SCC crack initiation of alloy 82 in hydrogenated steam at 400 degrees c

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DE LA RECHERCHE À L'INDUSTRIE

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SCC CRACK INITIATION OF ALLOY 82 IN HYDROGENATED STEAM AT 400°C

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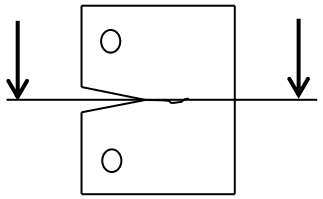
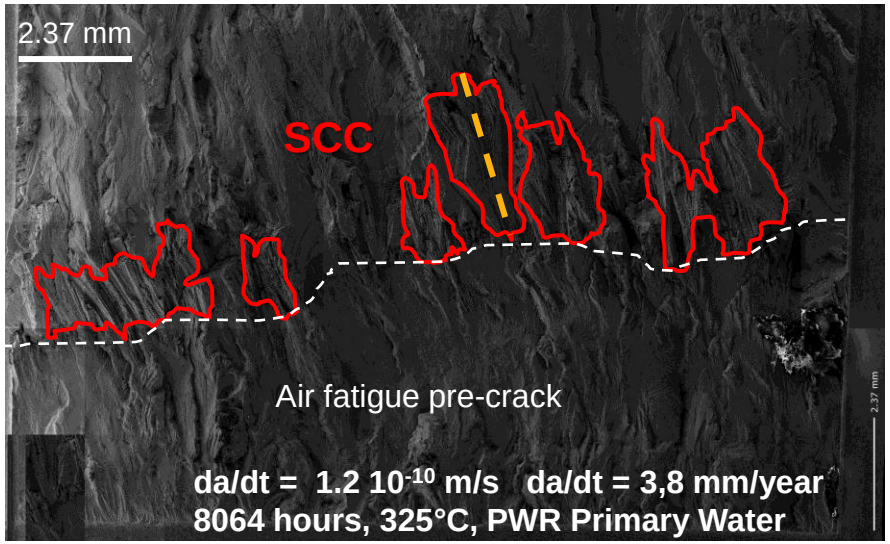
ICG-EAC meeting, 2015

CONTEXT

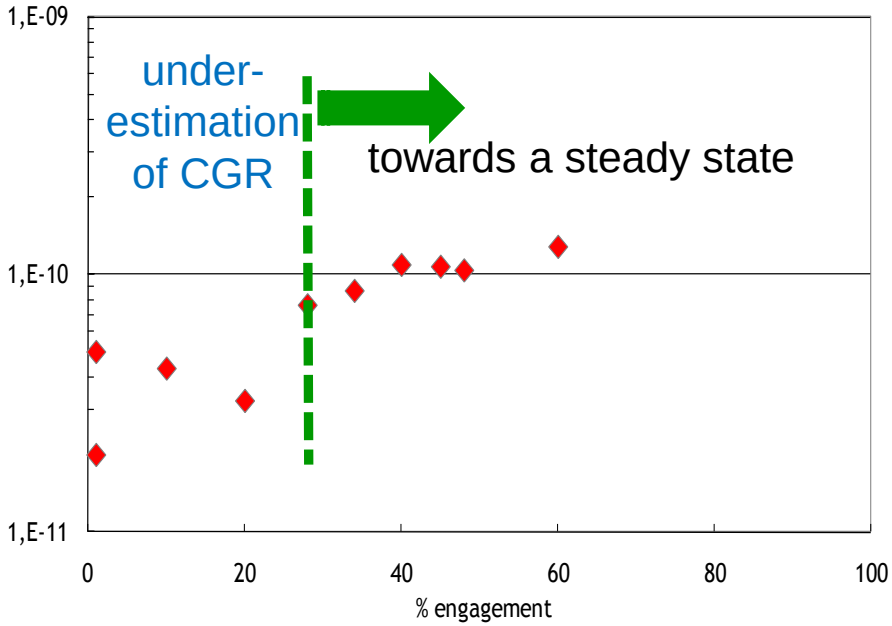
✓ SCC propagation tests [Guerre et al, 2011]



Alloy 82 CT specimen



Maximum crack growth rate (m/s)



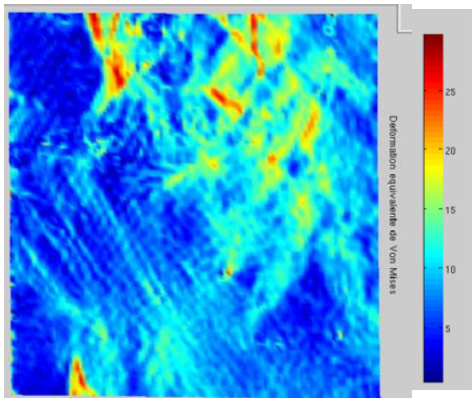
- Uneven crack front with pockets of IG cracks : % of engagement of the crack front is below 100%.
- Along susceptible grain boundaries, the crack growth rate can be very high (few mm/year).

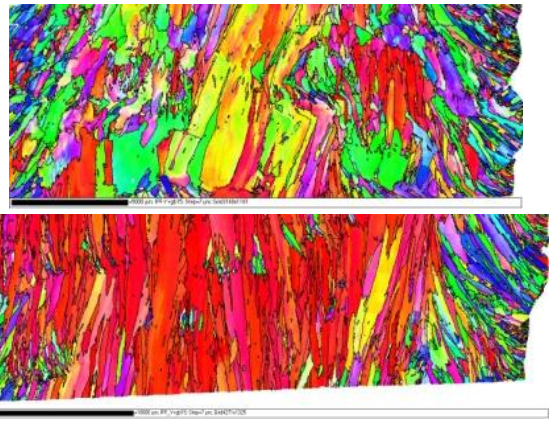
→ SCC behavior of welds is strongly related to their microstructure.

→ Life time depends on the initiation time.

C. Guerre and al., 15th Int. Conf. on Env. Deg. of Materials in Nuclear Power Systems-Water Reactors, 2011

APPROACH AND AIM

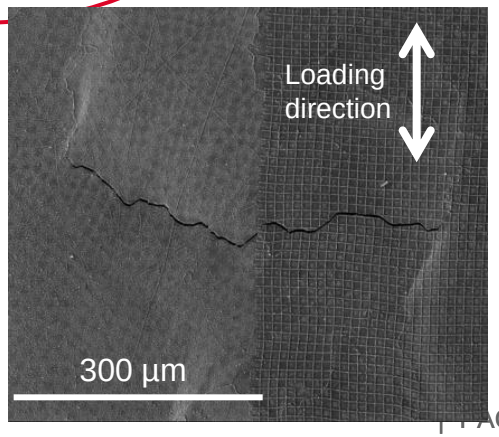




Microstructure characterization : EBSD analyses and TEM

Local mechanical characterization : Strain field (DIC)

