

Couplages Mécanique-Microstructure-Oxydation

Eric Andrieu

INP Toulouse-CIRIMAT-UMR 5085

Seminaire UTC: 5/06/2019

Plan du séminaire

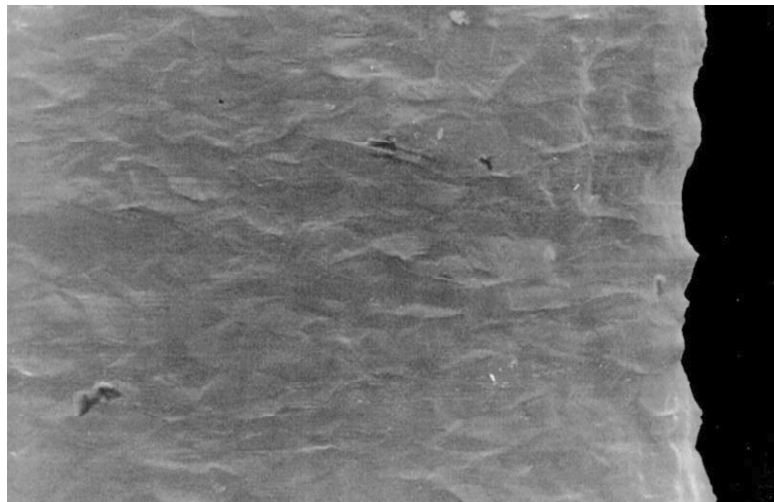
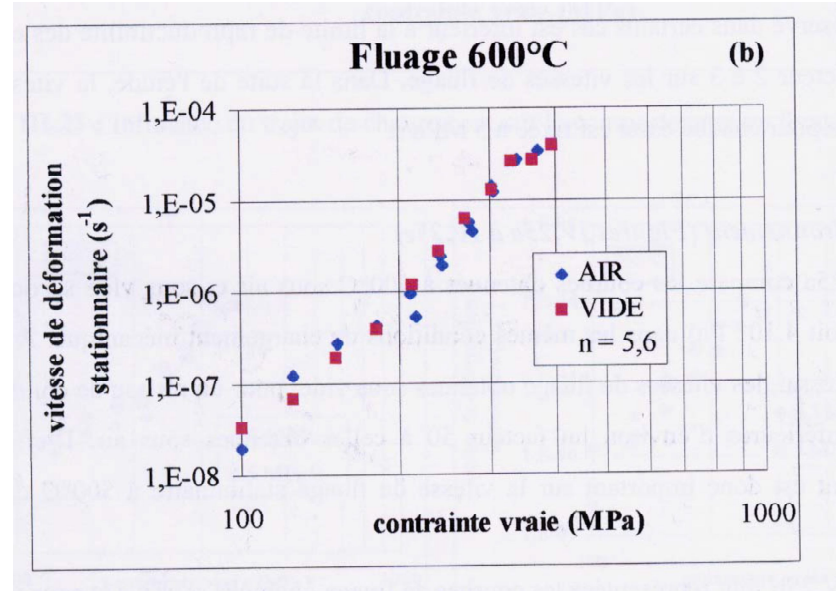
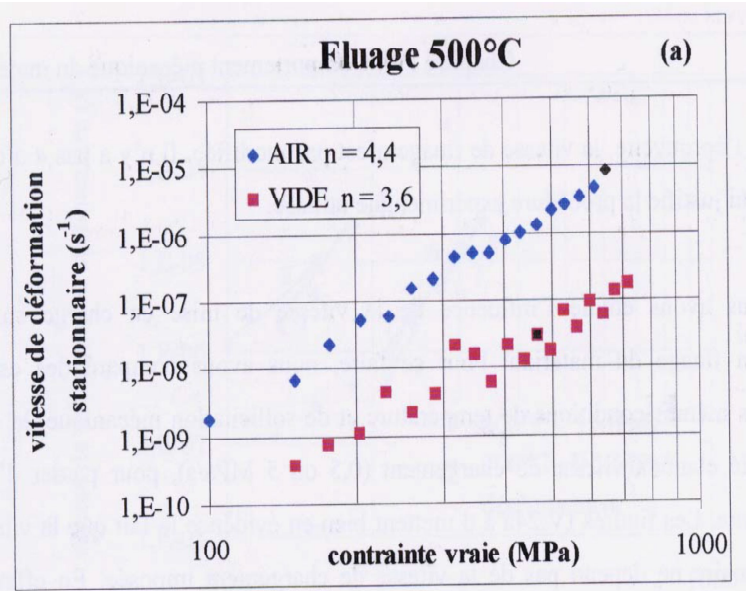
Quelques illustrations

- Air ou vide
- Cyclage environnemental et/ou mécanique.
- Effets de microstructure
- Conclusions

Essais sous air « laboratoire » ou sous vide (primaire? Secondaire?)

NiCr alloy (80/20)

