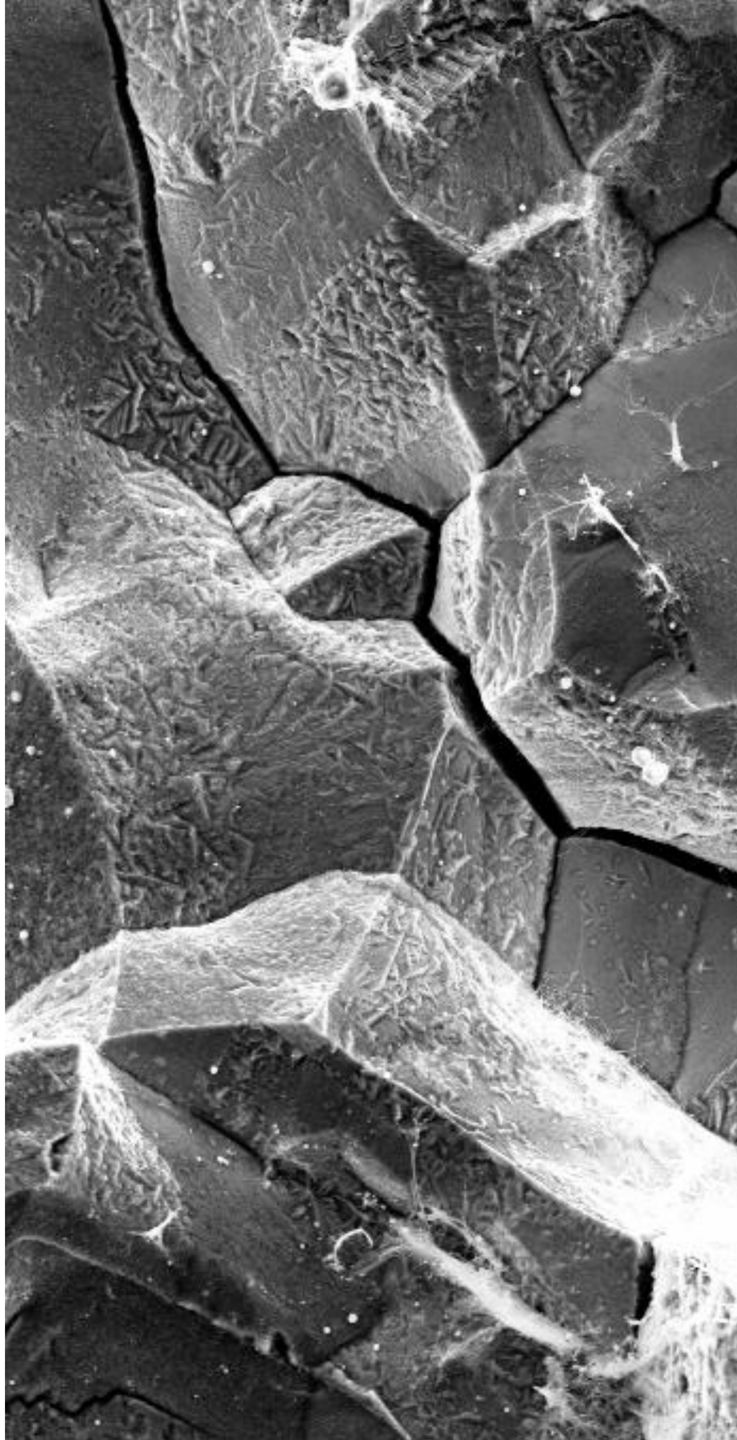
Long-term approach to manage Stress Corrosion Cracking

NRC workshop on structural materials: Research for beyond 60 years

October 1-4, 2024

thierry.couvant@edf.fr



LTO

Main concern

- Some components cannot be replaced: reactor pressure vessel, reactor containment, reactor pit
- Some components are difficult to replace: RPV internals, cables

Background

- Long-term research programs addressing ageing (due to high temperature, irradiation, environment, stress) and consequences on safety
- Interactions with French Regulatory regarding operation beyond 60 years

Main objectives

- Allow safe operating beyond 60 years
- Prepare next 10 yearly in-depth inspections