SCC Initiation tests

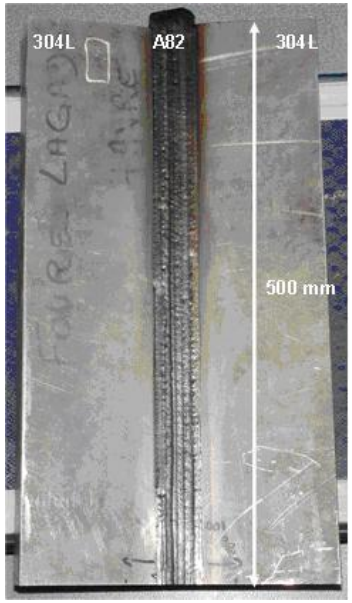


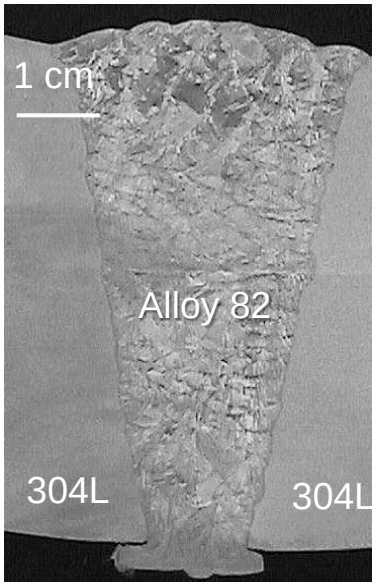
→ **To identify which microstructural features associated with mechanical fields enable SCC initiation.**

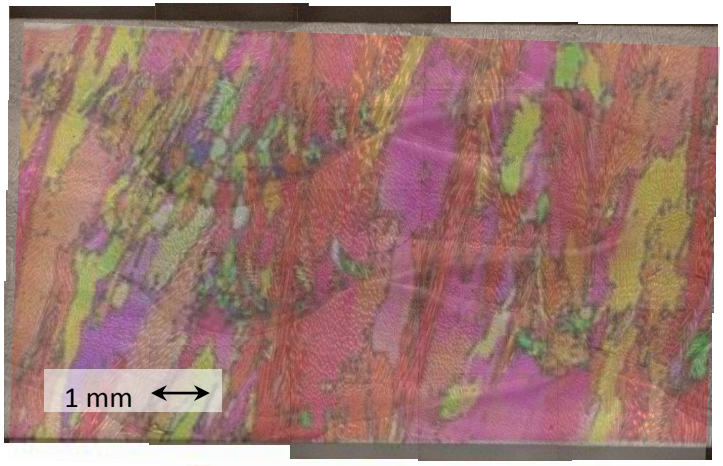
MATERIAL

✓ Welds : Alloy 82 (no restraint)

- ❑ millimetric columnar grains made of several slightly misoriented dendrites







L

S

T

Dendrite growth direction

✓ Chemical composition of Alloy 82 (weight%)

	C	S	Si	Mn	Ni	Fe	Cu	Cr	Nb	Ti	P	Co	Mo	O
RCC-M requirements	<0.1	<0.015	<0.5	2.5/3.5	>67	<3	<0.5	18-22	2/3	<0.75	<0.03	<0.1	-	-
Alloy A	0.025	<0.001	0.07	2.57	71.7	3.07	<0.01	19.12	2.41	0.1	0.004	0.04	0.02	0.0016
Alloy B	0.014	0.017	0.17	2.88	72.9	2.3	<0.01	18.15	2.83	<0.01	0.002	0.01	0.05	0.067

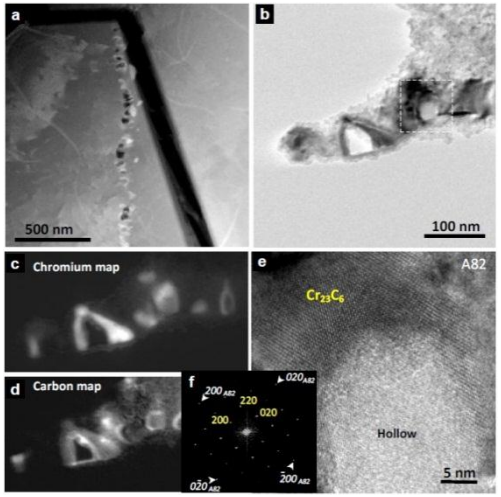
MATERIAL

Butt weld reference	Chromium content	Carbon content	Metallurgical state	Welding process
Alloy A (AW)	19%	0.025%	As-Welded	Gas Tungsten Arc Welding (GTAW)
Alloy A (HT)	19%	0.025%	Heat-Treated[1] (7 hr @ 600°C)	Gas Tungsten Arc Welding (GTAW)
Alloy B (AW)	18%	0.014%	As-Welded	Flux Cored Arc Welding (FCAW)

[1] similar to the in-service stress relief treatment

- Effect of the heat treatment on the precipitation:
  - Alloy A : intergranular chromium carbides precipitation ($Cr_{23}C_6$)
  - Alloy B : no IG chromium carbides

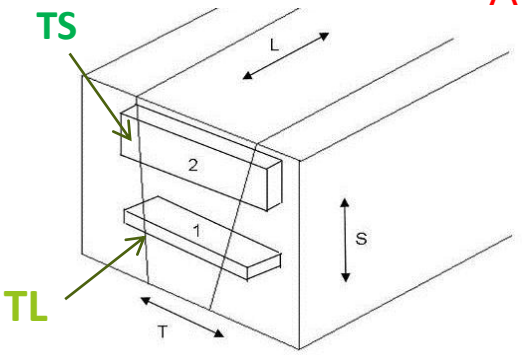
A82 19% Cr
Heat treated



M. Sennour, E. Chaumun, J. Crépin, C. Duhamel, F. Gaslain, C. Guerre, I. de Curières, TEM investigation on the effect of chromium content and of stress relief treatment on precipitation in Alloy 82, Journal of Nuclear Materials, Volume 442, Issues 1–3, November 2013, Pages 262–269