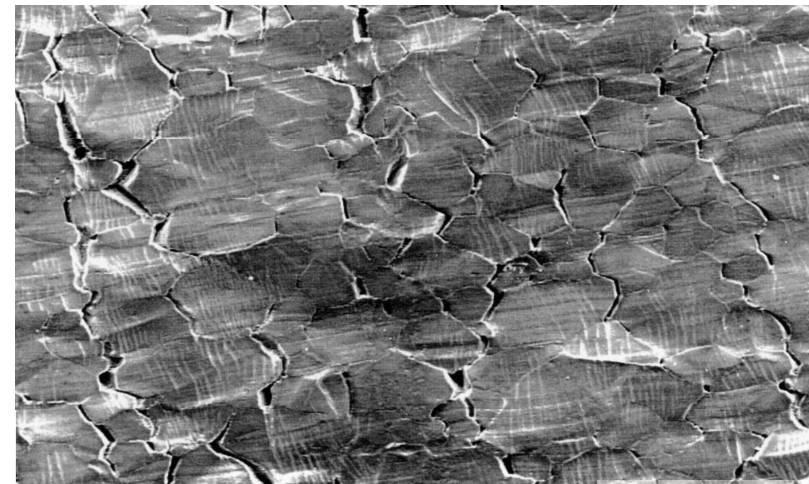
PhD G.Calvarin 1998 ENSMP



$t = t_{rupt}$

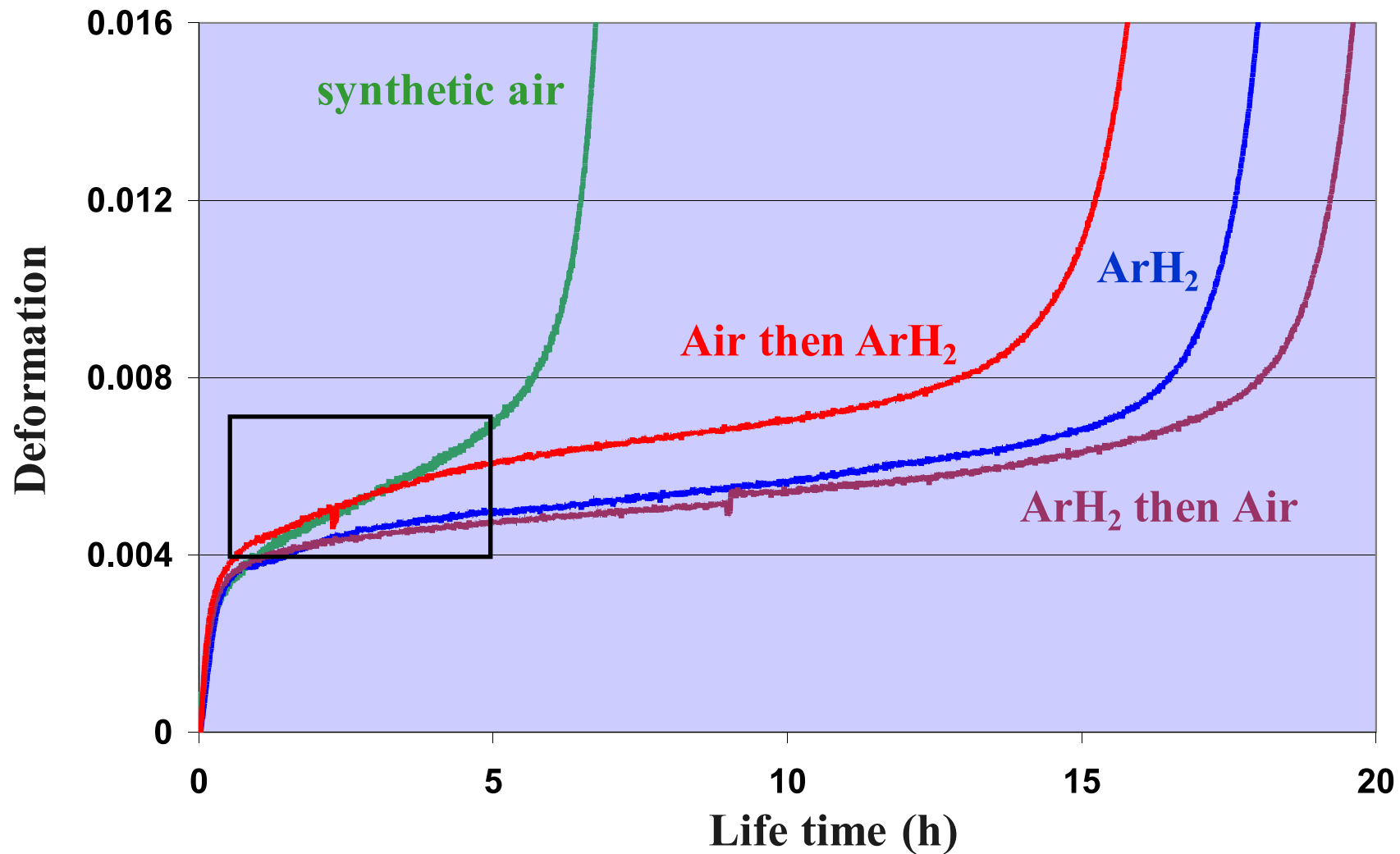
$T < 500^\circ \text{C}$

20 μm



$t = t_{rupt}$