EAC: INDUSTRIAL NEED

1. Understand in-service degradations → understanding underlying mechanisms
2. Adjust non-destructive examination strategies → accurate NDEs + accurate cracking kinetics
3. Mitigate → Factor of improvement (given the cost) ?
4. Operational solutions for repairing/replacement
5. Anticipate Future degradations

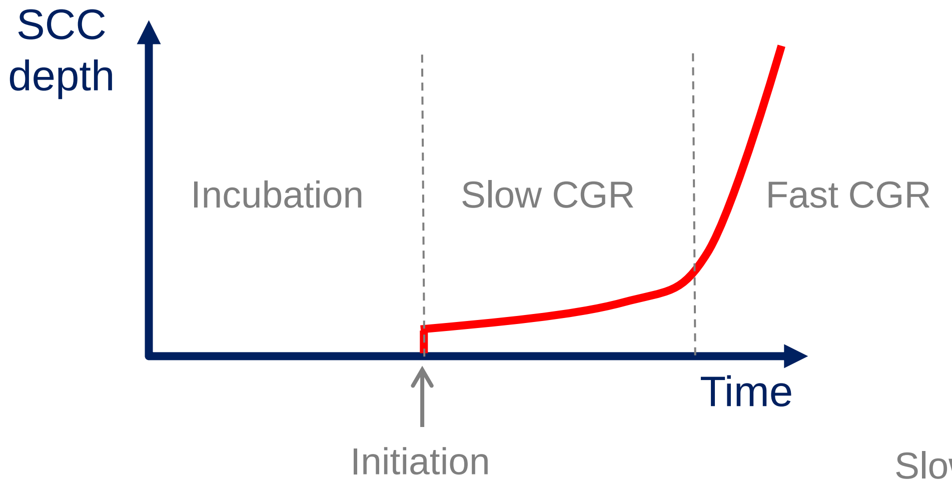
Challenge: how to be

- Proactive: funding building/improvement of knowledge (data, mechanisms), tools, methodologies
- Confident: managing uncertainties taking into account lessons learned from OE
- Quantitative: where, when, how fast cracking may occur
- Reactive: when necessary, ready to rapidly evaluate the current situation based on NDE and EAC simulation

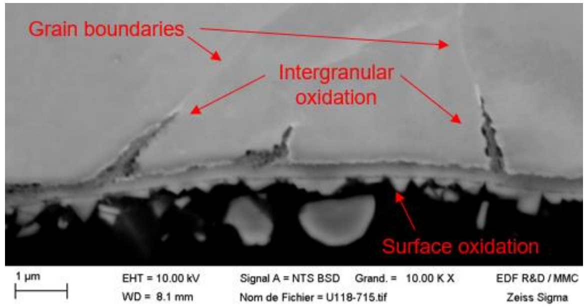
HOW TO UNDERSTAND IN-SERVICE CRACKING?

- Having **knowledge** on the **fabrication** of components (bulk, surface finish, HAZ) and **operating conditions** (environment, loading)
- Having appropriate knowledge on **underlying mechanisms**, considering what EAC is:
  - Coupling between material/environment/loading
  - Progressive degradation involving incubation, initiation and crack growth periods

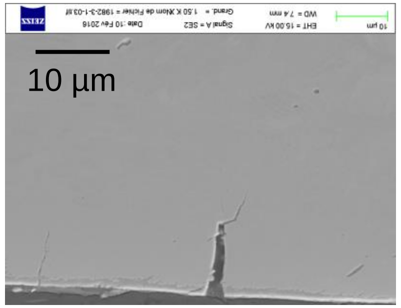
How to validate assumed mechanisms?



