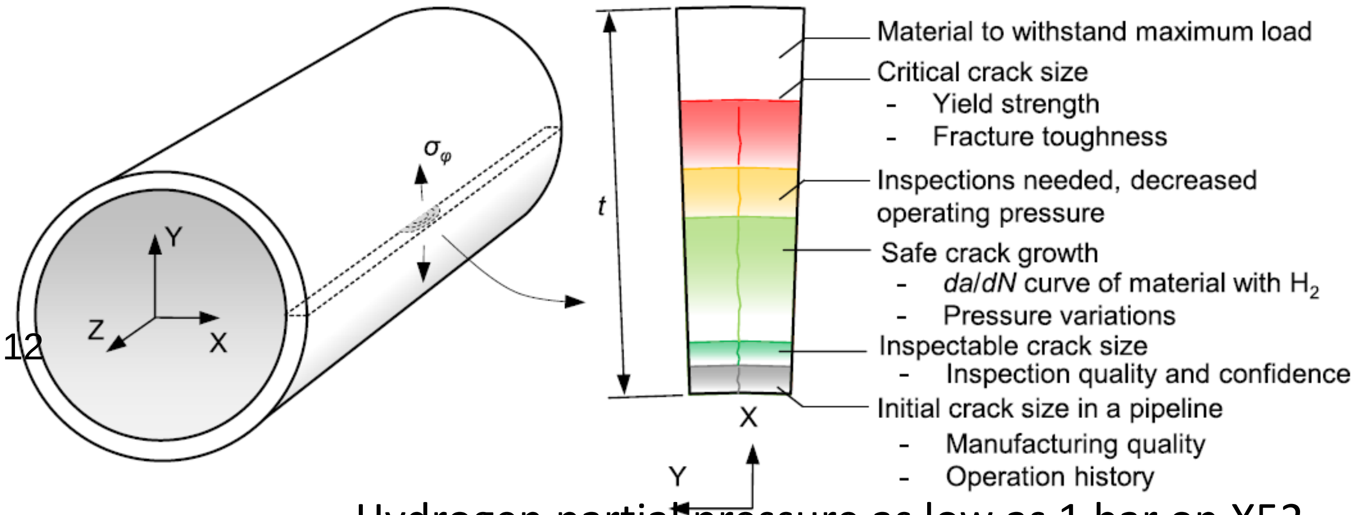
Hydrogen pipeline fatigue testing and analysis HyGCEL project



ASME B31.12 features a nonlinear correlation (in log-scale) between crack growth rate and SIF range. ASME B31.12 suggests a characteristic design da/dN curve for hydrogen pressure under 20 MPa (200 bar).

$$\frac{da}{dN} = a1\Delta K^{b1} + \left[\left(a2\Delta K^{b2} \right)^{-1} + \left(a3\Delta K^{b3} \right)^{-1} \right]^{-1}$$

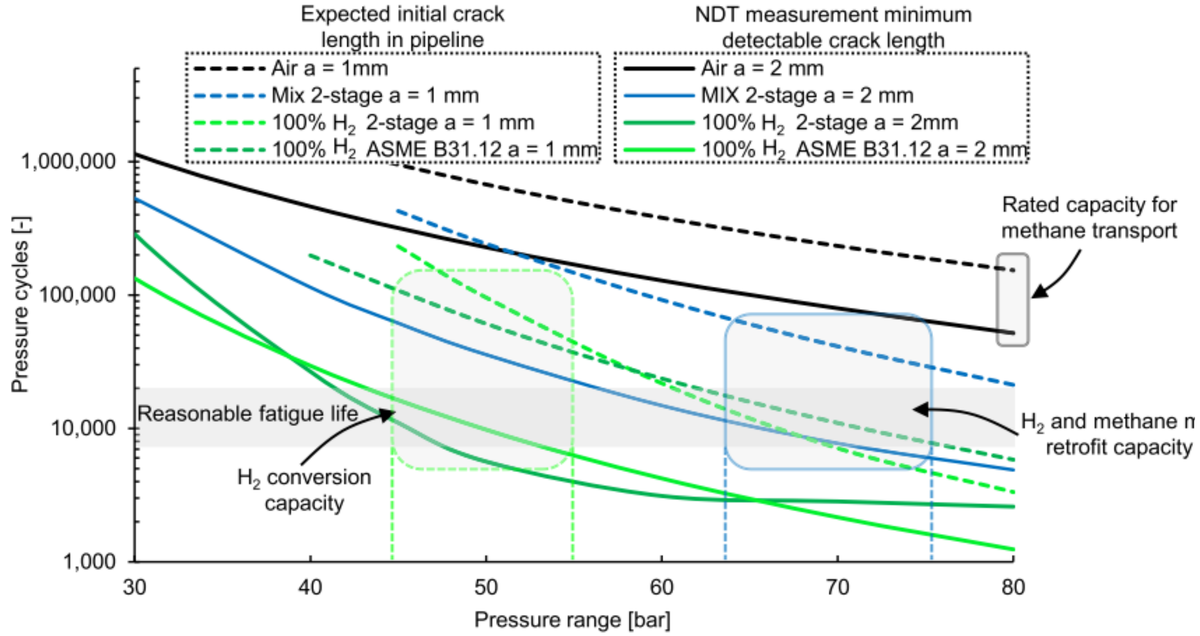


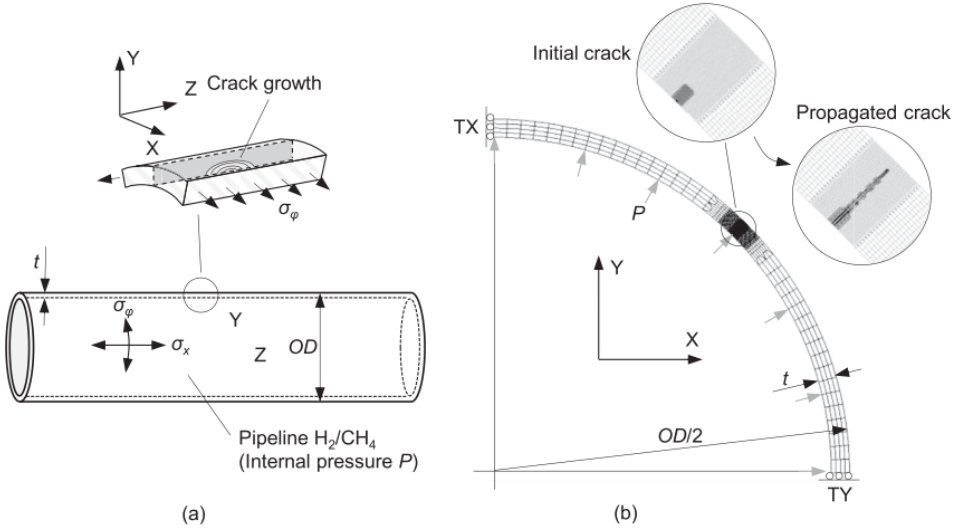


Hydrogen partial pressure as low as 1 bar on X52 will degrade the material.

Design and testing hydrogen pipelines in Finland

Fatigue life as a function of pressure range for DN500 t ¼12.7 mm pipeline



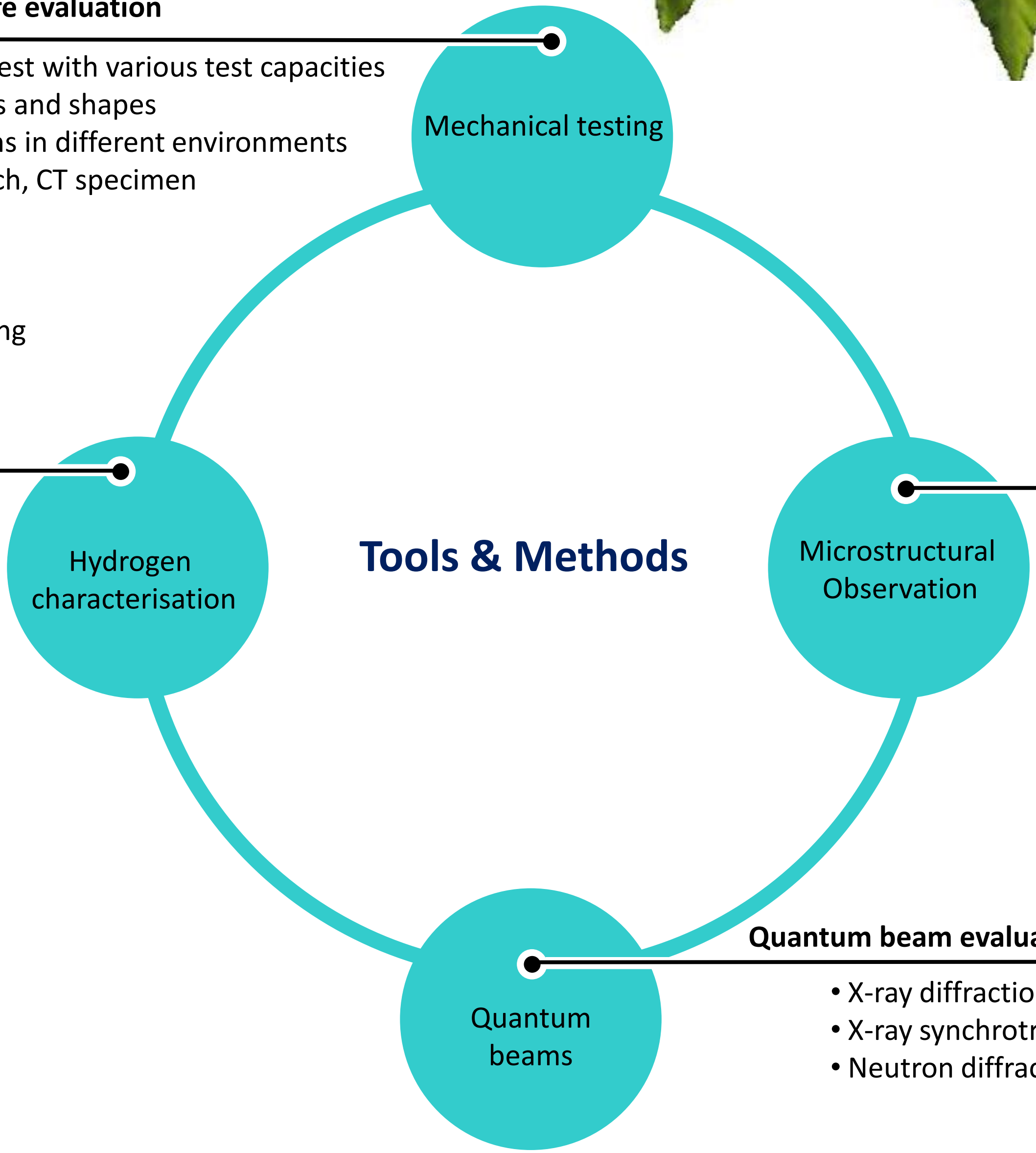


Facilities developed so far in LUT

LUT University

Mechanical Testing and Fatigue Life evaluation

- High Cycle and Low Cyclic Fatigue Test with various test capacities
- Mechanical testing in different sizes and shapes
- Mechanical testing of the specimens in different environments
- Fracture mechanics testing approach, CT specimen
- High Cycle and Low Cyclic Testing
- Micro-Hardness Testing
- Slow Strain Rate Testing
- Finite Element and Machine Learning



Analytical Hydrogen Characterisation

- Hydrogen Mapping by Hydrogen Microprint Technique/ Silver Decoration
- Thermal Desorption Spectroscopy (TDS)
- Hydrogen Hot/Melt Extraction
- Hydrogen Electrochemical Permeation Tests
- Hydrogen Diffusion & Profile in Metals by finite element analysis
- Hydrogen Mapping by SKPFM
- Hydrogen Mapping by LIBS
- Hydrogen Mapping by NanoSIMS

Microstructural Observation

- SEM/EDS
- Optical Microscopy
- 3D Surface Measurement Device
- SEM/EBSD/FIB
- TEM
- HRTEM
- Atom Probe Tomography