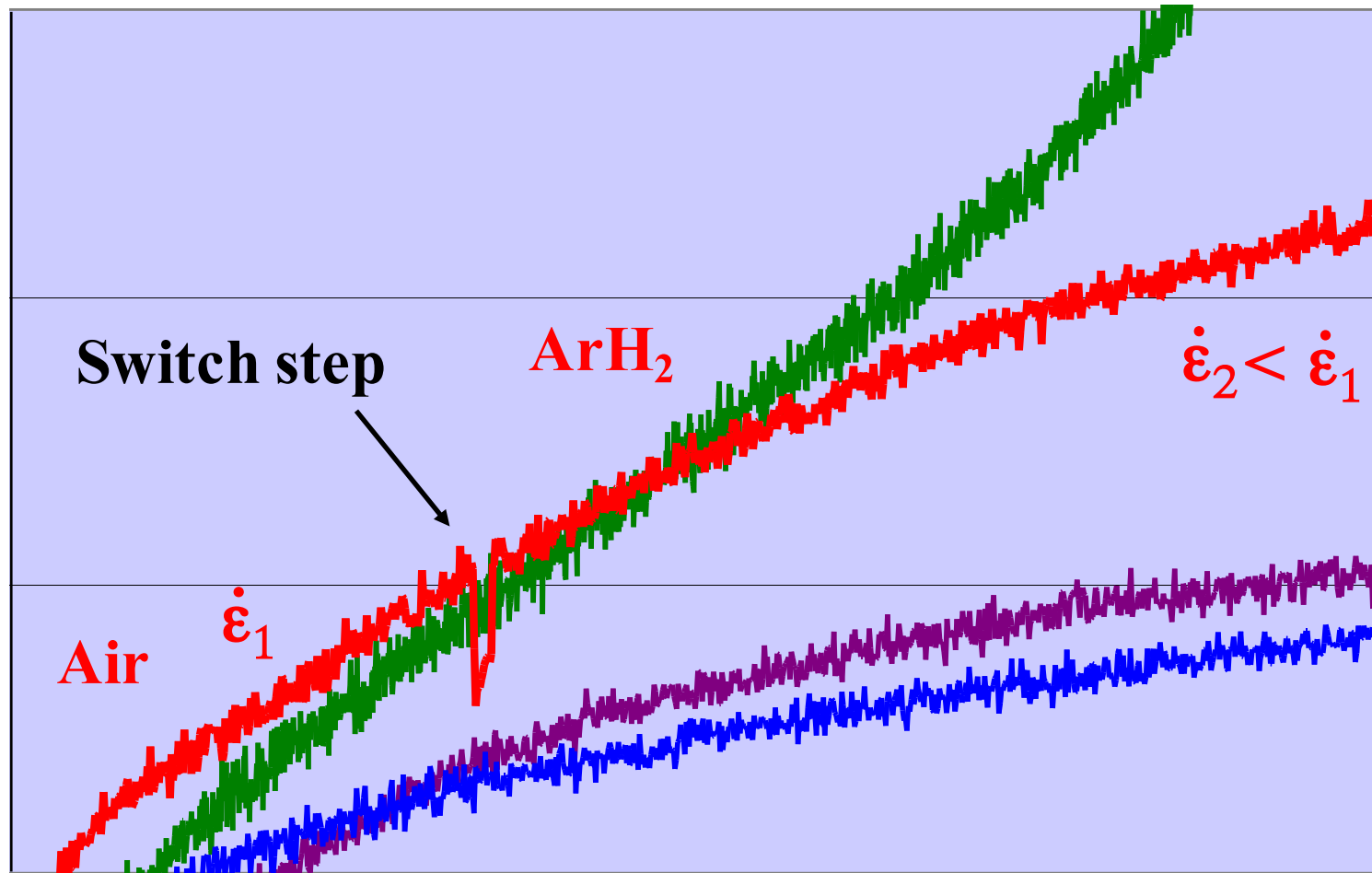
Effet de l'oxydation sur le comportement en fluage du MC2



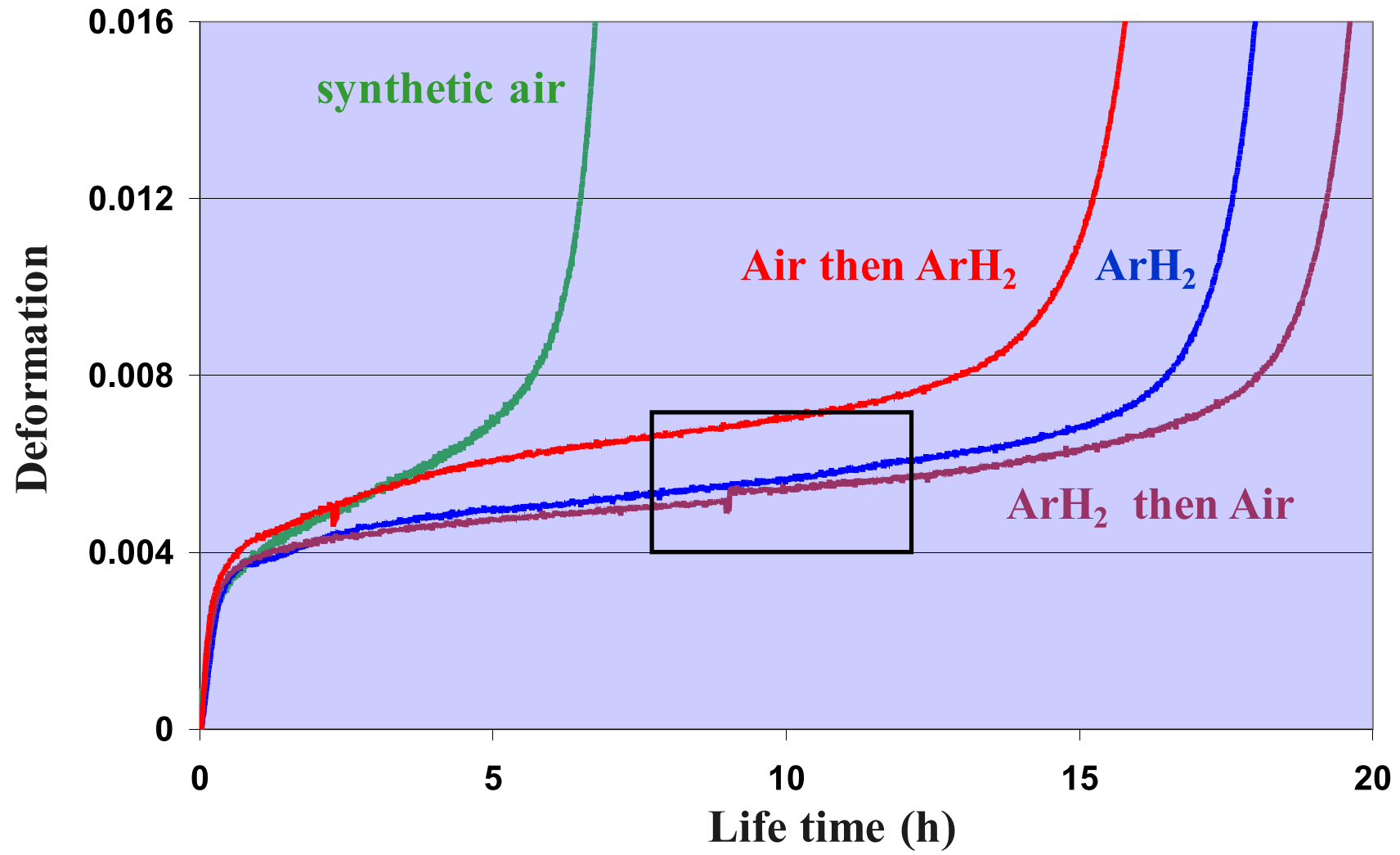
Creep of MC2 at 1150° C, 80 MPa on polished samples