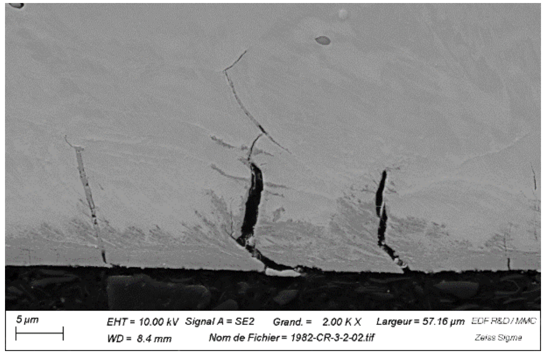
Incubation (oxide intrusion)



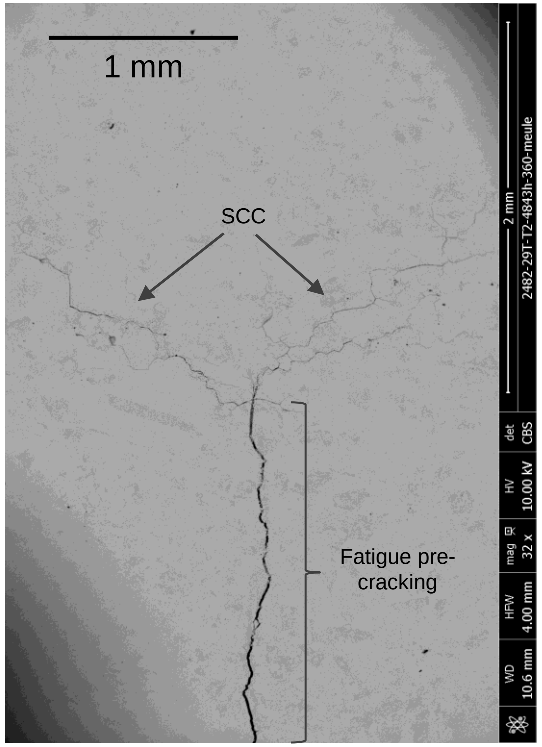
Initiation (cracking of oxide intrusions)



Slow CGR

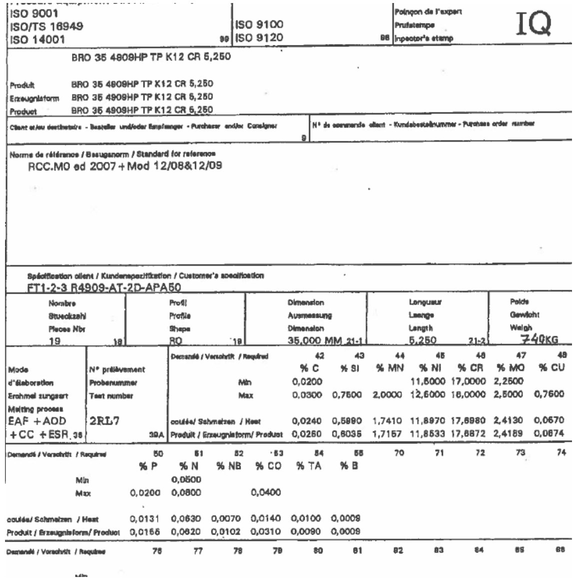


Fast CGR



HOW TO BETTER KNOW IN-SERVICE CONDITIONS?

- Having **access to records** (manufacturing, on-site measurements when possible)
- Performing complementary **examinations** on as-manufactured **components** (bolts, pins…), on representative **mock-ups** and on (retired) components



ISO 9001
ISO/TS 16949
ISO 14001 99 | ISO 9100
ISO 9120 98 | Poinçon de l'expert
Prufstempe
Inpector's stamp | IQ

BRO 35 4909HP TP K12 CR 5,250

Produkt BRO 35 4909HP TP K12 CR 5,250
Erzeugnisform BRO 35 4909HP TP K12 CR 5,250
Product BRO 35 4909HP TP K12 CR 5,250

Client et/ou destinataire - Besteller und/oder Empfänger - Purchaser and/or Consignee 9 | N° de commande client - Kundebestellnummer - Purchase order number

Norme de référence / Bezugsnorm / Standard for reference
RCC.M0 ed 2007 + Mod 12/08&12/09

Spécification client / Kundenspezifikation / Customer's specification
FT1-2-3 R4909-AT-2D-APA50