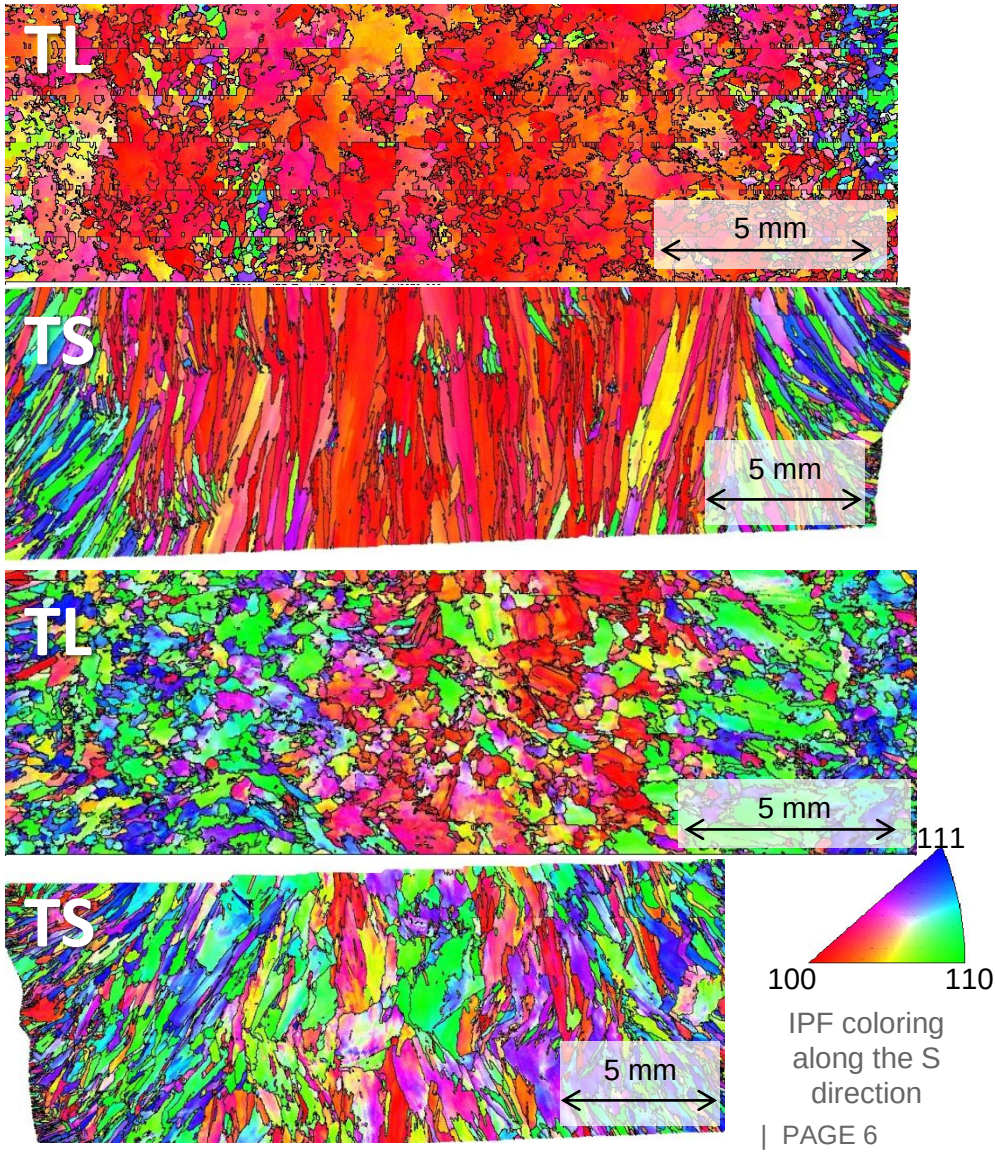
MICROSTRUCTURE

✓ EBSD analyses



Alloy B
AW FCAW

Alloy A
AW GTAW



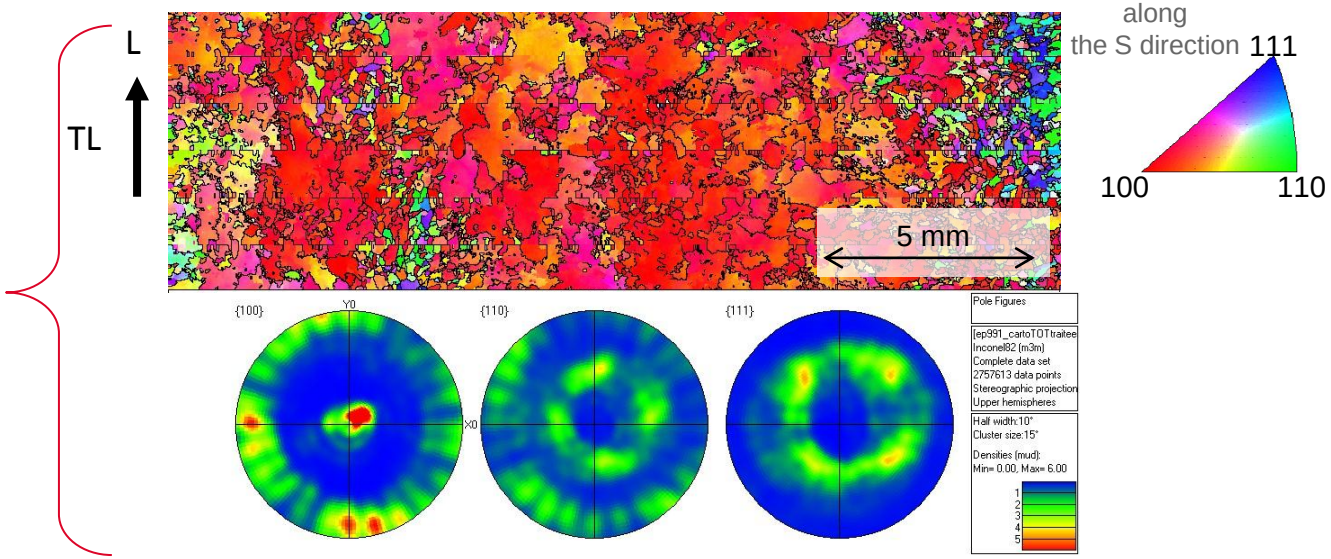
- ✓ Large grain size (mm) : macroscopic microstructure
- ✓ Heterogeneous grain size
- ✓ Nearly equiaxed shape (TL)
- ✓ Cristallographic texture isn't the same for the two alloys and depends on the welding process.

MICROSTRUCTURE

✓ EBSD analyses : crystallographic orientation

Alloy B

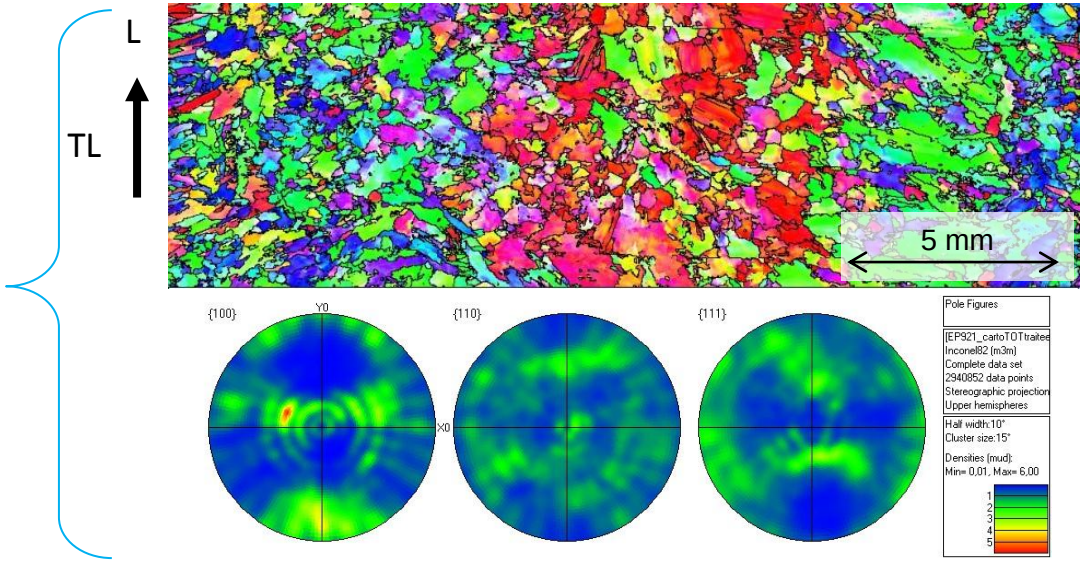
Cubic and transversal isotropic texture with [001] // dendrite growth direction