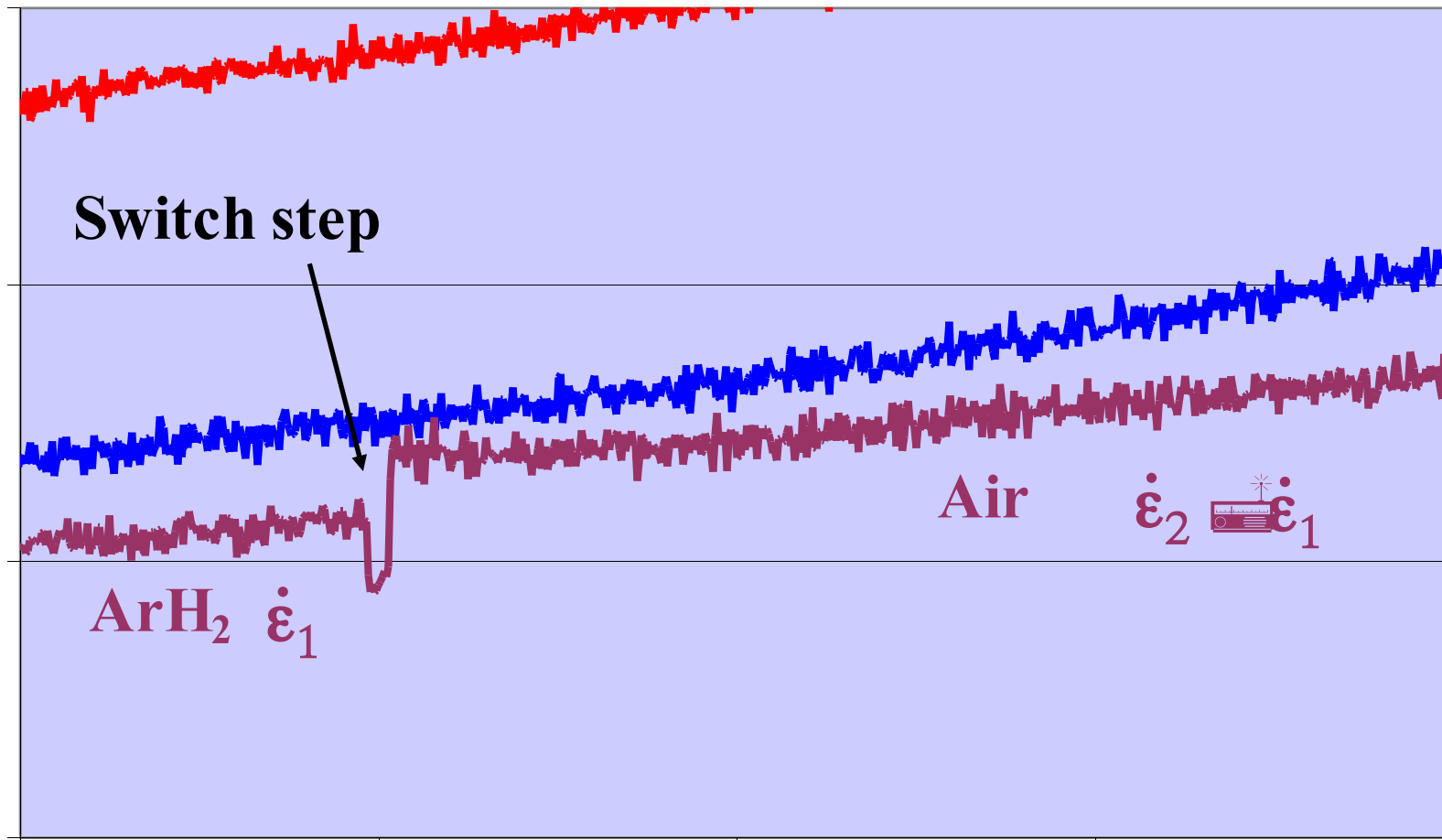
S.Dryepontd PhD Thesis

Effect of switching environment during the test



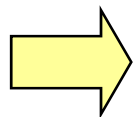
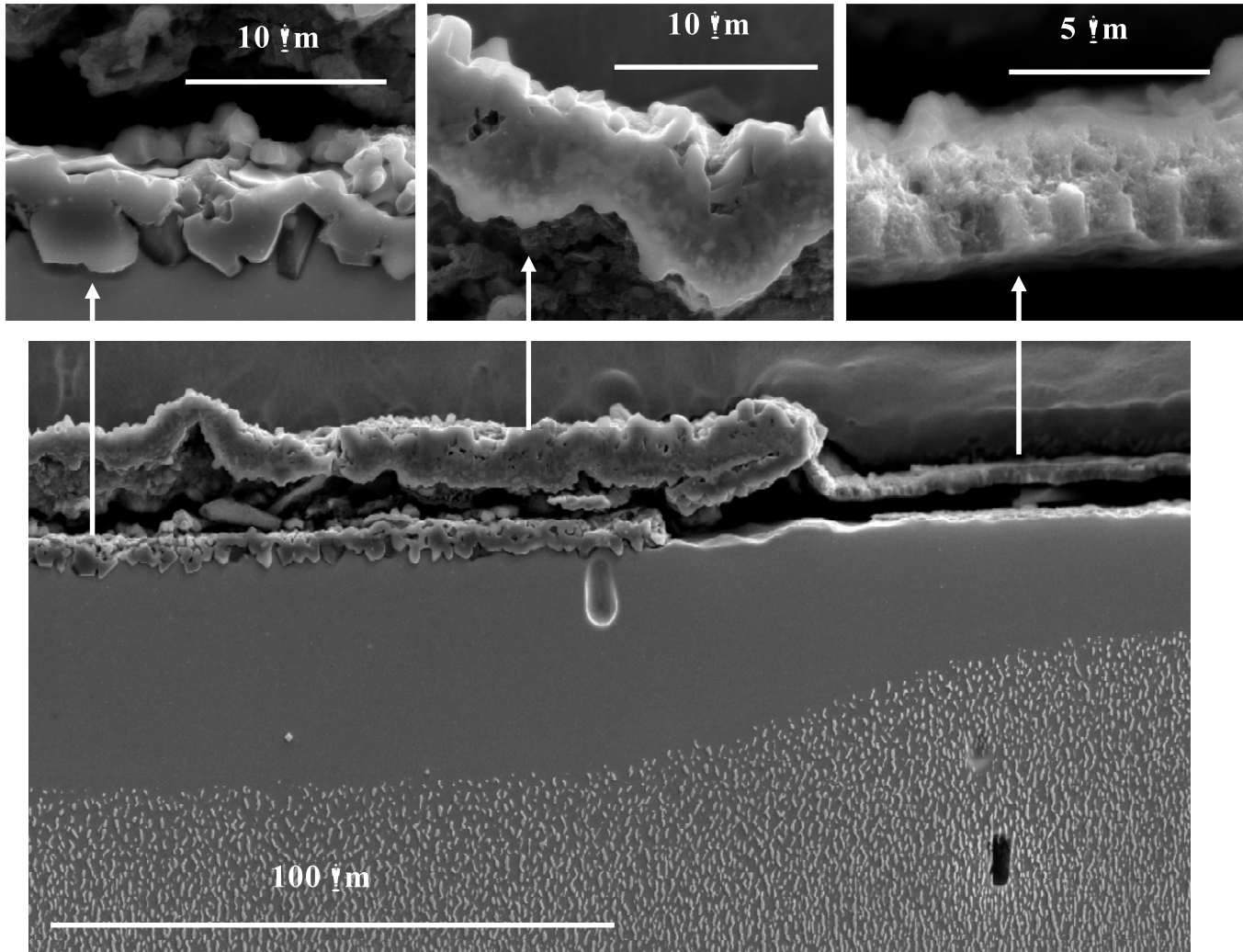
Creep strain rate variation after the switch step