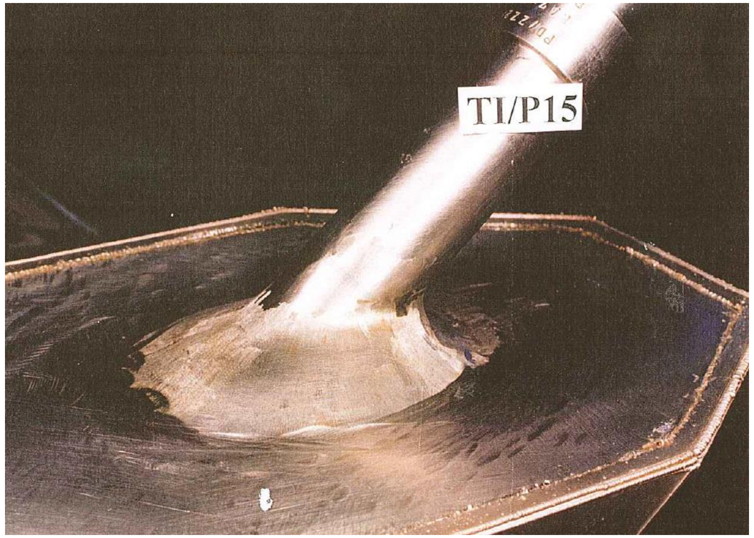
Nombre / Stueckzahl / Pieces Nbr	Profil / Profile / Shape	Dimension / Ausmessung / Dimension	Longueur / Laenge / Length	Poids / Gewicht / Weigh
19 (18)	RO (19)	35,000 MM (21-1)	5,250 (21-2)	740KG

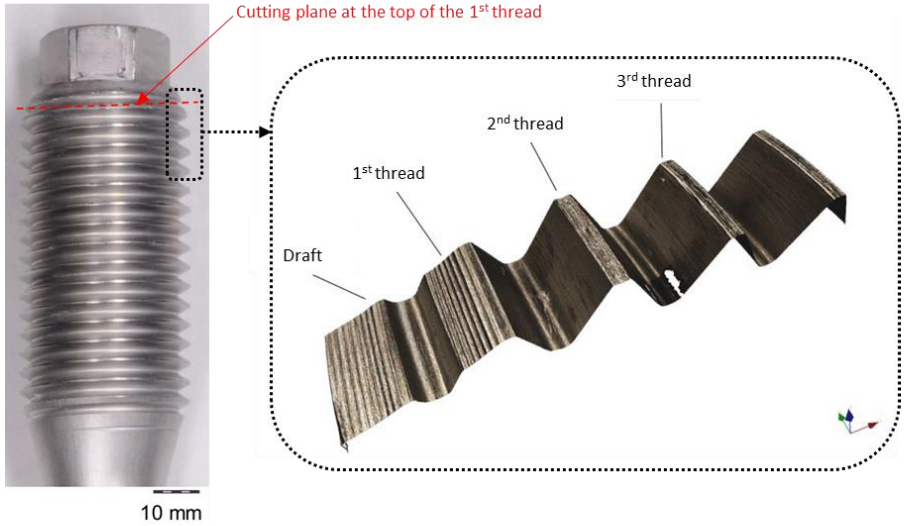
Mode d'élaboration / Erschmelzungsart / Melting process: EAF + AOD + CC + ESR (38)
N° prélèvement / Probenummer / Test number: 2RL7 (39A)

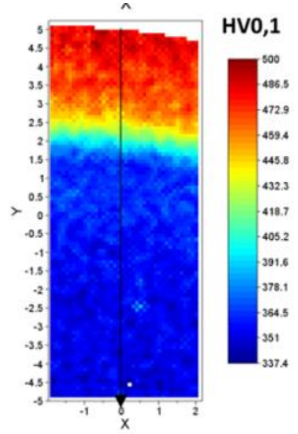
Demandé / Vorschrift / Required	42 % C	43 % SI	44 % MN	45 % NI	46 % CR	47 % MO	48 % CU
Min	0,0200			11,5000	17,0000	2,2500	
Max	0,0300	0,7500	2,0000	12,5000	18,0000	2,5000	0,7500
coulée/ Schmelzen / Heat	0,0240	0,5890	1,7410	11,8970	17,6980	2,4130	0,0670
Produit / Erzeugnisform/ Product	0,0260	0,6035	1,7157	11,8533	17,6872	2,4189	0,0674