Quantum beam evaluation of the stressed specimen

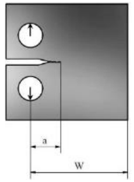
- X-ray diffraction
- X-ray synchrotron diffraction
- Neutron diffraction

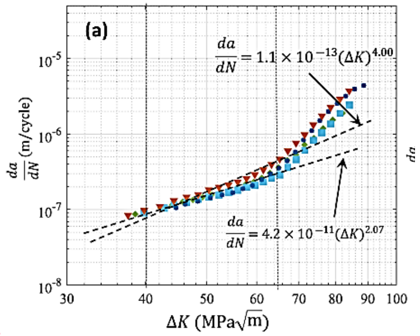
Facilities

Mechanical Testing and Fatigue Life evaluation

Mechanical testing

- High Cycle and Low Cyclic Fatigue Test with various test capacities
- Mechanical testing in different sizes and shapes
- Mechanical testing of the specimens in different environments
- Fracture mechanics testing approach, CT specimen
- High Cycle and Low Cyclic Testing
- Micro-Hardness Testing
- Slow Strain Rate Testing
- Fatigue testing in cryogenic condition
- Finite Element and Machine Learning

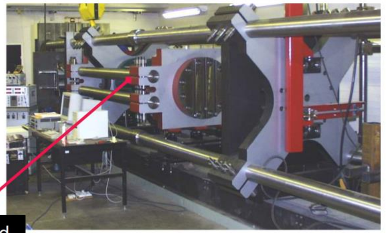




Fatigue crack growth behaviour by linear elastic fracture mechanics (LEFM)

MATERIAL TESTING MACHINES (LOAD FRAMES)

- Laboratory have seven (7) servo hydraulic load frames for dynamic and static loading test set-ups.
- Biggest test rig in Finland for dynamic testing up to 5 MN compression and tension loading.
  - Equipped with movable environment chamber down to -60°C to determinate material and connections behaviour at sub zero temperatures.
  - Full-scale tests of components made of high- and ultra-high-strength steels (S700-S1100).

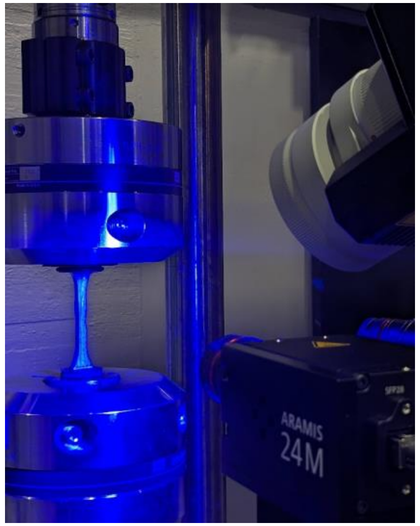


5MN load frame

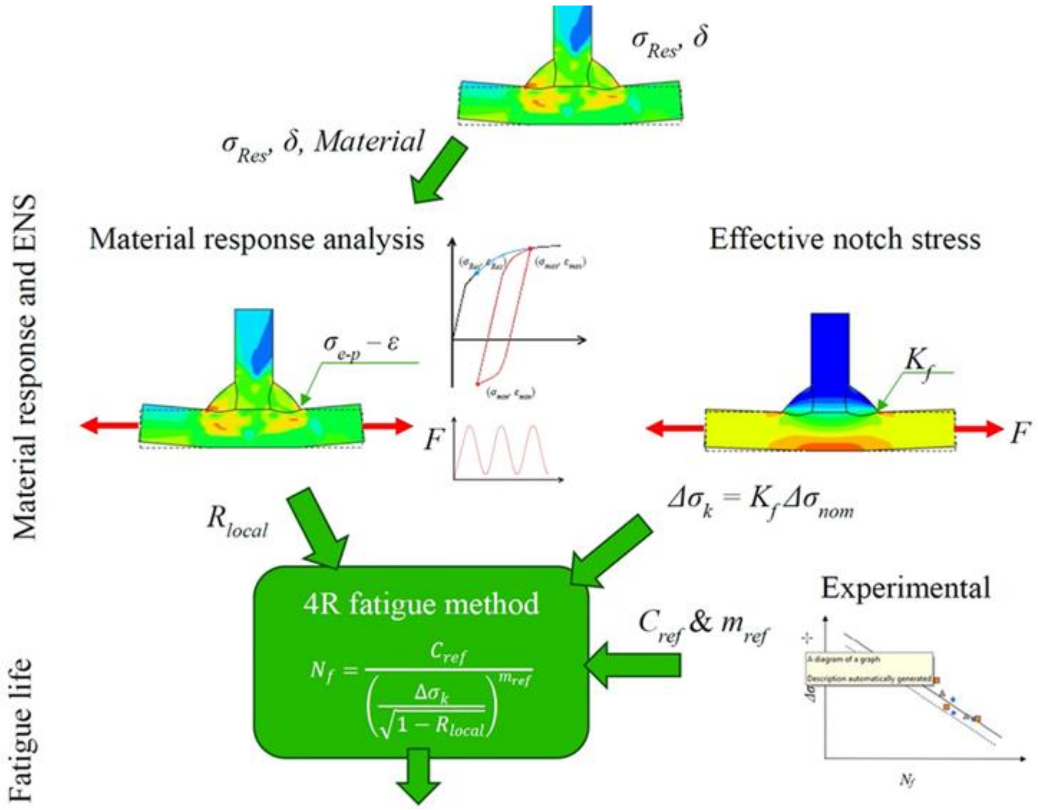
Environment chamber + Cooling unit

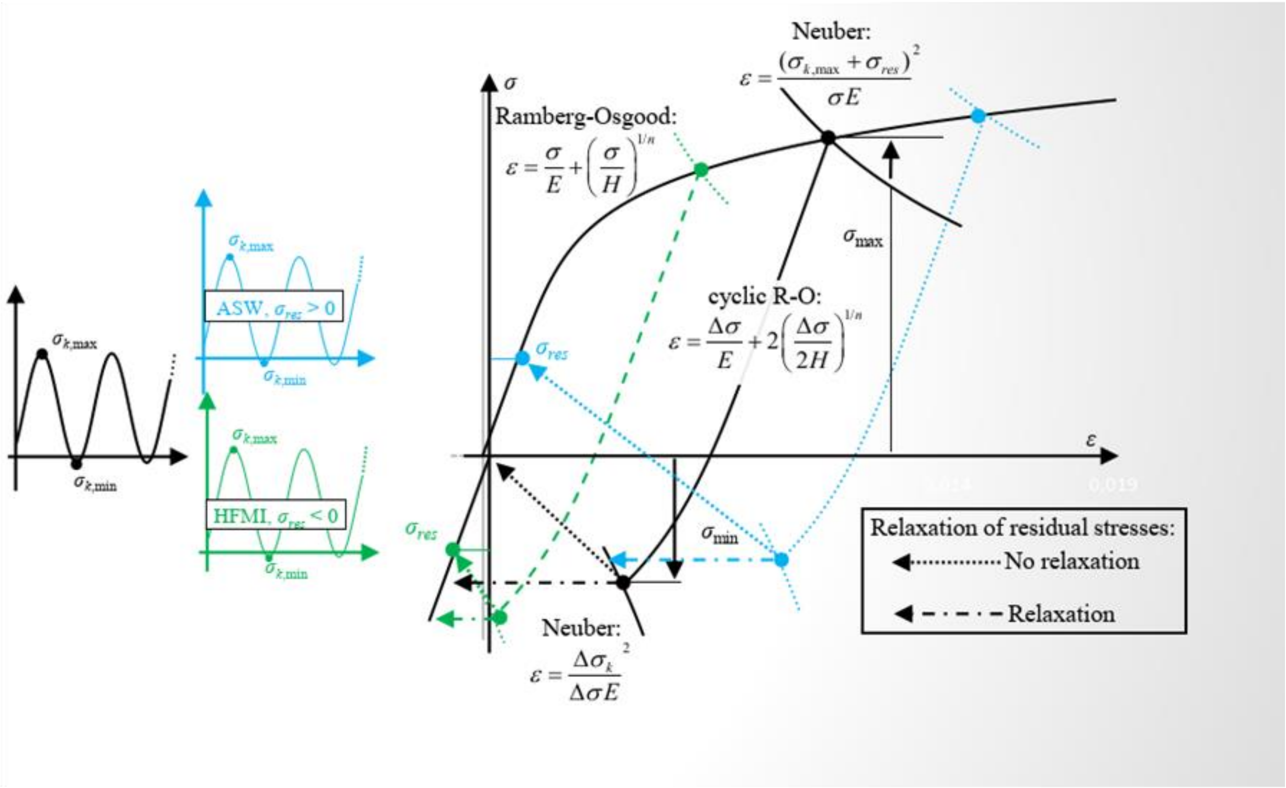
MATERIAL TESTING MACHINES (LOAD FRAMES)

- RUMUL Vibroforte 700 high frequency testing machine, April/2022
- 5 MN for static and dynamic loading
- 1200 kN and 750 kN for dynamic and static loading
- 400 kN for dynamic and static loading
- Hz1 and Hz2 frames for 150 kN dynamic and static loading
- 150 kN for dynamic and static loading
- 1 MN compression up to 7 m length columns and beams
- Drop weight testing machine for impact tests

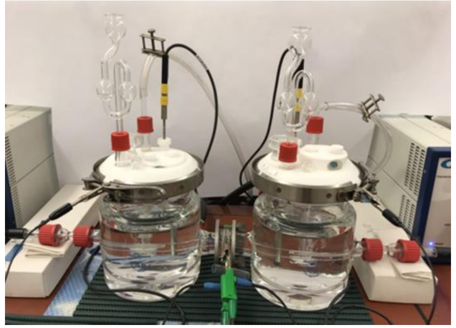


Low-cycle fatigue assessment: experiment & simulation

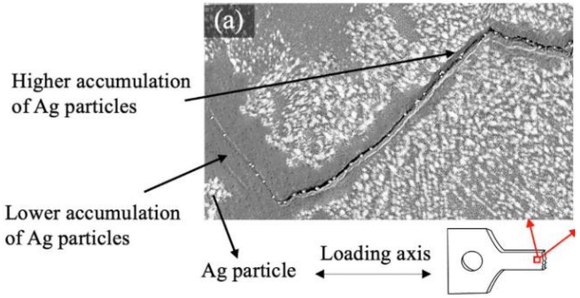




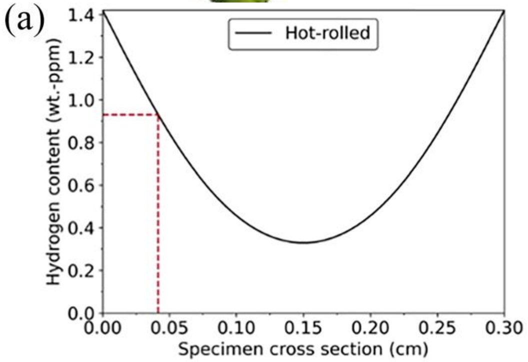
Facilities



Hydrogen Electrochemical Permeation Tests



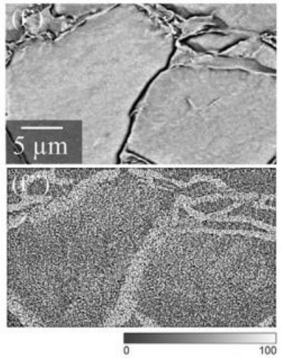
Hydrogen Microprint Technique



$$C_{tot} = \frac{C_0}{r}\left(\mathrm{erfc}\left(\frac{x}{\bar{x}}\right)\right) - \frac{x}{\sqrt{\pi}} e^{\left(\frac{-x}{\bar{x}}\right)^2} + \frac{\bar{x}}{\sqrt{\pi}} \text{ where}$$