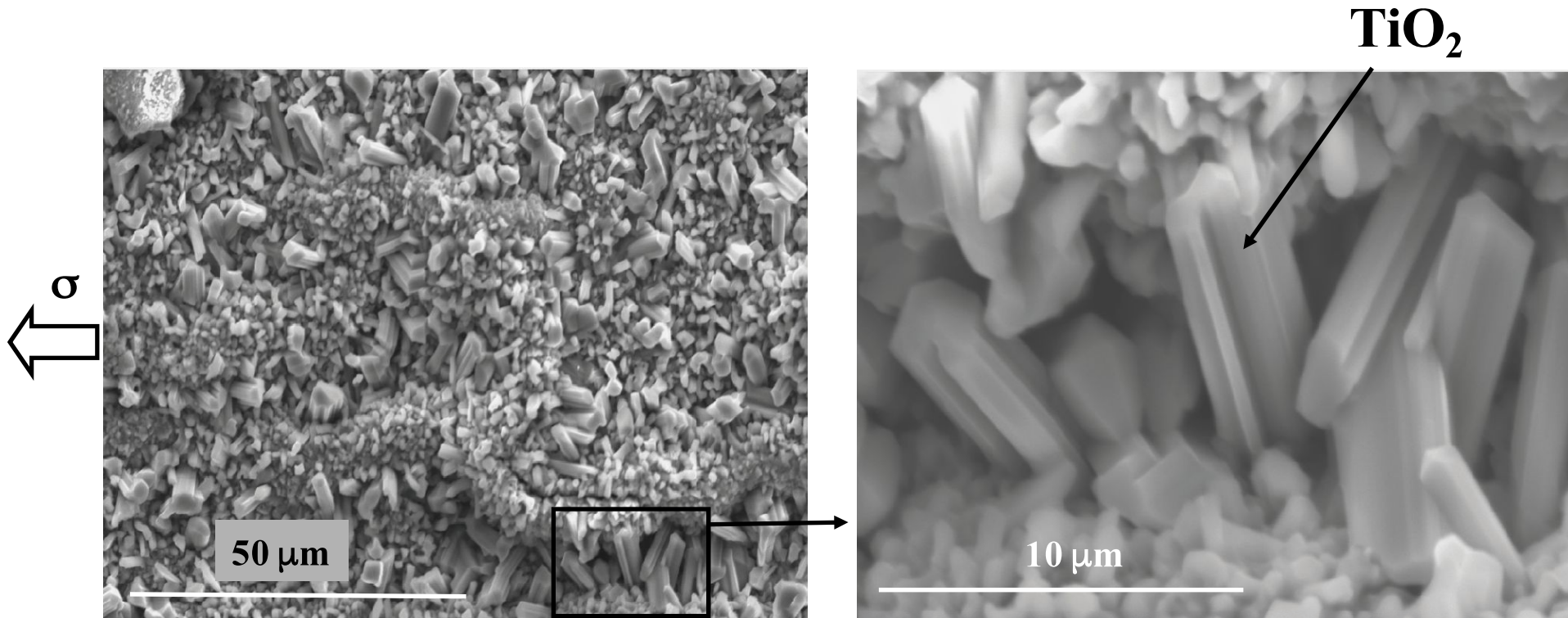
$\dot{\epsilon}$ remain unchanged after the switch step