Demandé / Vorschrift / Required	50 % P	51 % N	52 % NB	53 % CO	54 % TA	55 % B	70	71	72	73	74
Min		0,0500									
Max	0,0200	0,0800		0,0400							
coulée/ Schmelzen / Heat	0,0131	0,0630	0,0070	0,0140	0,0100	0,0009					
Produit / Erzeugnisform/ Product	0,0166	0,0620	0,0102	0,0310	0,0090	0,0009					

Demandé / Vorschrift / Required 76 77 78 79 80 81 82 83 84 85 86





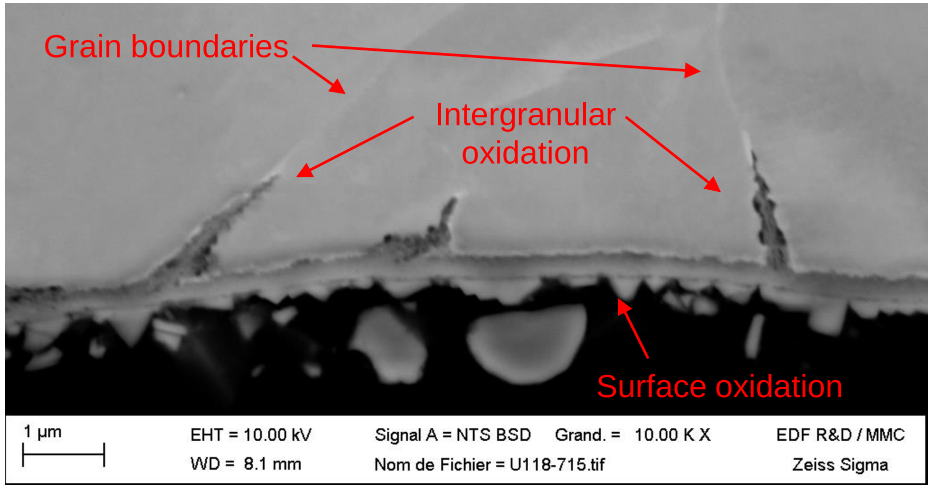


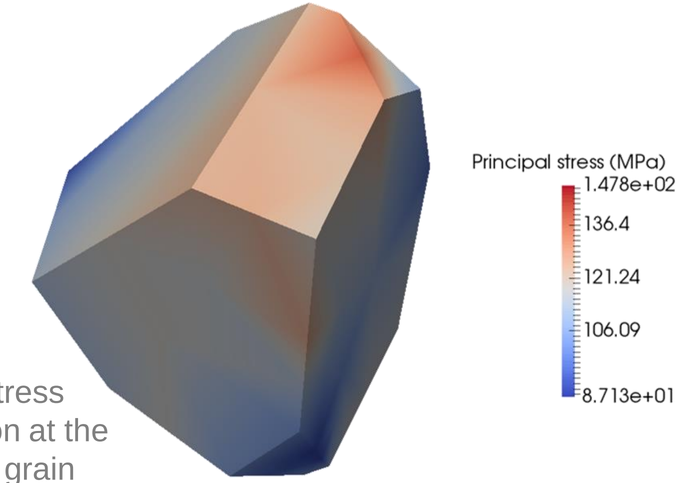
HOW TO VALIDATE ASSUMED MECHANISMS?

Simulating SCC and performing relevant predictions

Example: currently assumed mechanism for nickel alloys and stainless steels

- Initiation = probability to fail a set of sufficiently oxidized grain boundaries
- Time to initiation (IGSCC incubation) = time to reach the critical IG oxidation depth
- Initiation depth = oxidation depth
- Crack extension = same process as initiation, enhanced by stress/strain concentrations