$$\bar{x} = 2\sqrt{D_{eff} t}$$

Hydrogen Diffusion & Profile in Metals by Finite Element Analysis



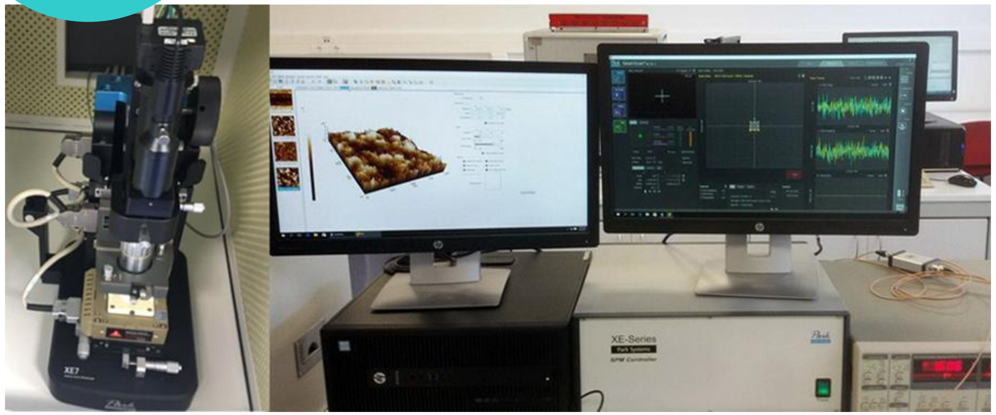
Nano SIMS

TDS at LUT

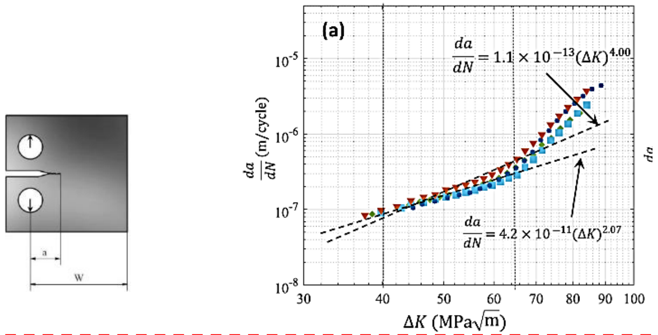
Analytical Hydrogen Characterisation

- Hydrogen Mapping by Hydrogen Microprint Technique/ Silver Decoration
- Thermal Desorption Spectroscopy (TDS)
- Hydrogen Hot/Melt Extraction
- Hydrogen Electrochemical Permeation Tests
- Hydrogen Diffusion & Profile in Metals by finite element analysis
- Hydrogen Mapping by SKPFM
- Hydrogen Mapping by LIBS
- Hydrogen Mapping by NanoSIMS)

Hydrogen characterisation



Hydrogen Mapping by SKPFM at LUT



Fatigue crack growth rate at LUT

Facilities

LUT University

Scanning electron microscopy (SEM) at LUT

Transmission electron microscopy (SEM) at LUT

Atom Probe Tomography

Microstructural Observation

Microstructural Observation

- Optical Microscopy
- 3D Surface Measurement Device
- SEM/EDS/EBSD
- TEM
- Atom Probe Tomography

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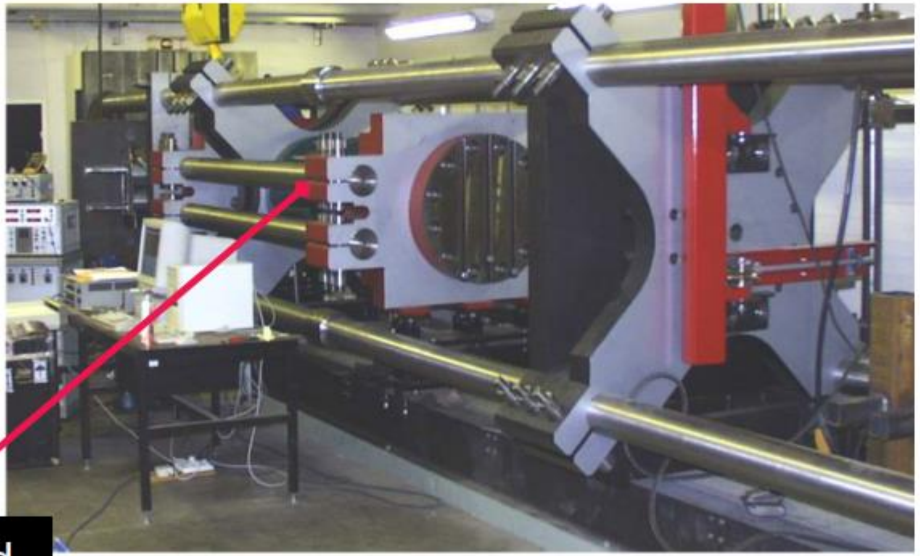
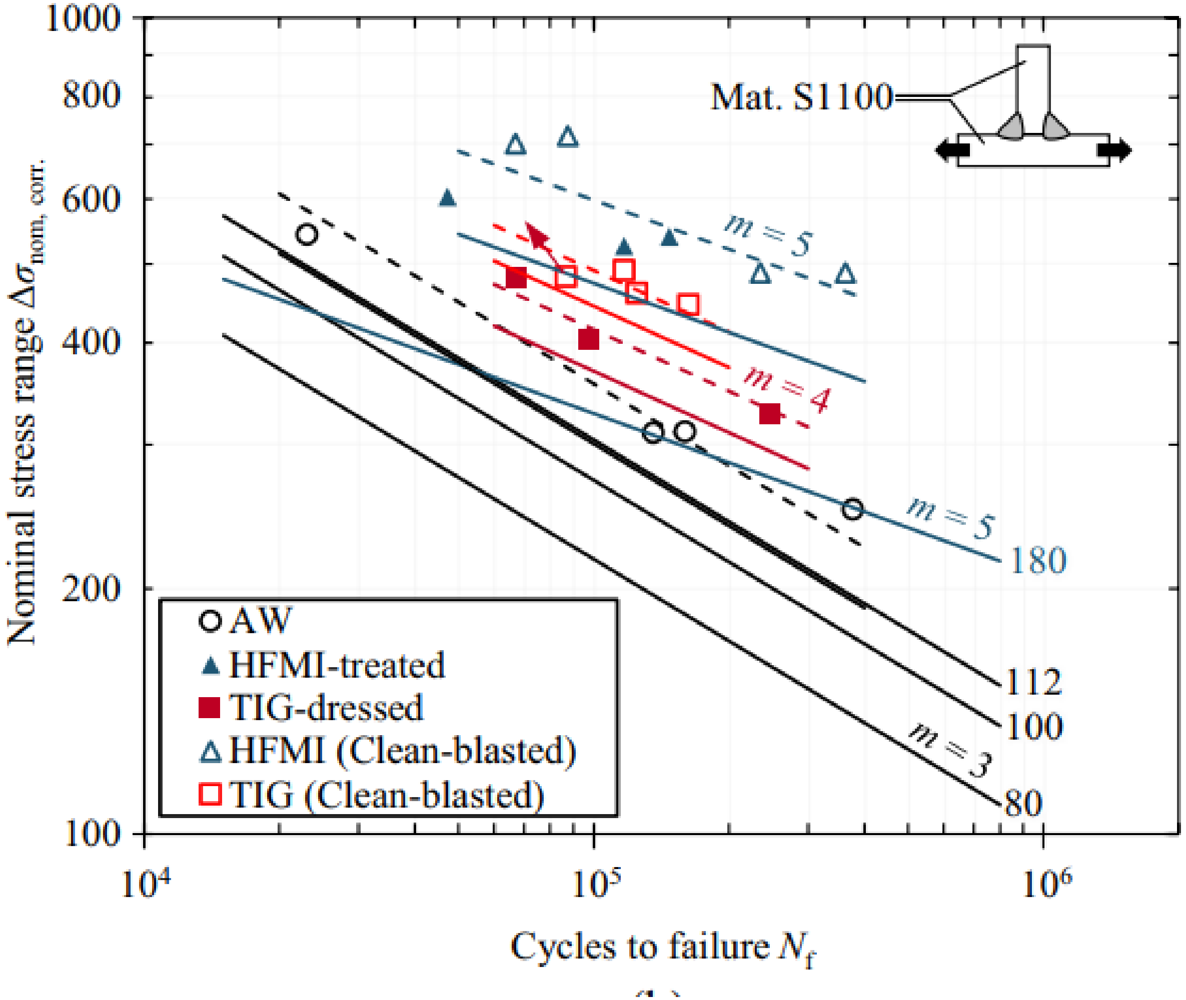
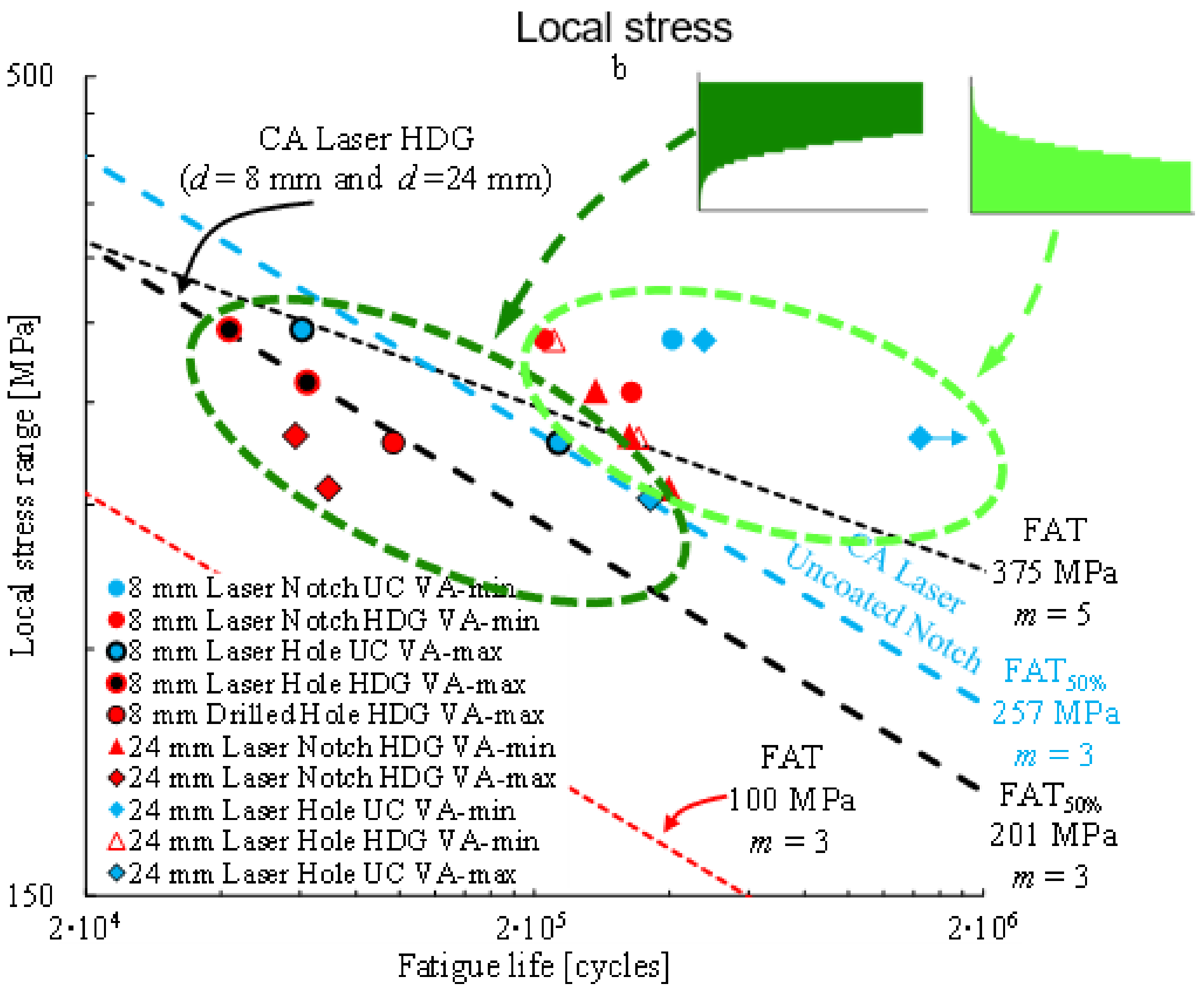