Creep under synthetic air testing conditions



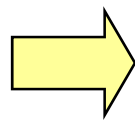
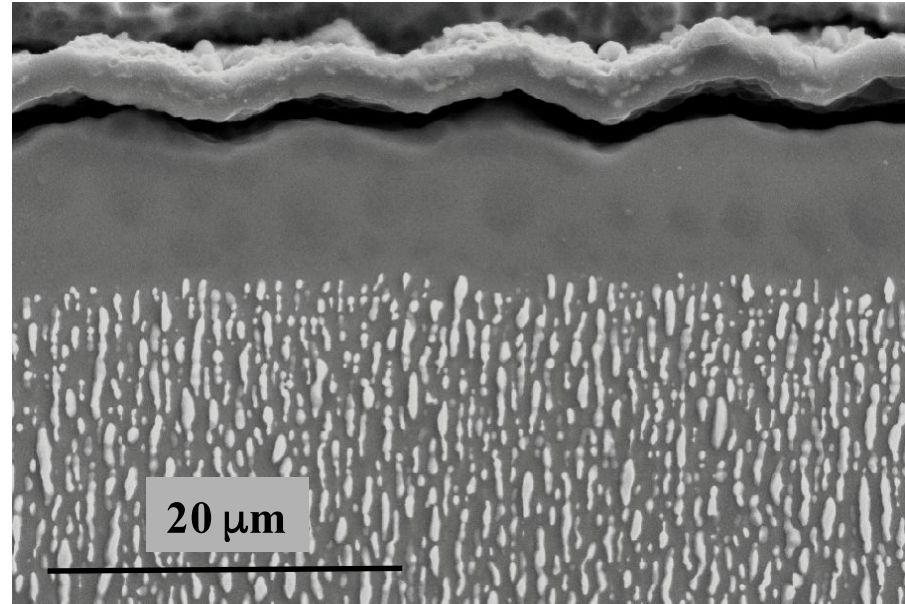
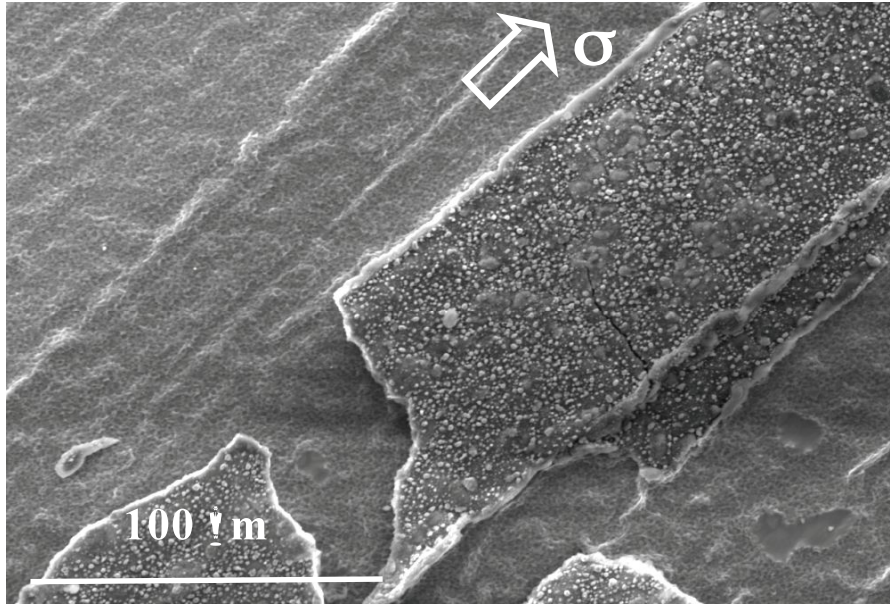
PFZ related to the local oxide scale thickness

Creep under synthetic air



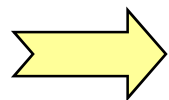
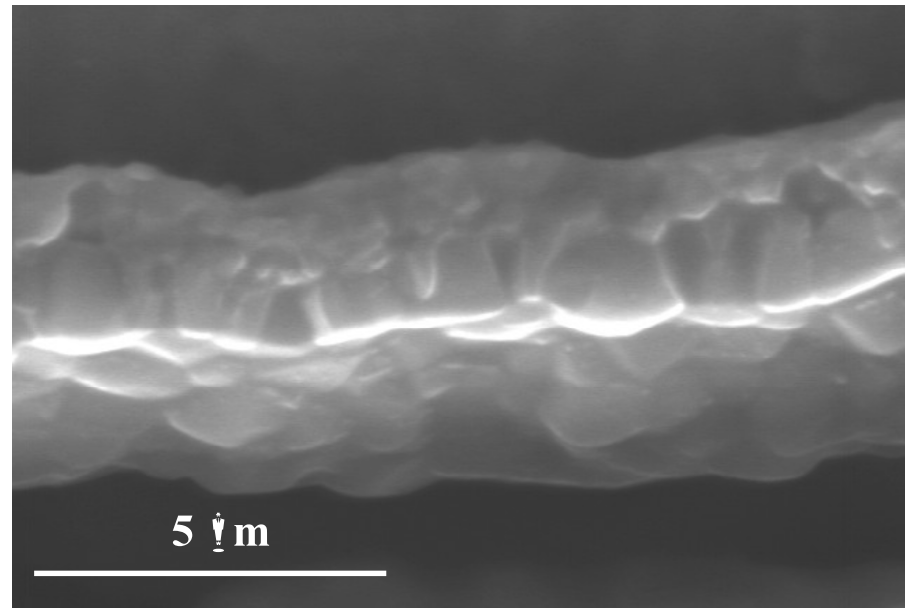
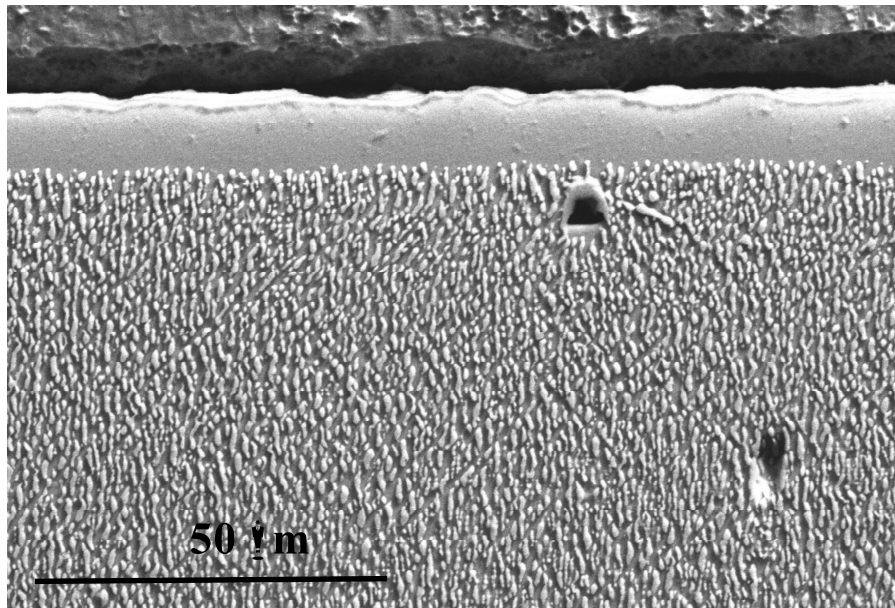
 **Alumina scale with other oxides**