IPF coloring along the S direction

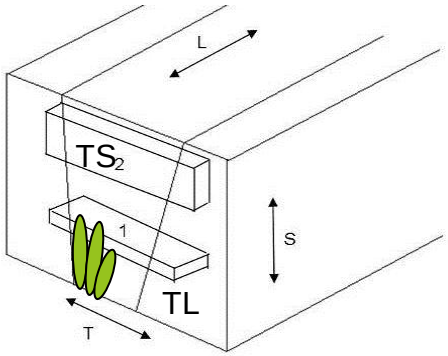
Alloy A

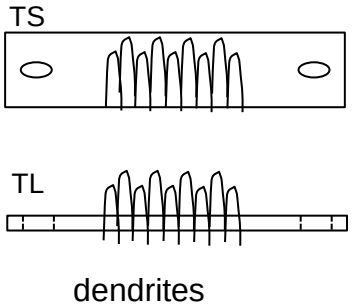
No crystallographic texture



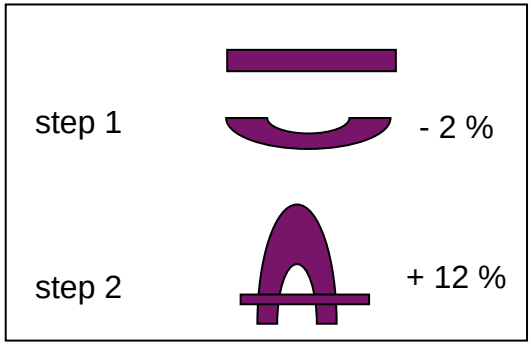
INITIATION TEST

→ U-bends specimen in hydrogenated steam





- Direct loading path or complex loading path:
0 % → +12%
0% → -2% → +12%

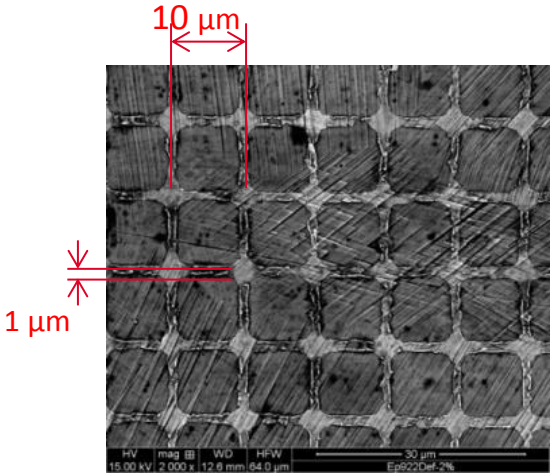


- Hydrogenated steam :

Temperature	400 °C
Total pressure	188 bar
Hydrogen partial pressure	0.7 bar

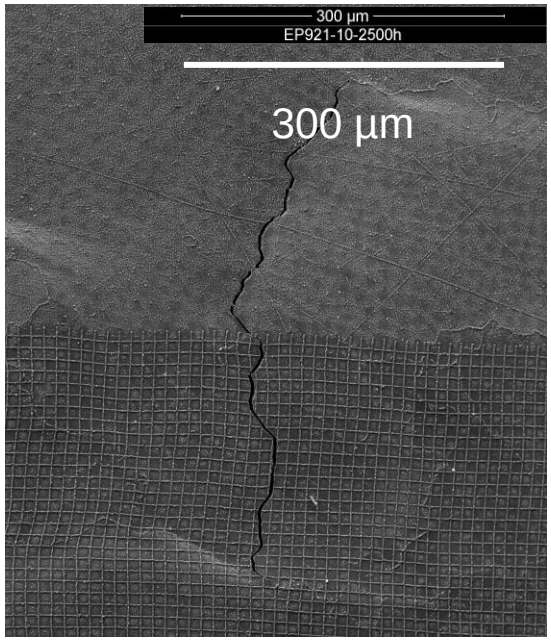
- Test time :
500 hr, 1500 hr, 2500 hr and 3500 hr.

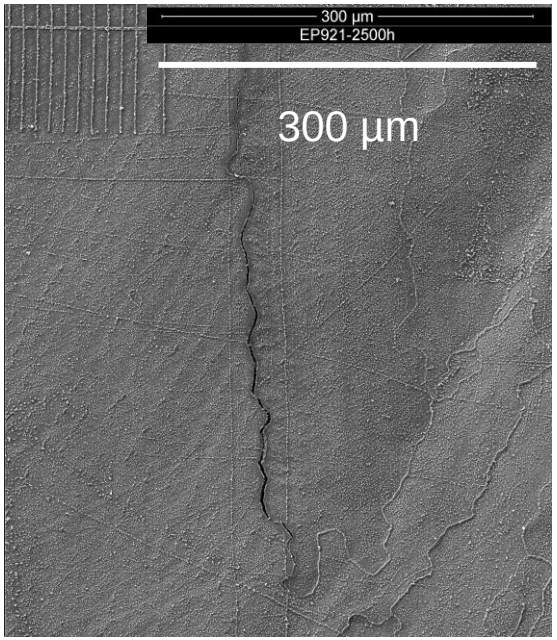
- Strain fields are measured using gold grids and Digital Image Correlation.



INITIATION TEST : RESULTS

- ✓ SCC susceptibility.
  - ✓ No crack after 500 hr in hydrogenated steam at 400°C.
  - ✓ First cracks are observed after 1500 hr for the as-welded alloy and after 2500 hr for the heat-treated alloy (only one shallow crack).
  - ✓ Cracks are intergranular.
  - ✓ Cracks are observed inside and outside gold grids (used for DIC and strain field measurements) : the cracks are not induced by the grids.
  - ✓ Most of the cracks are perpendicular to the loading direction.