5MN load frame

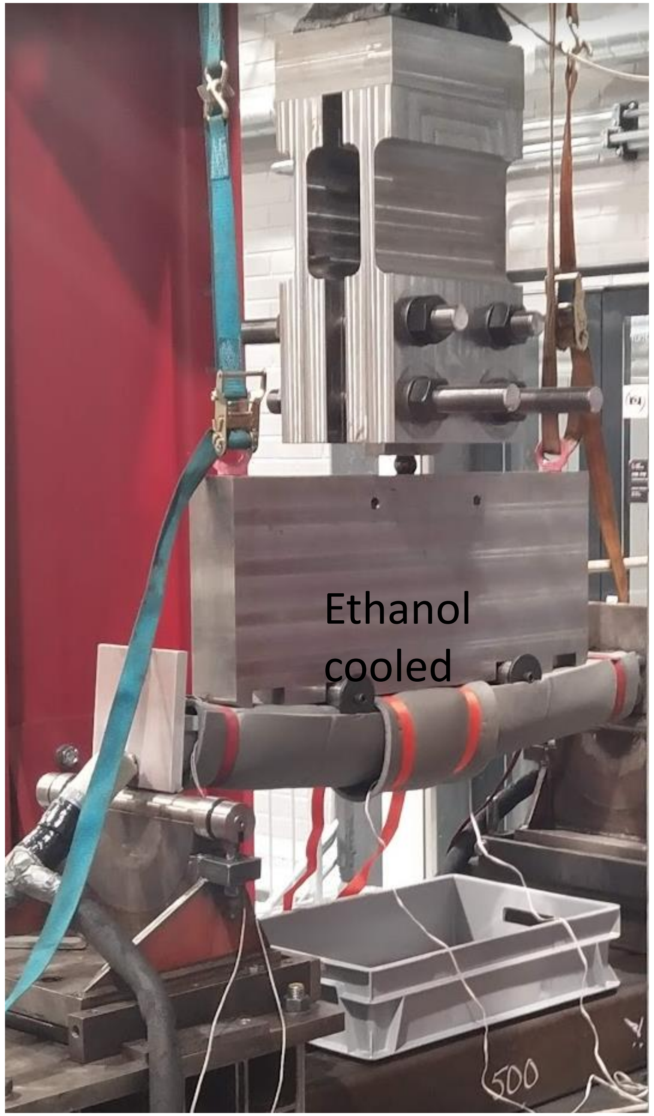
Environment chamber + Cooling unit

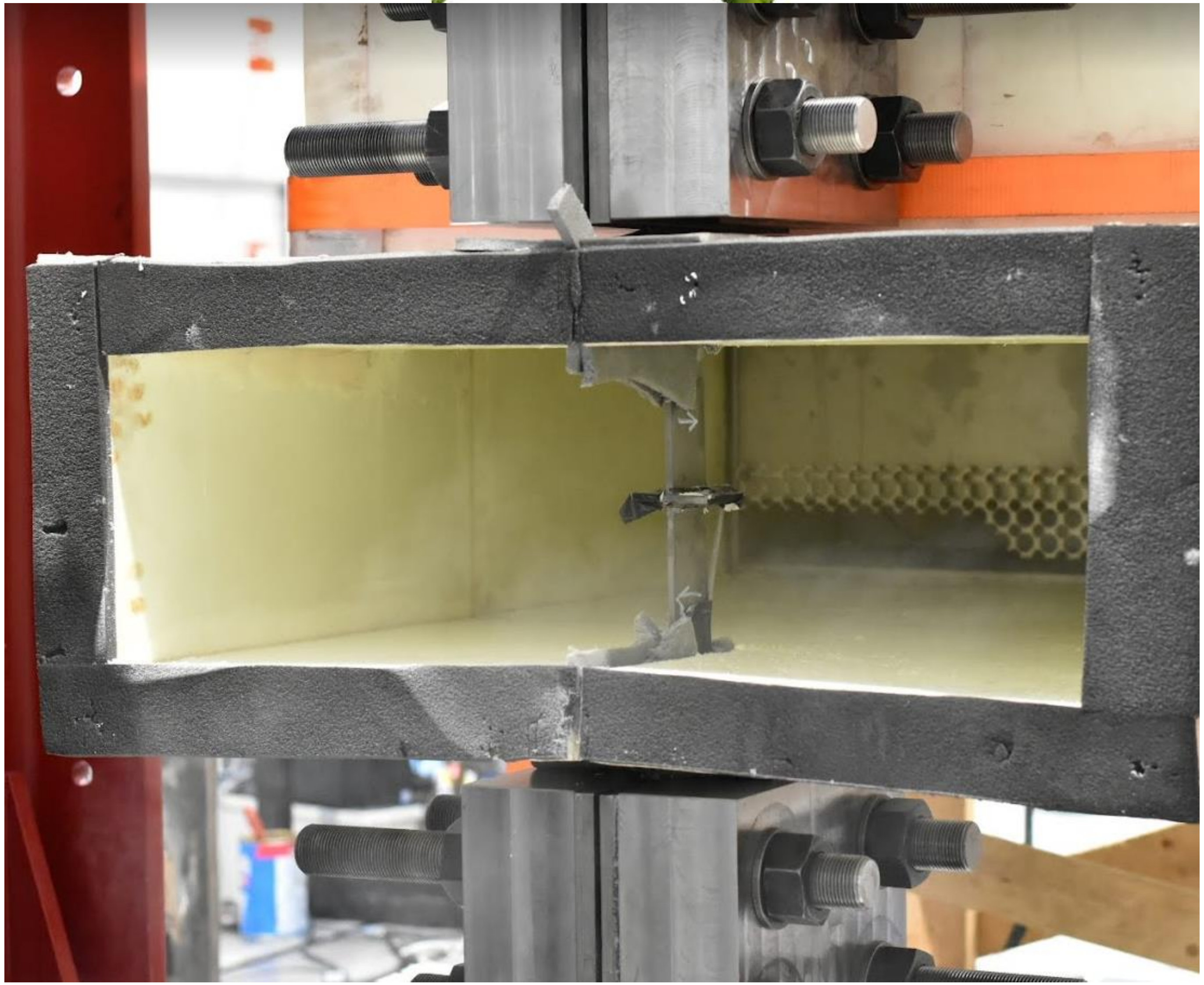
Fatigue performace – SN-curves



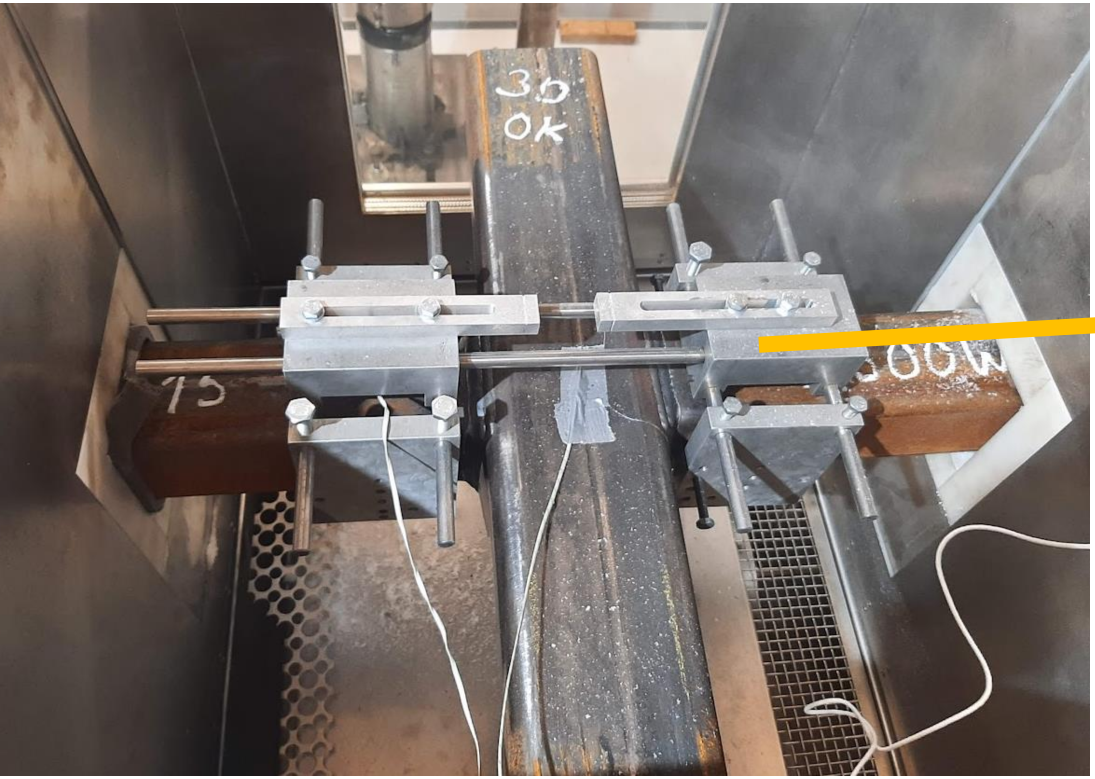


Sub-zero fatigue testing

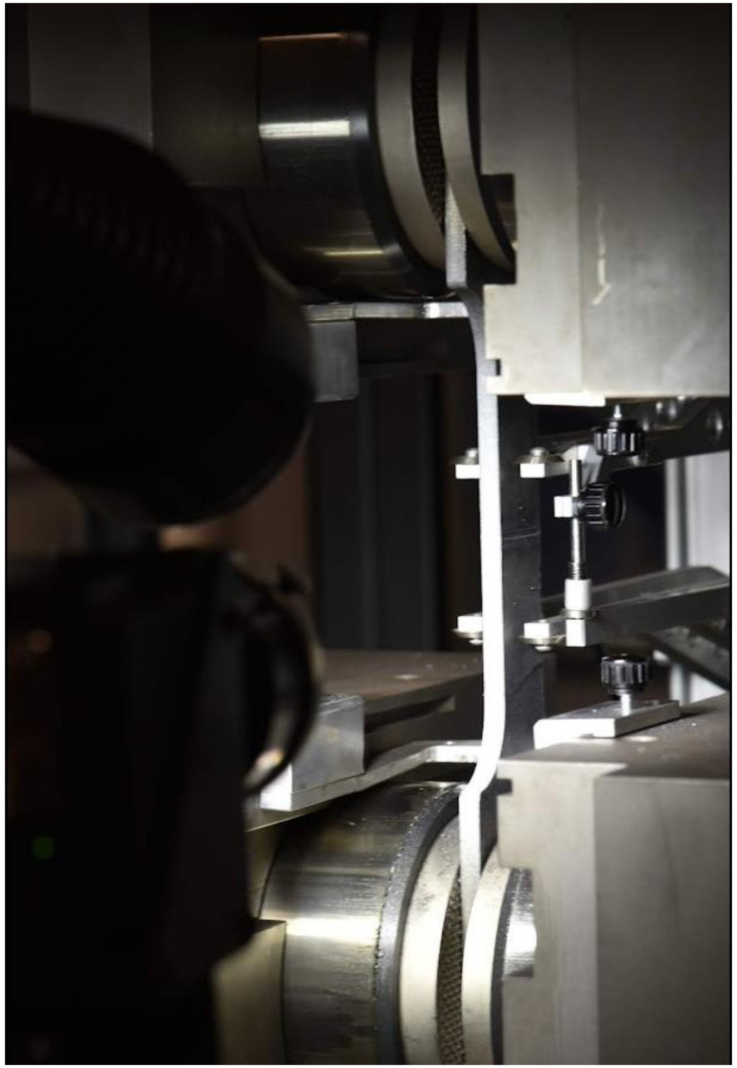


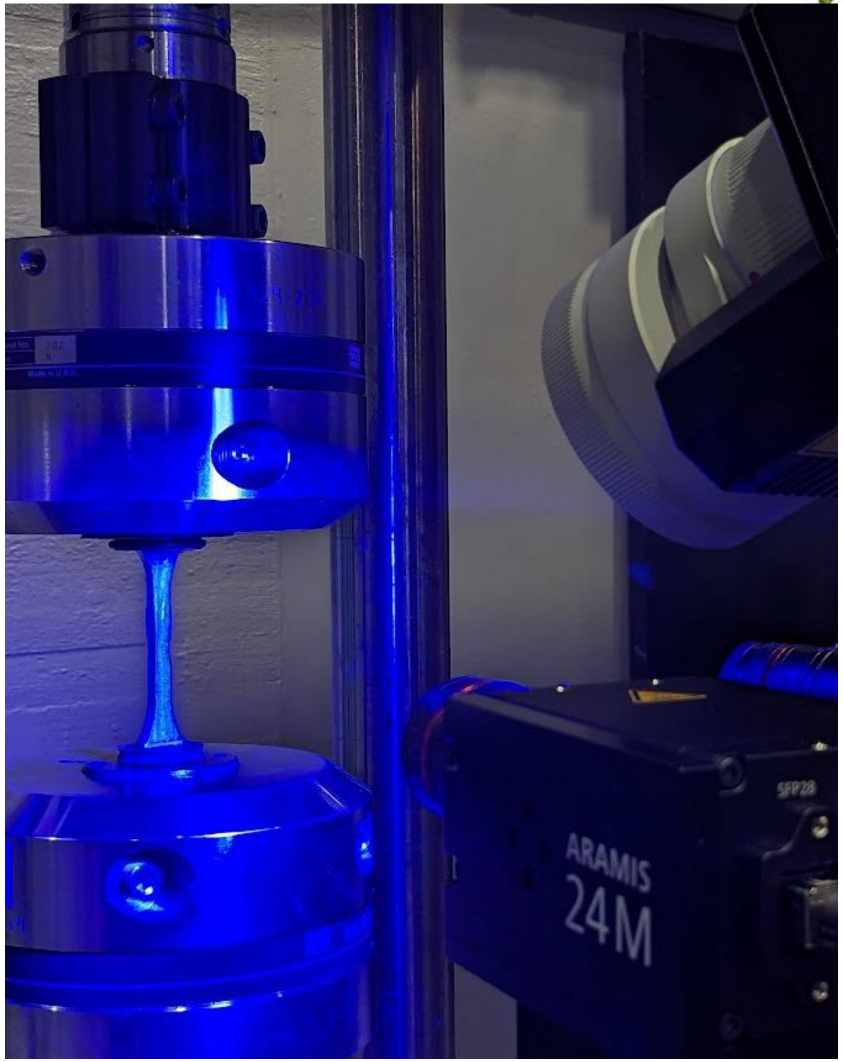


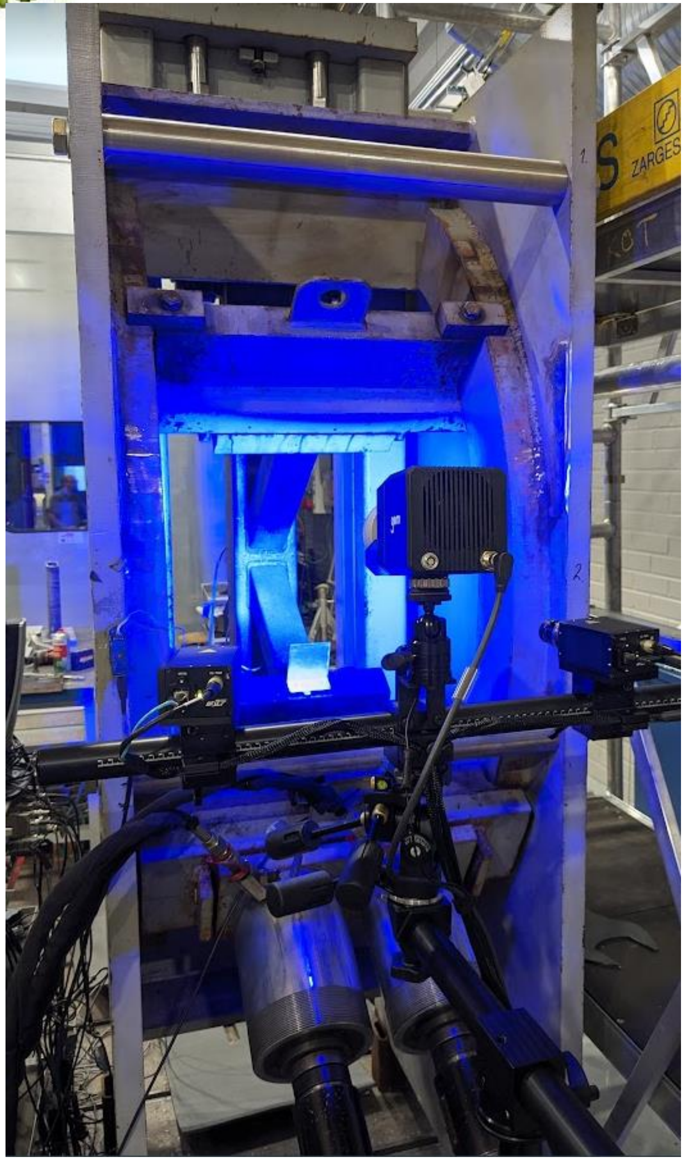
RHS X-joint (subzero)