Creep under ArH₂



Alumina scale only

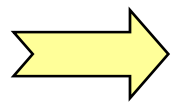
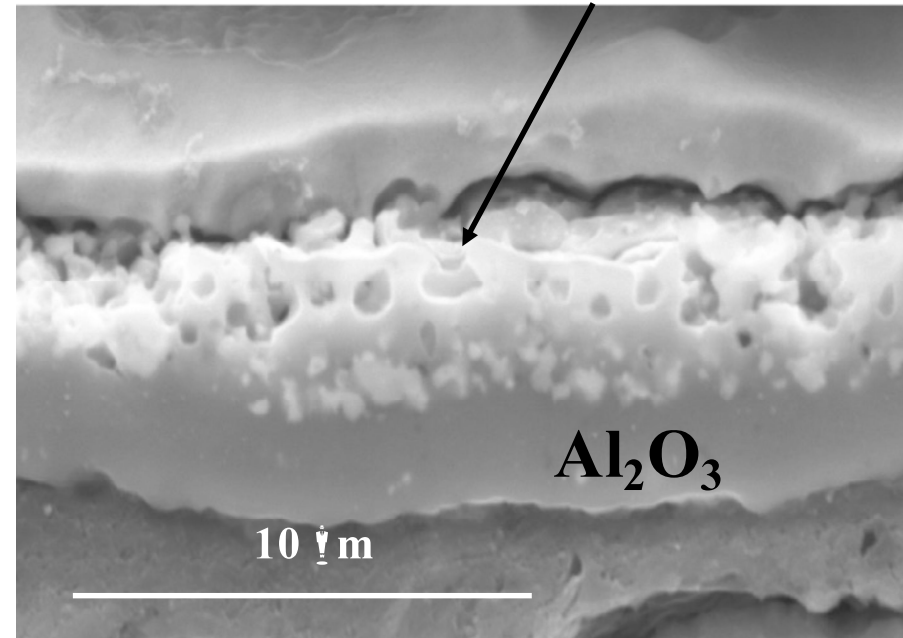
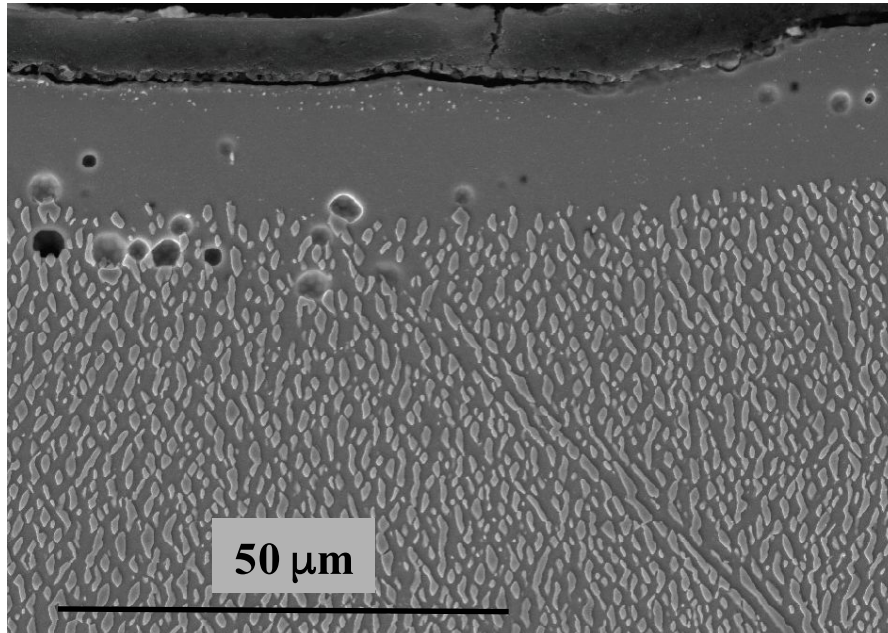
Creep under ArH₂ then under air testing conditions