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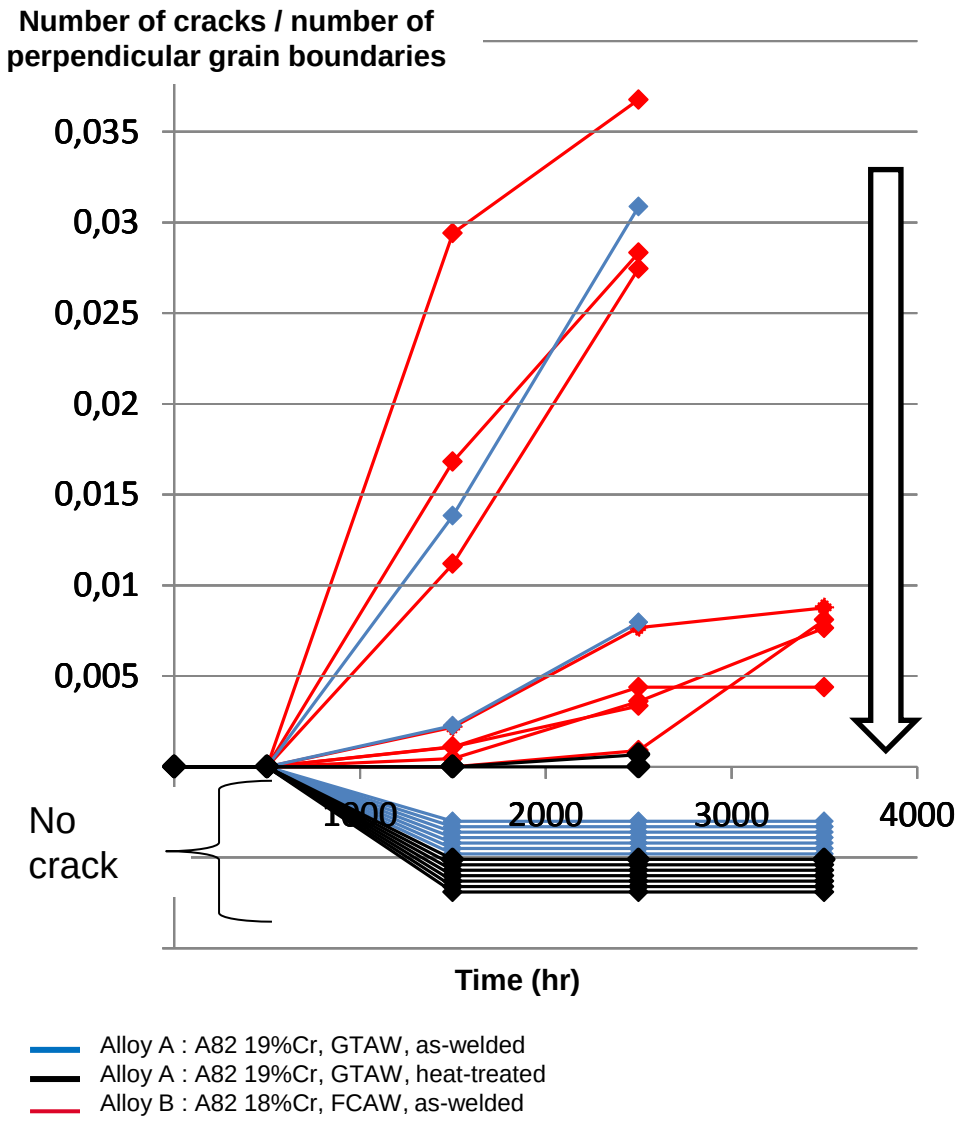
A82, 19%Cr
As-welded

INITIATION TEST : RESULTS



The number of cracks increases with time.

Alloy A (AW) is less susceptible than Alloy B (AW).

Alloy A (HT) is less susceptible than Alloy A (AW).

Number of cracked specimen.

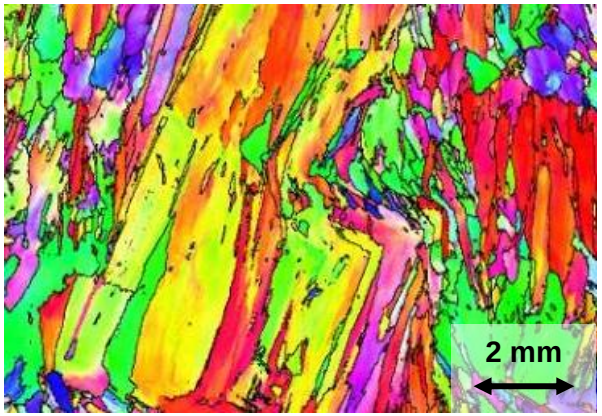
8 specimen were removed.

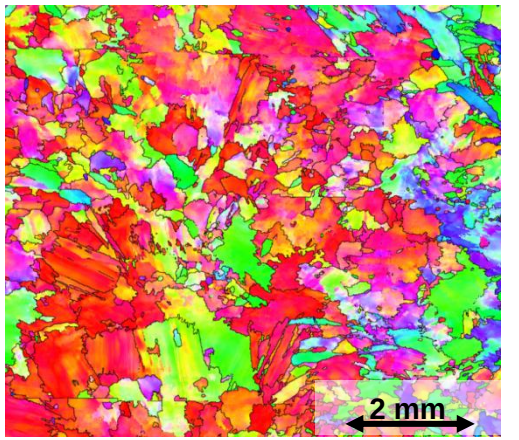
Time (hr)	500	1500	2500	3500
Alloy A AW	0/7	**2/7**	**2/7**	0/5
Alloy A AW	0/2	0/2	0/2	0/2
Alloy A HT	0/7	0/7	**1/7**	0/5
Alloy A HT	0/2	0/2	0/2	0/2
Alloy B AW	0/6	**5/6**	**6/6**	**2/2**
Alloy B AW	0/2	**2/2**	**2/2**	**2/2**

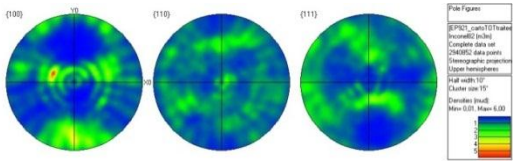
[Sennour2013] M. Sennour, E. Chaumun, J. Crépin, C. Duhamel, F. Gaslain, C. Guerre, I. de Curières, JNM, 2013