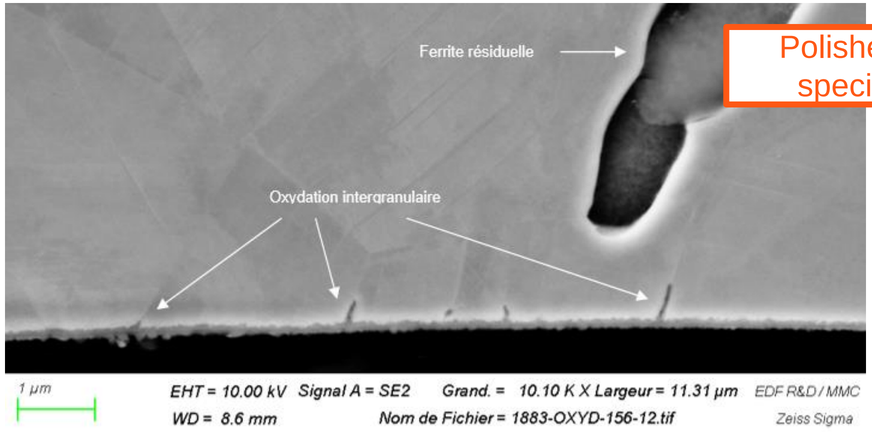




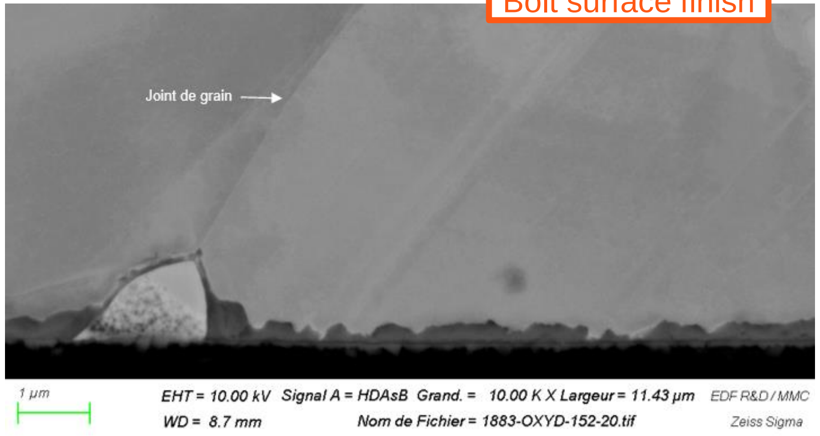
Simulated stress concentration at the surface of a grain (located in a polycrystal)

SCC simulation in a BMI nozzle (initiation at the OD of the tube)

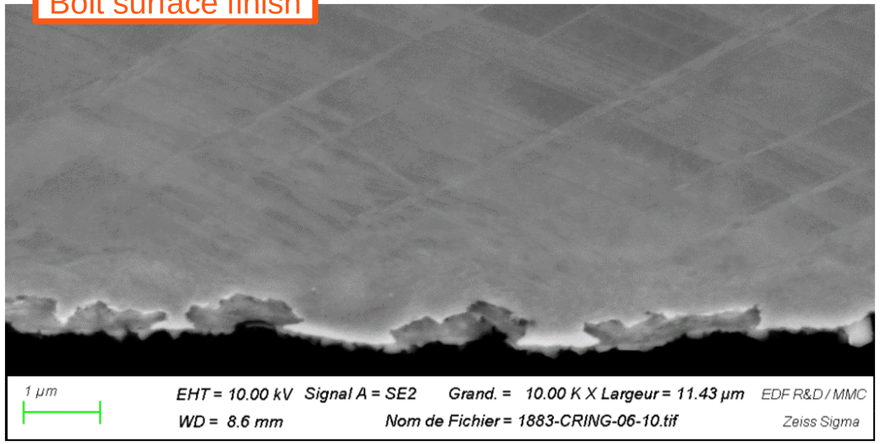
HOW TO PROPERLY CONSIDER THE EFFECT OF SURFACE FINISH OF COMPONENTS ON INITIATION?