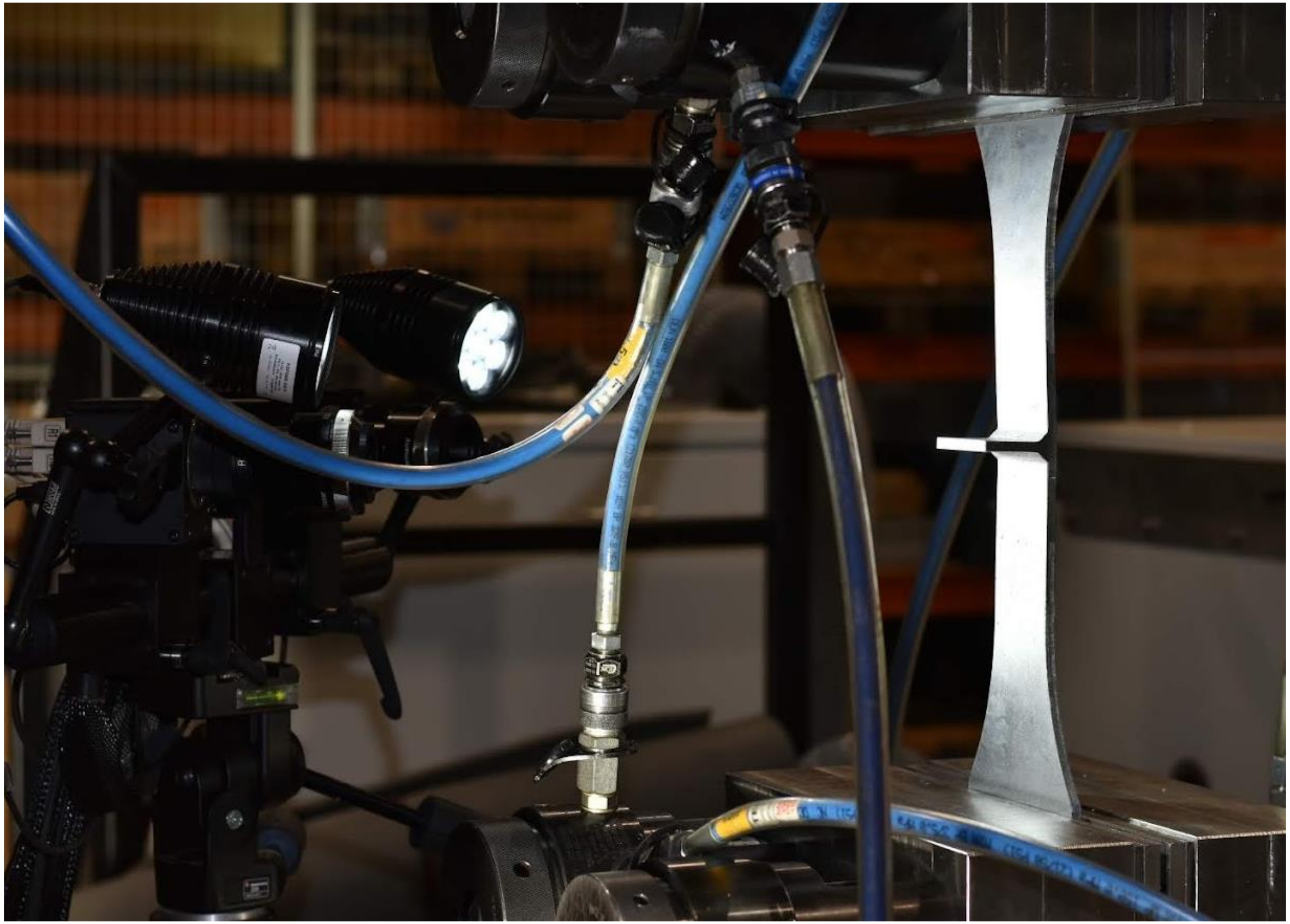
Ultimate capacity

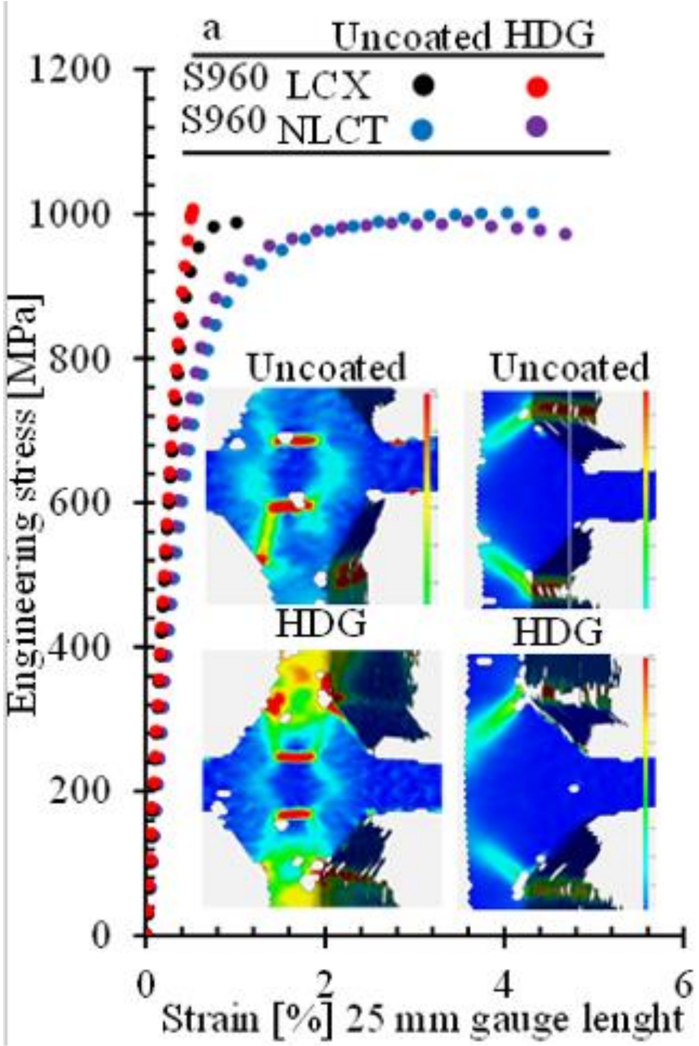




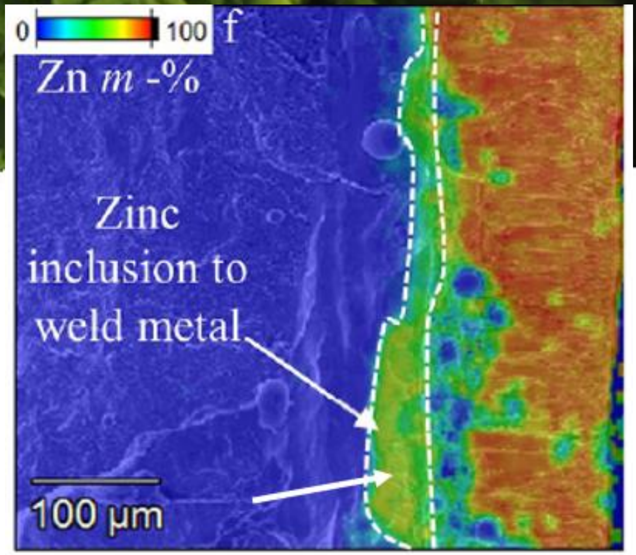


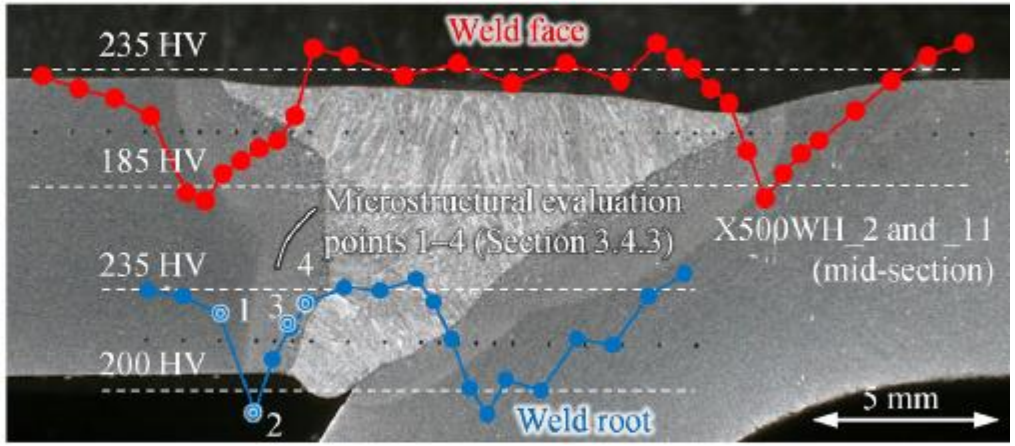
Ultimate capacity

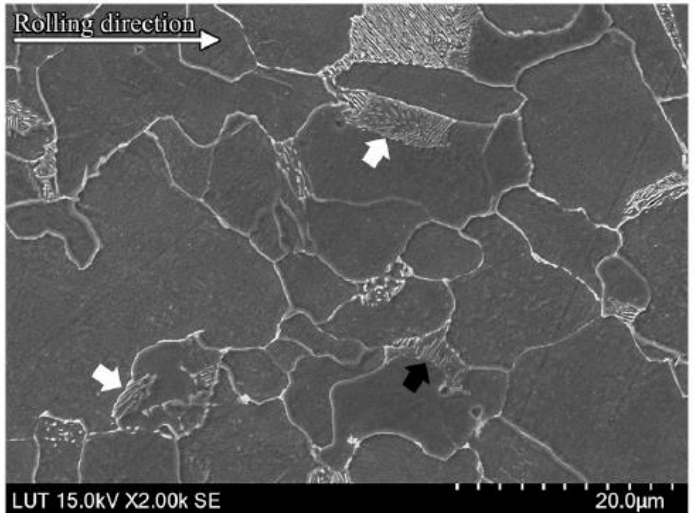


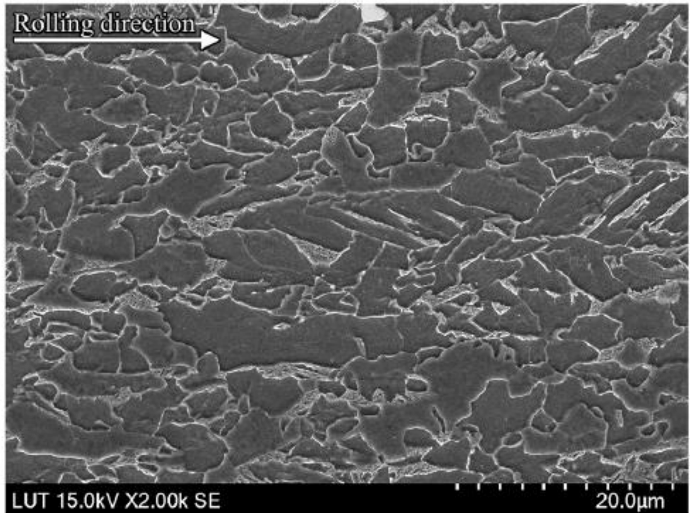


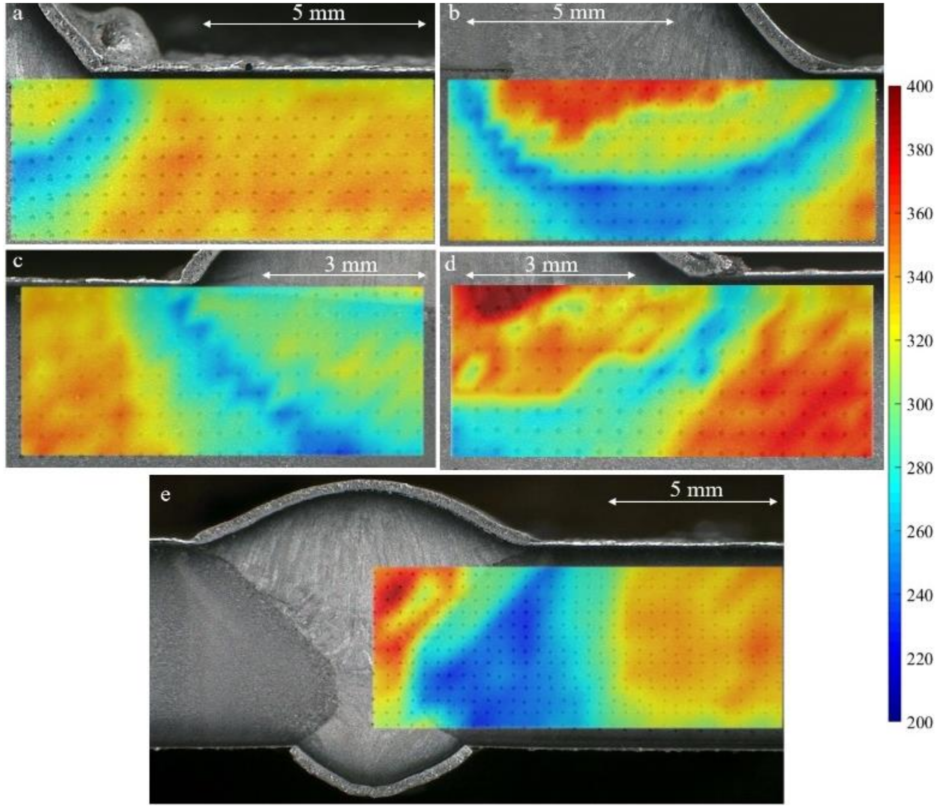