INFLUENCE OF THE MICROSTRUCTURE

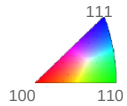
Alloy A : A82, 19%Cr GTAW, as-welded



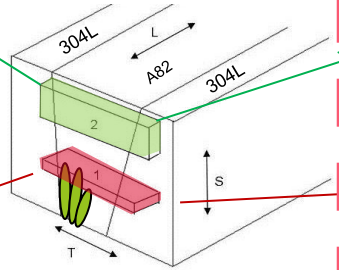


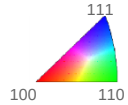


Direction de sollicitation

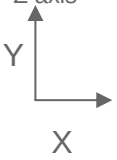


IPF colouring along the Y axis

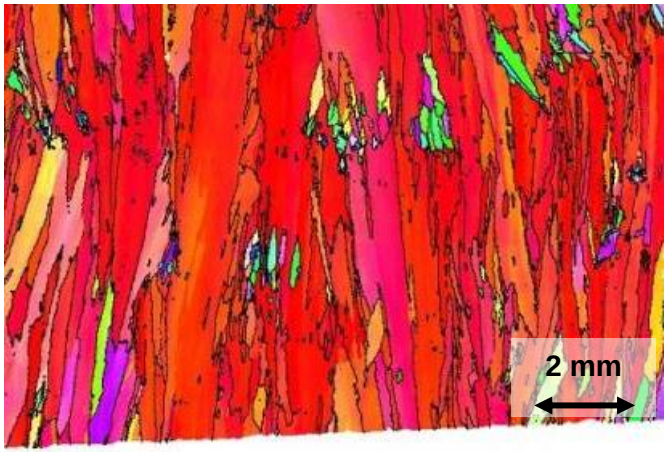


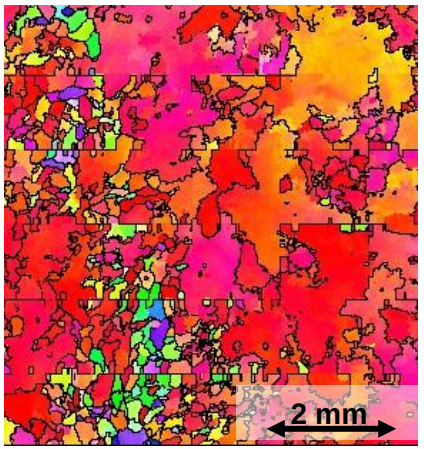


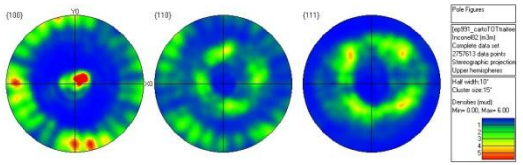
IPF colouring along the Z axis



Alloy B: A82, 18%Cr FCAW, as-welded

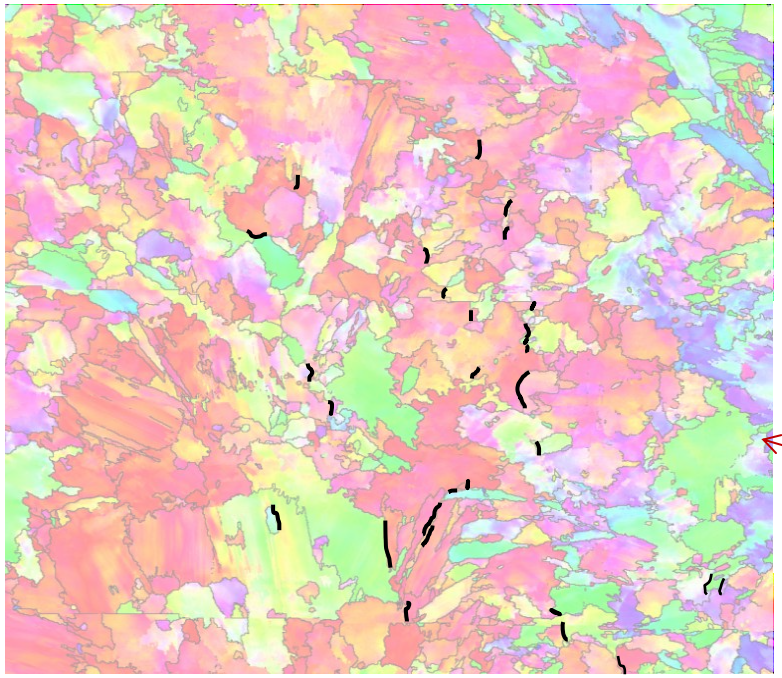




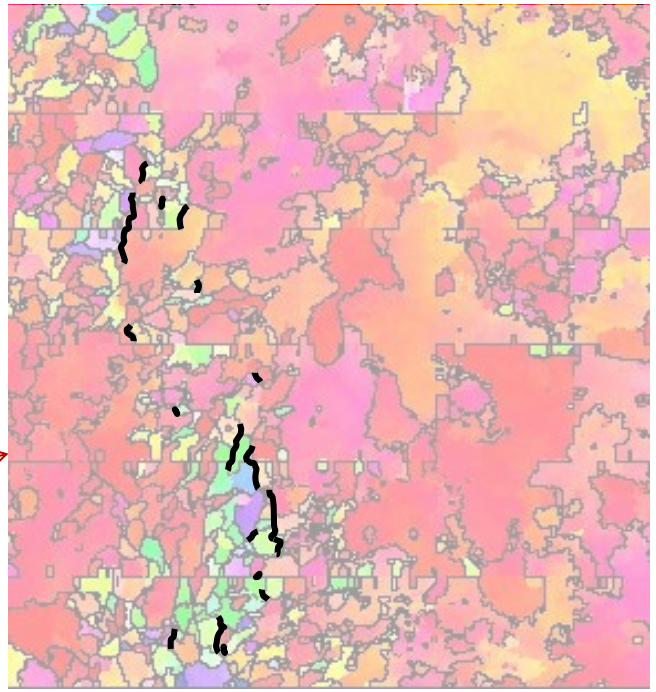


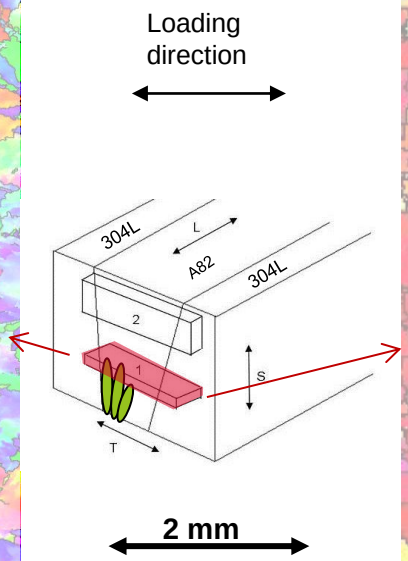
INFLUENCE OF THE MICROSTRUCTURE

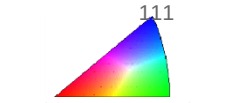
Alloy A : A82, 19%Cr GTAW, as-welded



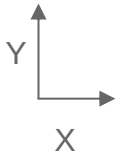
Alloy B: A82, 18%Cr FCAW, as-welded







IPF suivant l'axe Z



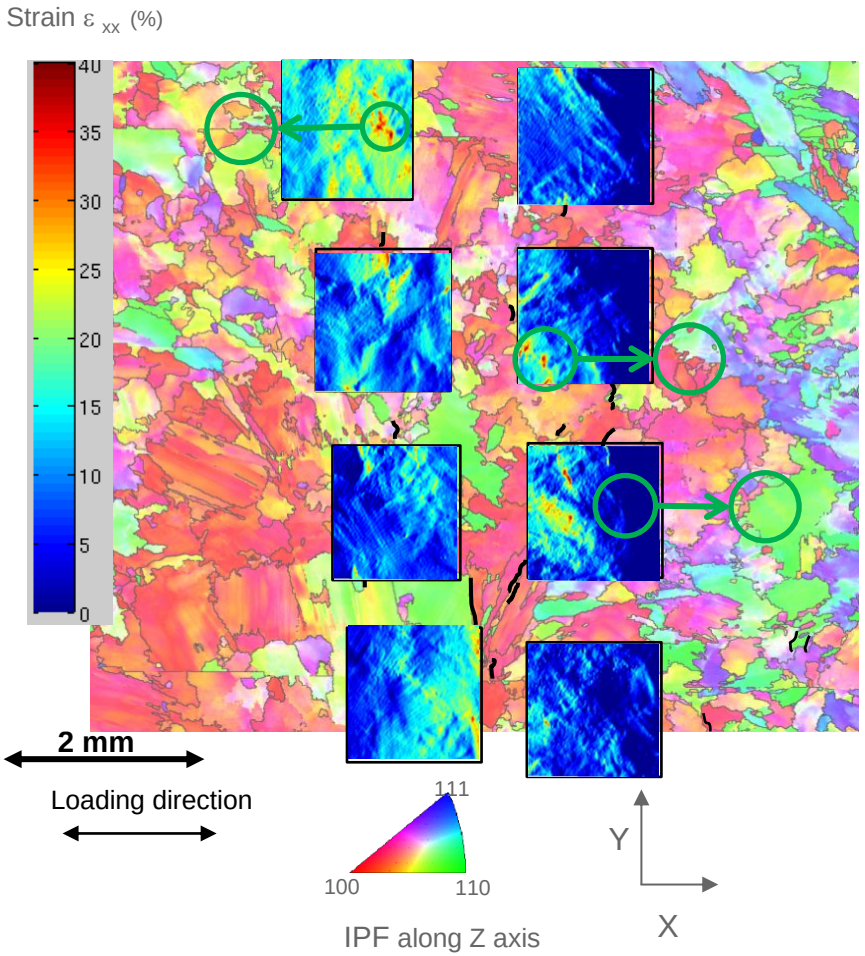
→ Cracks on **random grain boundaries**.

→ **No preferred grain orientation** next to cracked GB**.**

→ Most of the cracked GB are located **in zones containing small grains** (roots of the weld passes) : no segregation has been observed (SIMS, electron probe microanalyser).

INFLUENCE OF STRAIN LOCALIZATION

Alloy A : A82, 19%Cr GTAW, as-welded



Average Von Mises strain for each grid