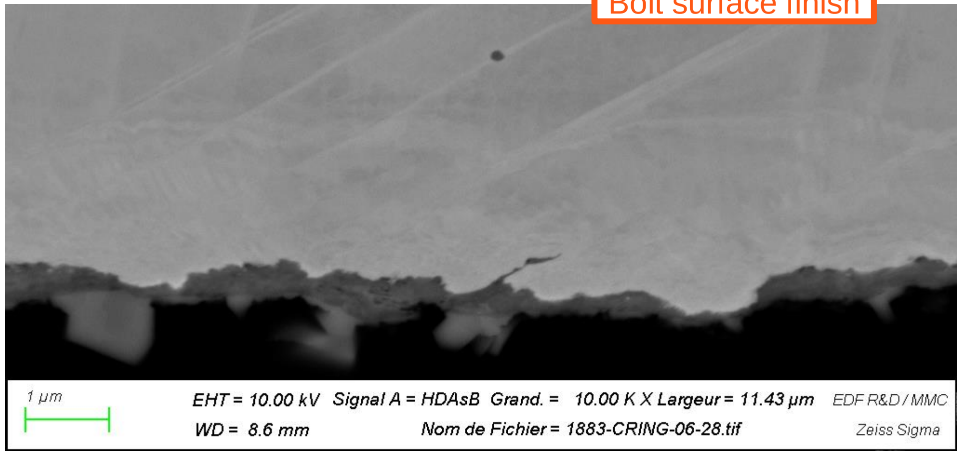
Polished lab specimen



Bolt surface finish



Bolt surface finish

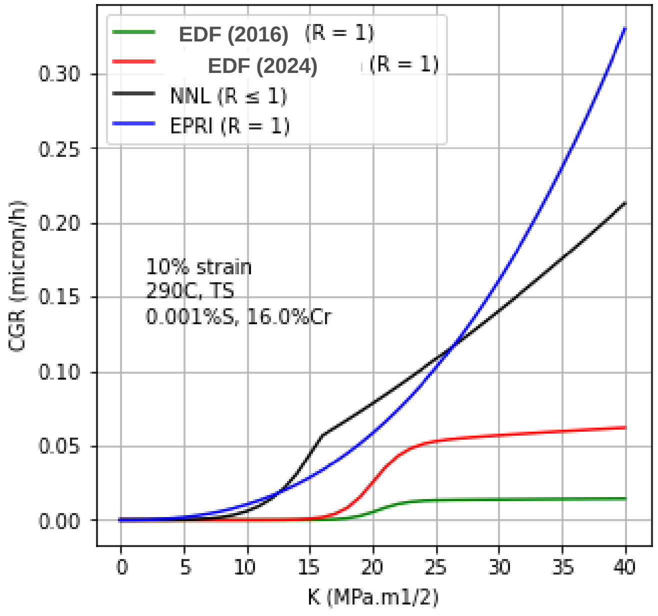


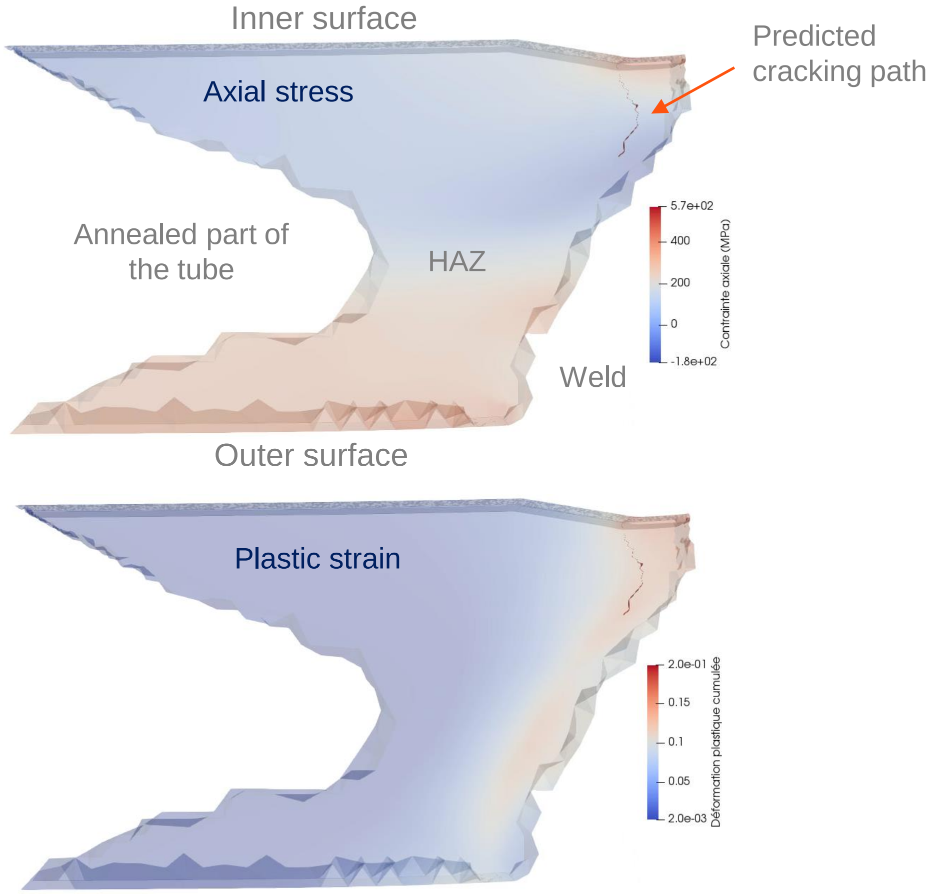
Bolt surface finish

HOW TO BE CONFIDENT IN SCC MODELS?

- Having good databases: details on testing conditions and methodologies
- Reaching the same predictions using different models
- Properly adjusting the level of conservatism

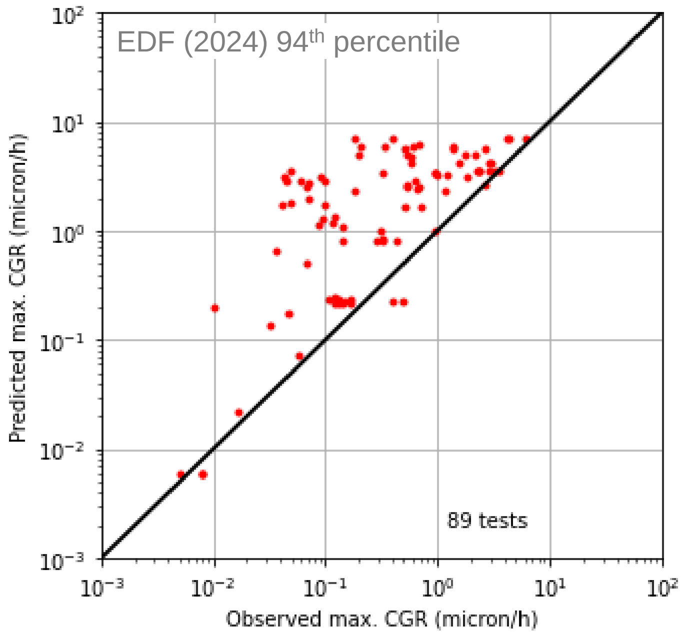
Stainless steel SCC growth rate





SCC simulation in the HAZ of a SIS pipe

Stainless steel SCC growth rate



HOW TO MANAGE UNCERTAINTIES?

- Having an **industrial NDE strategy**
- **Quantifying** the consequences of the selected tuning of the level of conservatism
- Splitting epistemic and aleatory uncertainties:
  - Long-term **Research** to reduce epistemic uncertainties
  - Quantifying the consequences of aleatory uncertainties: aleatory behavior can lead to deterministic outcome
- **Questioning** certainties

Only intermediate positions cannot be predicted

ON-GOING RESEARCH: EXAMPLES

Testing on already installed materials: A600, A182, A690, A718, X750, 316(L)(N), 304L, A286…

Testing on possible alternative materials/manufacturing: XM-19, A725, hot isostatic pressing, high entropy alloys…

Building **databases** (including references) to feed **digital tools**

Improving/validating **models** (based on databases, mockups, OPEX)

Simulating observed/suspected phenomena:

- FEM: weld residual stresses/strains in pipes/nozzles, in-service stress
- NDE: microstructural/shape effects on defect detection in pipes and J-welds
- SCC: cracking kinetics in auxiliary lines, bolts, nozzles
- CFD (computational fluid dynamics): temperature and water velocity in auxiliary lines

Quantifying FOIs (based on simulation): welding conditions, MSIP, material replacement (including alternative manufacturing/materials), changes in design (surface finish, max. stress)

Thank you