Various postprocessing evaluation





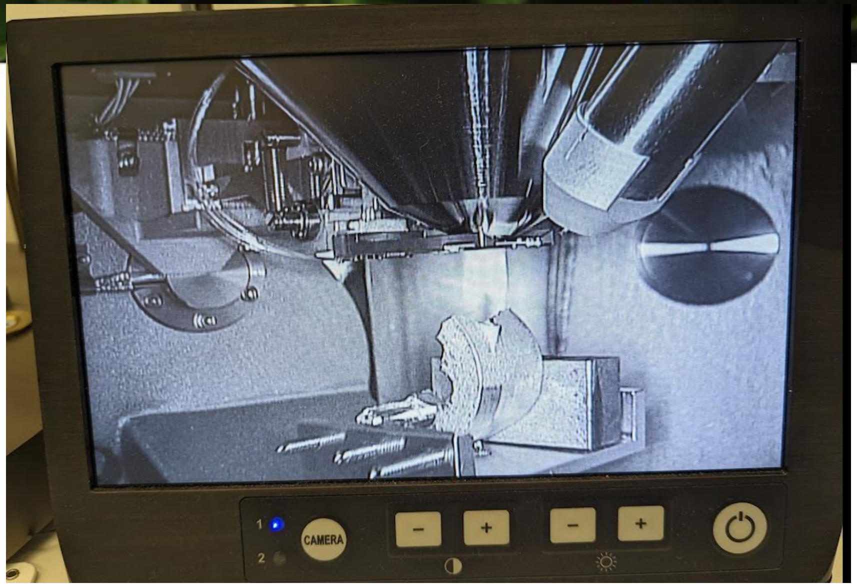


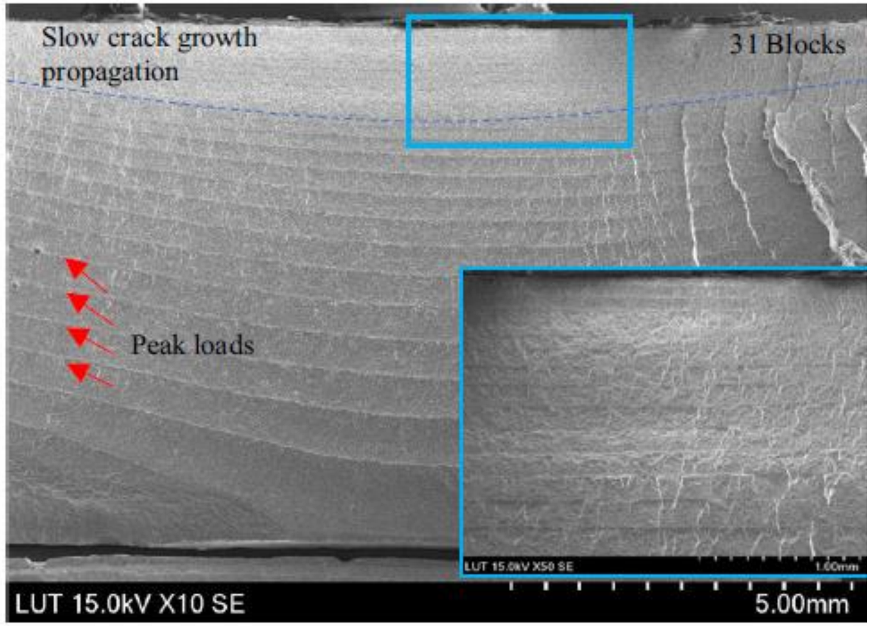


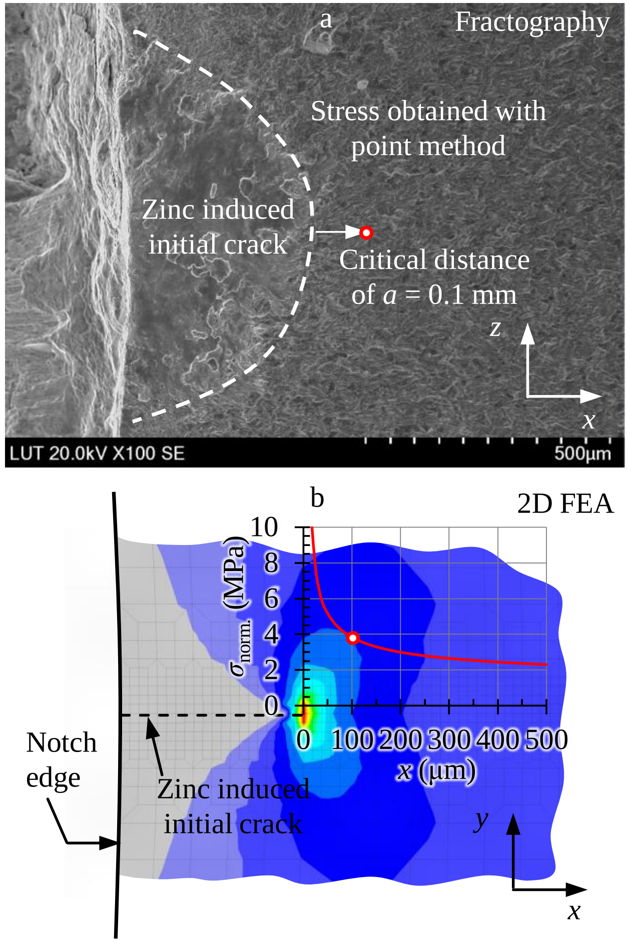


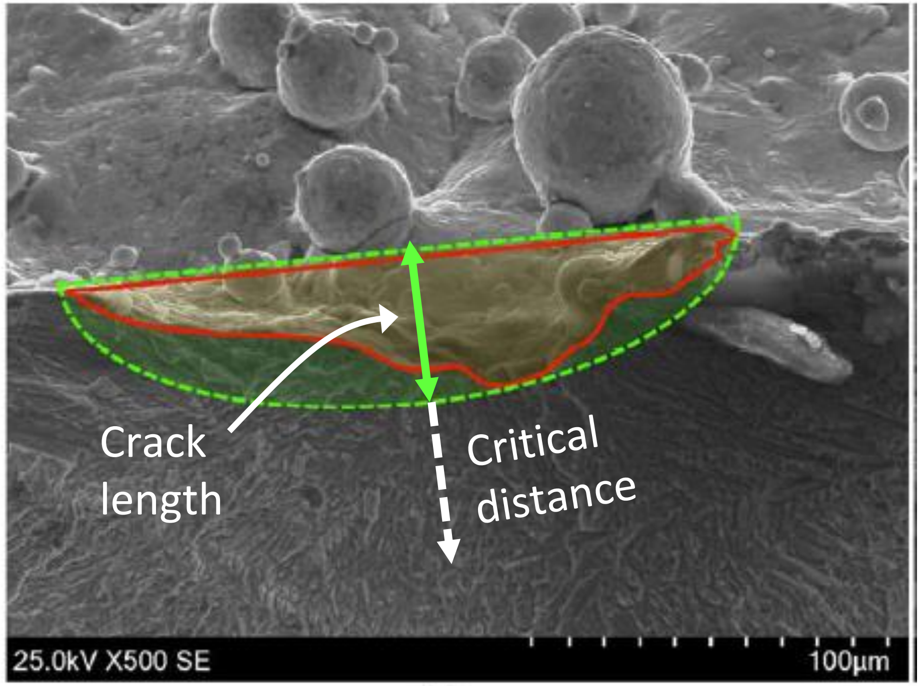
Fractograpghy

- SEM for analysis
- Connecting local quality and fatigue performance

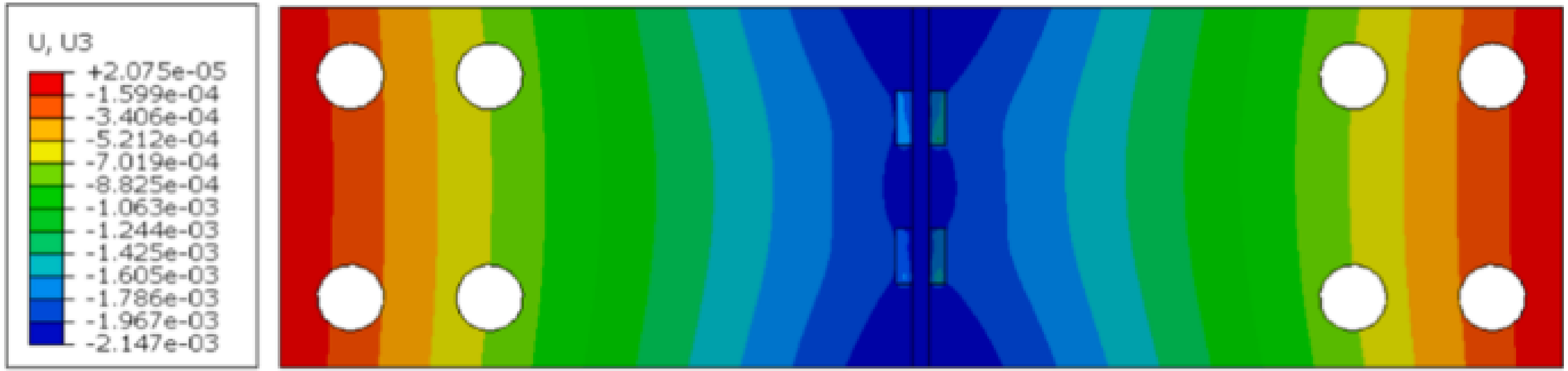