	16 %	**5,2 %**	
	10,4 %	**4,6 %**	
	8 %	**5,4 %**	
	11 %	**4,8 %**	

→ Heteregenous strain flields are measured by digital image correlation.

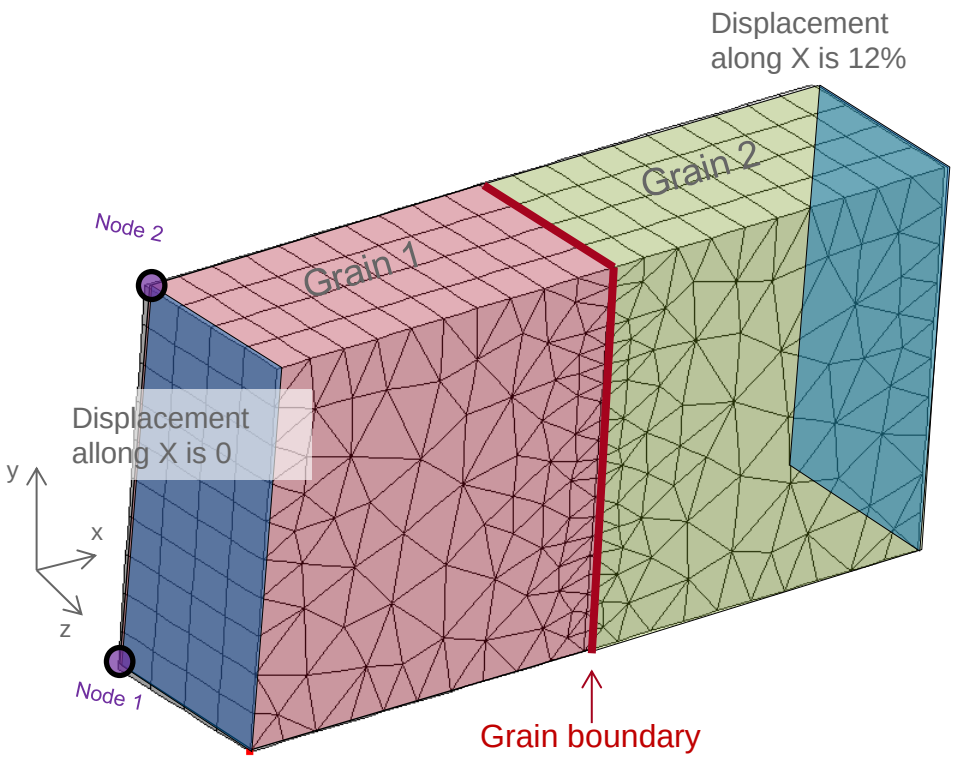
→ No direct correlation between strain localization and crack initiation[1].

→ **Finite element simulations** have been carried out in order to determine normal **stress fields** along cracked and uncracked grain boundaries.

[1] Initiation of SCC crack in nickel based weld metals : influence of microstructural features, E. Chaumun et al., Proceedings of the 16th International Conference on Environmental Degradation of Materials in Nuclear Power Systems - Water Reactors, 2013

INFLUENCE OF STRESS

→ **Simulation of stress fields by finite elements** are performed on **bicrystals simulating one GB** in the case of 16 cracked grain boundaries and 13 uncracked grain boundaries.



→ Crystallographic orientations are extracted from the EBSD characterizations.

→ Crystallographic law (octaedric elasto-viscoplastic law)[1]

$$\dot{\gamma} = \left\langle \frac{(\overline{\sigma - X}) - R}{K} \right\rangle^{n}$$

$\dot{\gamma}$: shear rate
σ : critical resolved shear stress
X : kinematic hardening
R : isotropic hardening
K and n : Norton law's parameters

→ Boundary conditions :
a displacement along X is applied

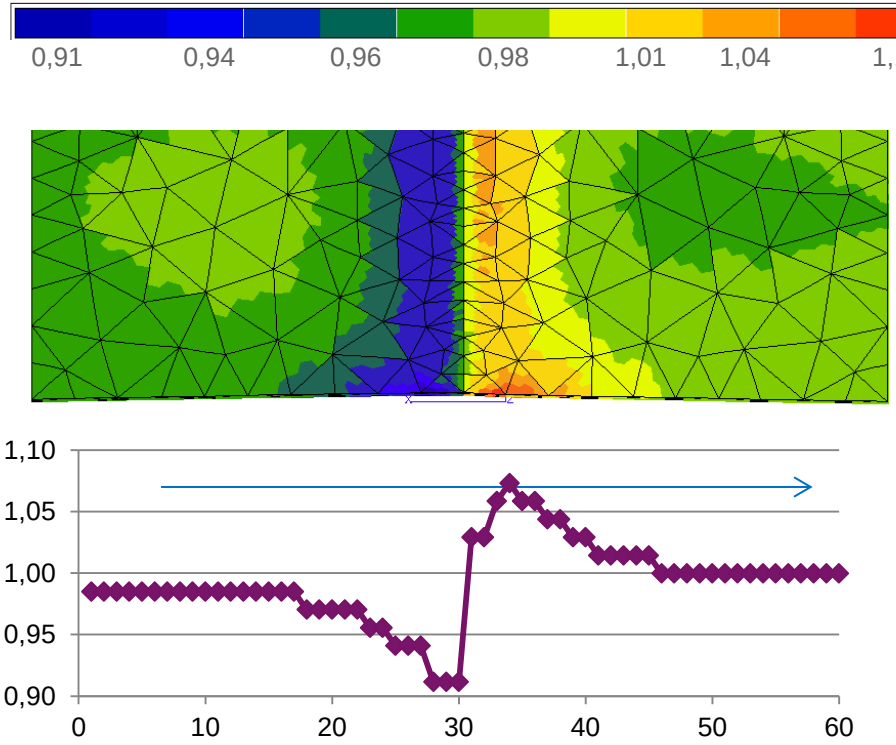
→ First step : a macroscopic deformation of 12 % is applied on true crystallographic orientations.

[1] [Méric-Cailletaud]L. Méric, P. Poubanne, and G. Cailletaud, Journal of engineering materials and technology transactions of the ASME,1991

INFLUENCE OF STRESS

→ Results : maximum normal stress

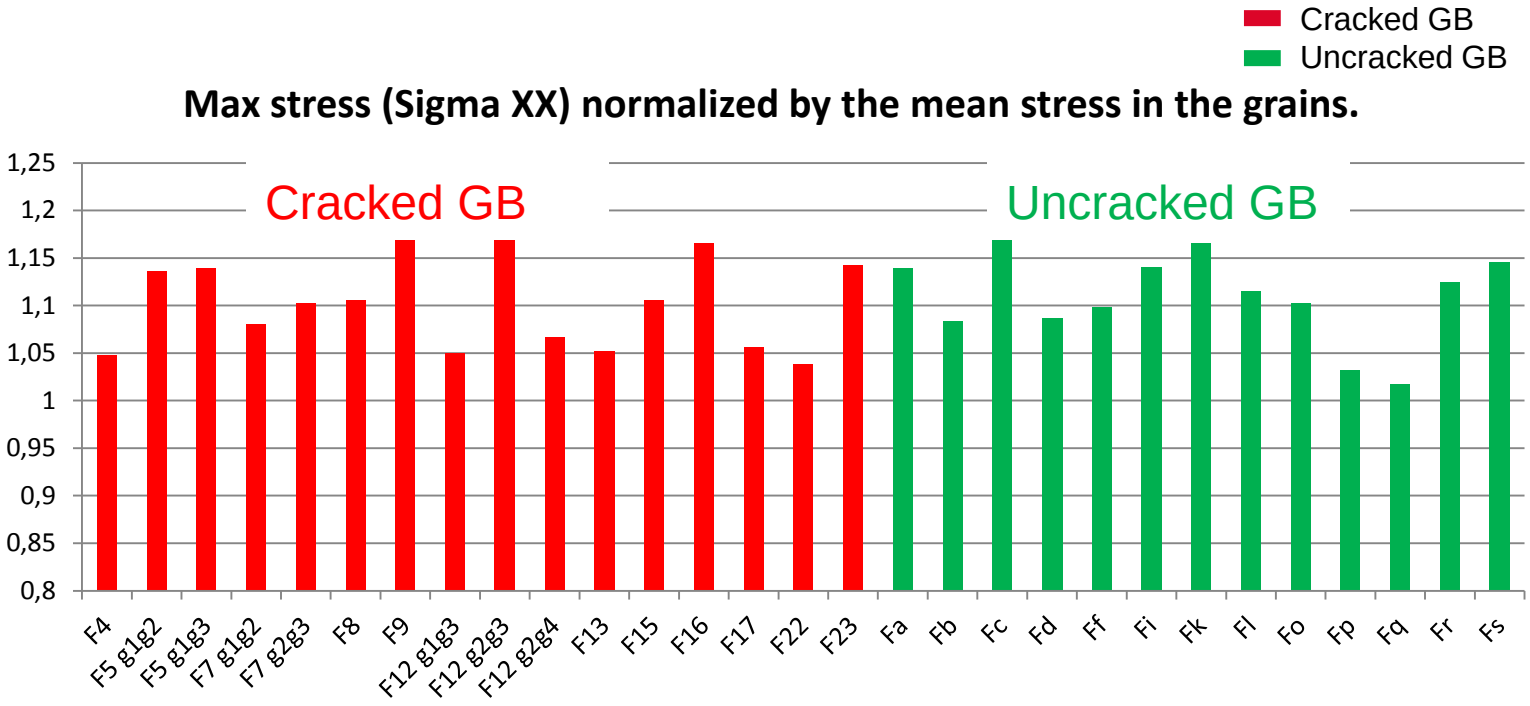
Max stress (Sigma XX) normalized by the mean stress in the grains.



→ Stress localisation close to the grain boundary in all cases (cracked and uncracked GB).

INFLUENCE OF STRESS

→ Comparison between cracked and uncracked grain boundaries.



→ The stress is not systematically higher for cracked grain boundaries.

→ The **strain field** (measured by DIC) should also be used **as a boundary condition** : both experimental crystallographic orientation and strain fields -> is the maximum normal stress a criteria to predict cracked GB ?

CONCLUSIONS AND PERSPECTIVES

- SCC initiation test:
  - **Alloy 82** is **susceptible to SCC** initiation in hydrogenated steam at 400°C : first cracks are observed **after 1500 hr**.
  - The **thermal treatment** (similar to the in-service stress relief treatment) can decrease the susceptibility to SCC. In this study, it is probably due to the **formation of intergranular chromium carbides**.
  - As – welded Alloy B is more susceptible to SCC than as-welded Alloy A : not the same chemical composition and not the same crystallographic texture (welding process is different). No IG chromium carbides for both alloys.

- Correlations between microstructure / strain fields and SCC :
  - **Crystallographic orientations and strain localization are not sufficient parameters to predict susceptible grain boundaries.**
  - Most of the cracks are located **in zones with the smallest grains** (roots of the weld passes) **-> chemical analysis are in progress**

- Future **FE simulations** will take into account **both the strain fields measured by digital image correlation and the crystallographic orientations** : critical normal stress to discriminate between cracked and uncracked GB ?

- *Which one of those parameters will be at the first order of magnitude ?*