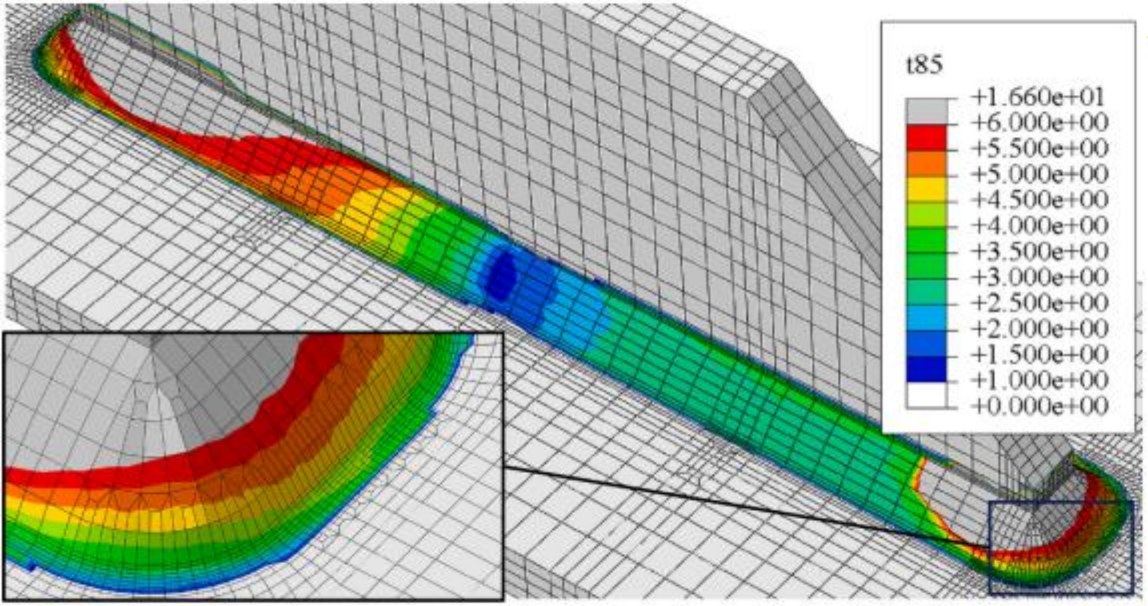


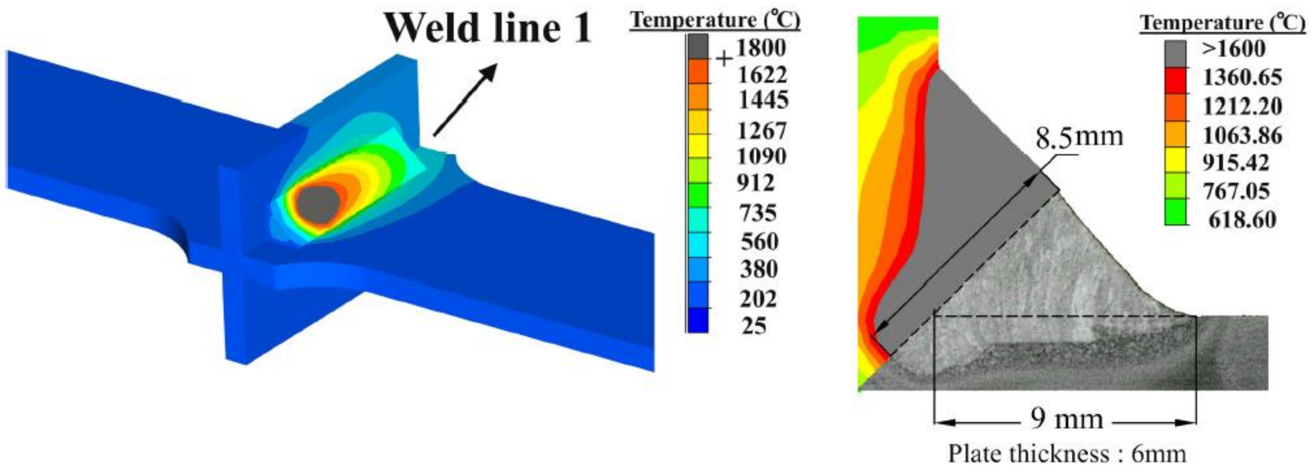




Welding simulation







(a) (b)

Fatigue prediction based on ENS method

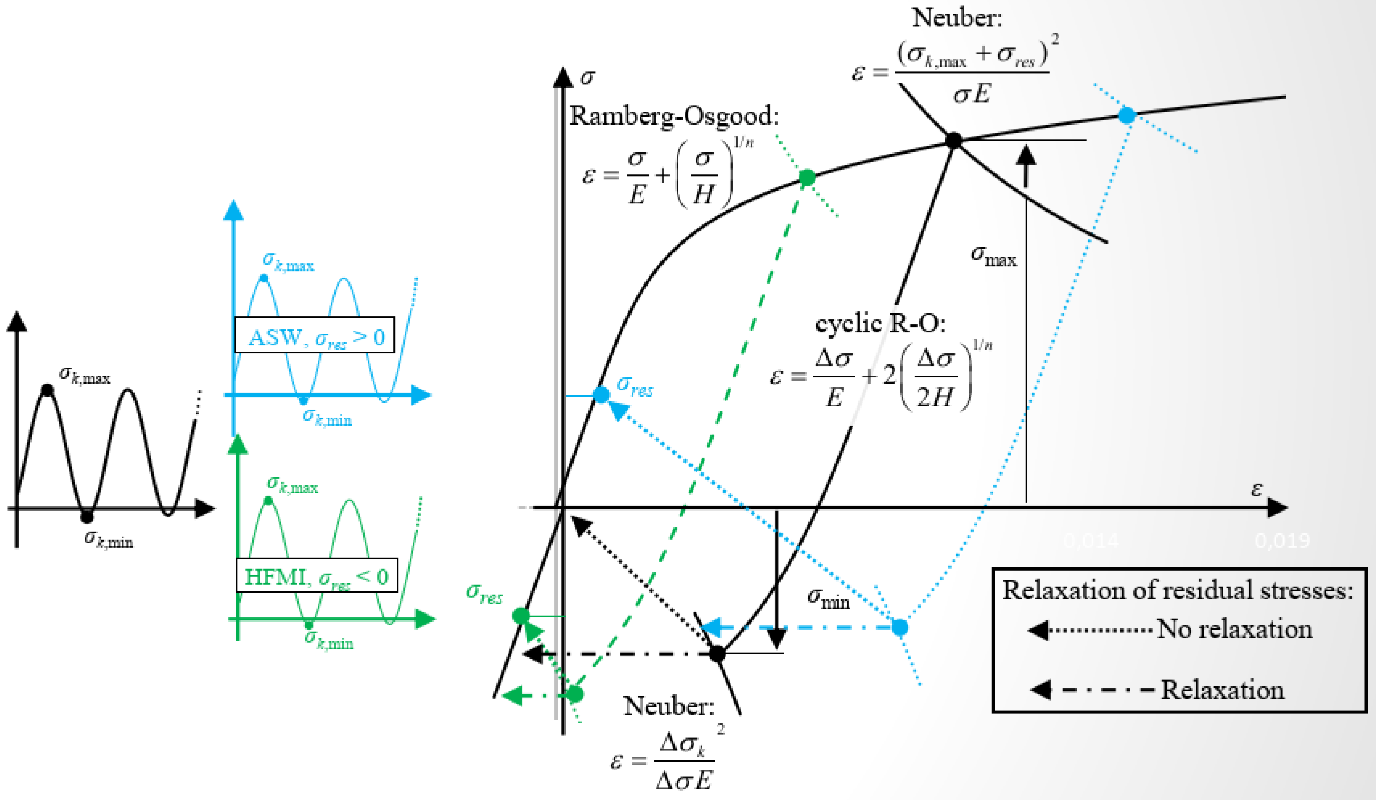
LUT University

4R METHOD FOR FATIGUE DESIGN OF WELDED JOINTS AND COMPONENTS

Novel multi-parametric fatigue assessment approach that considers:

- Material ultimate strength ($\boldsymbol{R_m}$)
- Residual stresses (σ_{res})
- External stress ratio ($\boldsymbol{R}$)
- Weld toe radius ($\boldsymbol{r_{true}}$)

Acting stress ratio (R_{local}) at notch root is obtained using well-known material models (Ramberg-Osgood and Neuber's notch theory) considering the four essential parameters



Symposiums organised by LUT Steel Structures

HRO SUUNNITTELUFOORUMI
www.lut.fi/hro

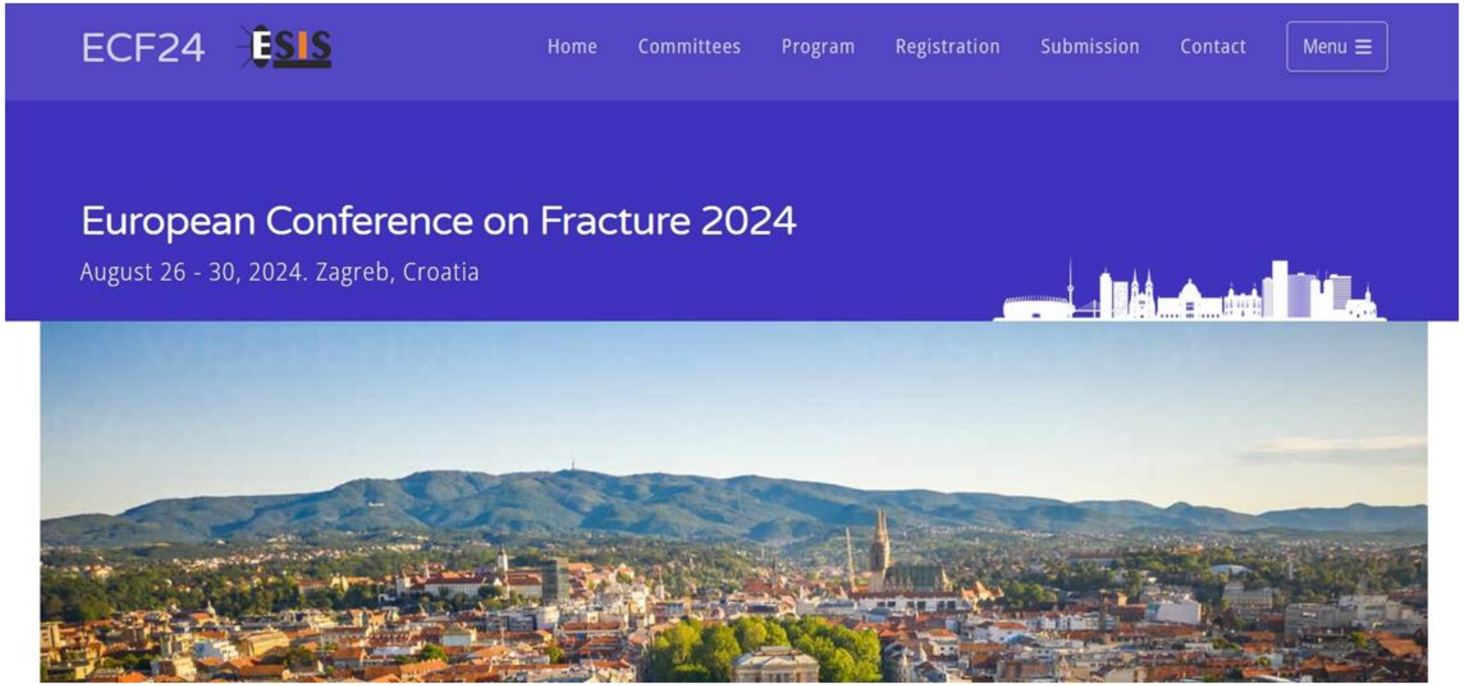
- Teräsrakenteiden laboratorion koordinoima foorumi vaativien rakenteiden suunnittelijoille, tuotekehittäjille ja tutkijoille sekä valmistuksesta, tarkastuksesta ja kunnossapidosta vastaaville
- SHY:n Suunnittelufoorumi
- Yhteensä 38 + jäsenyritystä

- Tavoitteet:
  - ✓Tuottaa uutta tutkimustietoa (tutkimusprojektit + HRO diplomityöt)
  - ✓Toteuttaa Suomen hitsaavan teollisuuden kannalta tärkeitä tutkimusprojekteja (BF, SA, EU..)
  - ✓Välittää uusin tarpeellinen tutkimustieto maailmalta kotimaiselle teollisuudelle (IIW)
  - ✓ Luoda ja ylläpitää alan yritysten välisten yhteistyötä ja kontaktointia
  - ✓Tuottaa palvelututkimusta ja koulutusta yrityksille (HRO alennus jäsenyrityksille)

- HRO Suunnittelufoorumin teemapäivät
  - ✓Alan viimeisimpien tutkimustulosten esittely (LUT + tutkimuslaitokset)
  - ✓Jäsenyritysten ja kutsuvieraiden omat esitykset
  - ✓Kansainvälinen vieraileva luennoitsija
  - ✓Kaksipäiväiset vuosittain

Symposiums (co-)organised by LUT Steel Structures

The 24th European Conference on Fracture (ECF24) is organised by the European Structural Integrity Society (ESIS).
ECF24 will be held on-site in Zagreb, Croatia, with possible online participation, from 26 - 30 August 2024.



TC 21 HYDROGEN EMBRITTLEMENT IN METALLIC MATERIALS: PIPELINE TRANSPORT, HYDROGEN STORAGE, AND OTHER APPLICATIONS

https://ecf24.eu/symposia.html

TC21 ´´Hydrogen Embrittlement´´ ECF24 symposium organizers:

- Prof. Frank Cheng, FRSC, University of Calgary, Canada
- Prof. Tom Depover, University of Ghent, Belgium
- Prof. Milos Djukic, University of Belgrade, Serbia
- Prof. Motomichi Koyama, Tohoku University, Japan
- Prof. Livia Cupertino Malheiros, Imperial College London, UK
- Prof. Masoud Moshtaghi, LUT University, Finland
- Dr. Birhan Sefer, Swerim AB, Sweden

Commission XI: Pressure Vessels, Boilers and Pipelines

Chair: Prof. Masoud Moshtaghi
Head of Steel Structures RG,
LUT University, Finland

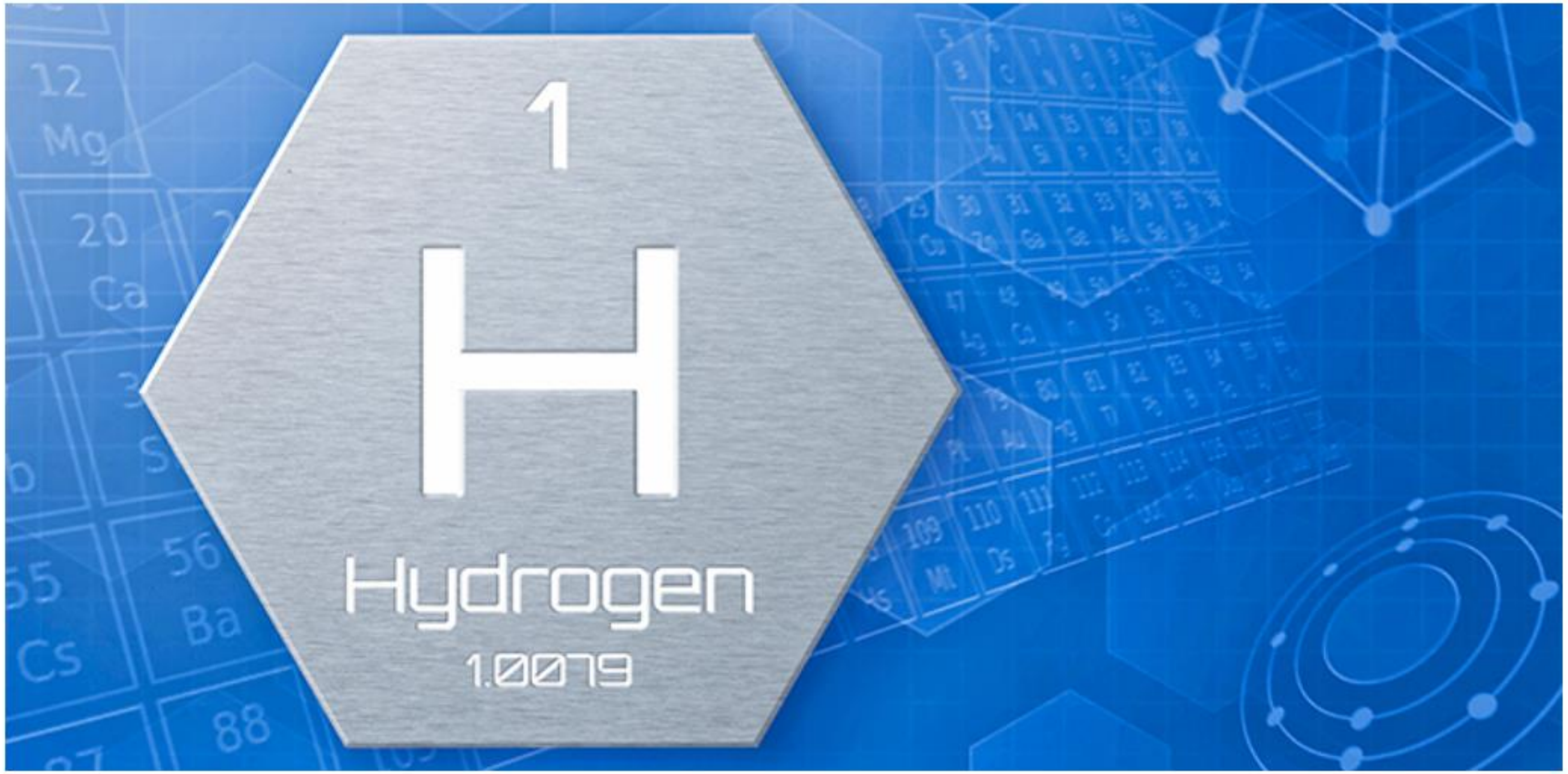
Selected topics:
1- Welded hydrogen pipelines
2- Wire arc additive manufacturing
3- Laser welding
4- Hybrid welding
5- Laser powder bed fusion
6- Hydrogen storage
7- Hydrogen transport
8- Underground hydrogen storage

Contribution of LUT Steel Structures

LUT University

6th Swedish Hydrogen seminar

– Embrittlement phenomena in metallic materials



Keynote speaker:

Prof. Masoud Moshtaghi

Design of Hydrogen Embrittlement Resistant High Strenght Steels for Different Applications

Date and time

10 October 2024

Location

Jernkontoret with online option

Kungsträdgårdsgatan 10

Stockholm

Contact

Rachel Pettersson

rachel.pettersson@jernkontoret.se

+46 8 679 17 04

Thank you for your attention!

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https://www.scopus.com/authid/detail.uri?authorId=55387560300

FWF
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FFG Promoting Innovation.
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Co-funded by the European Union
SSAB
voestalpine ONE STEP AHEAD.
JSPS

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