No difference with creep under ArH₂

Creep under air then under ArH₂ testing conditions

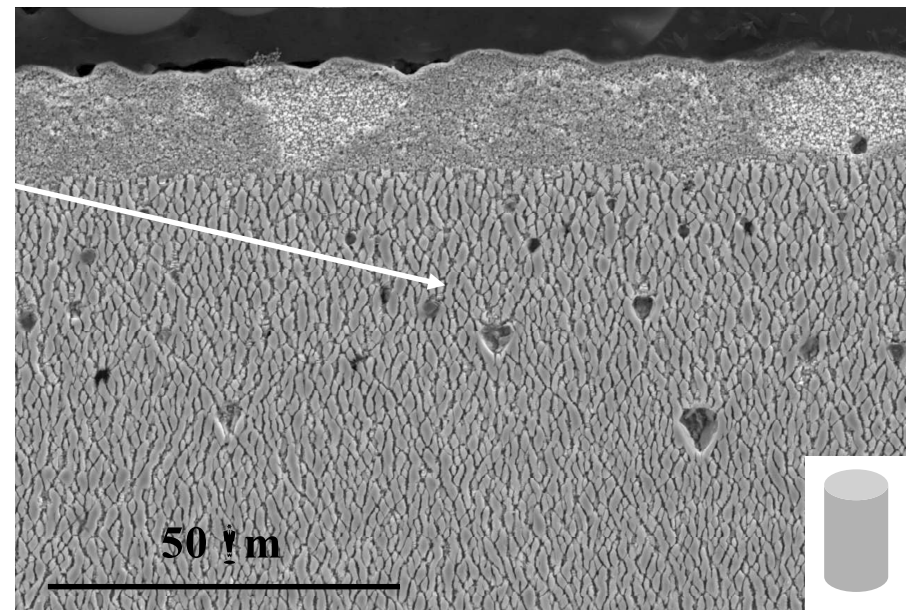
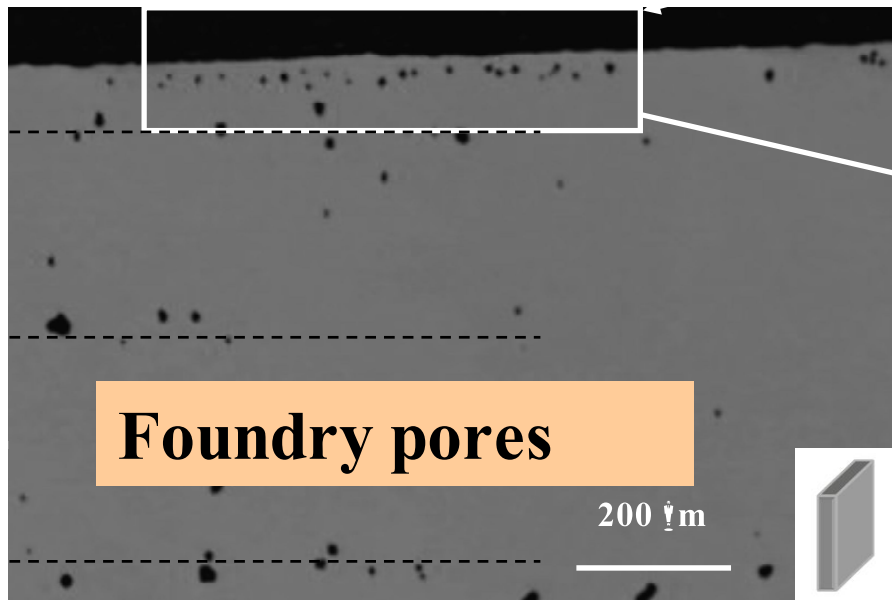
Ni, Ti, Cr oxides



**Oxide microstructural evolution
between the air and ArH₂ testing
conditions.**

Vacancies injection

Pores occurrence
[Hancock 76, Perusin 2004]

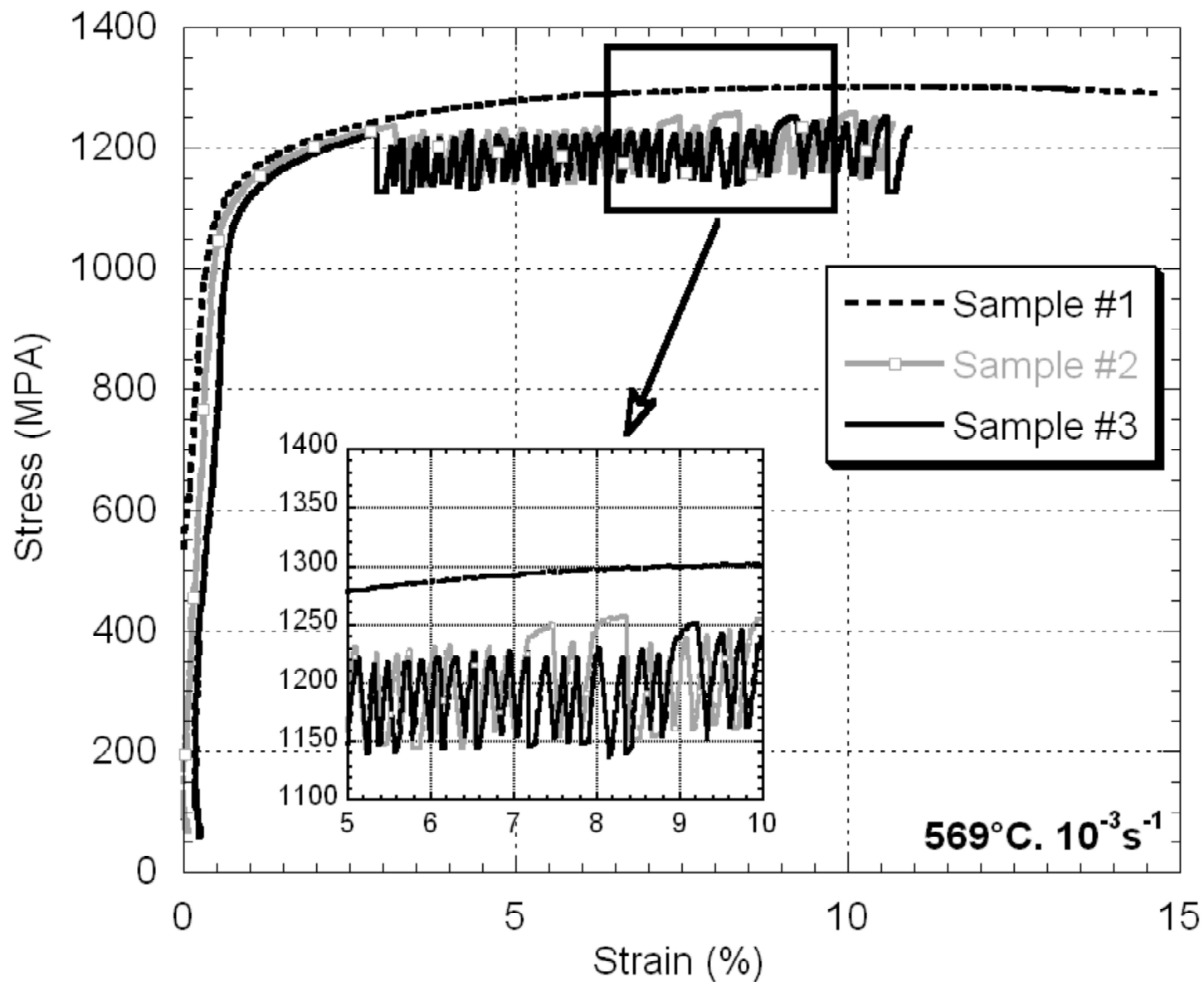


Effect of vacancies injection on diffusion processes and on dislocations climbing component [Gourgues 99]

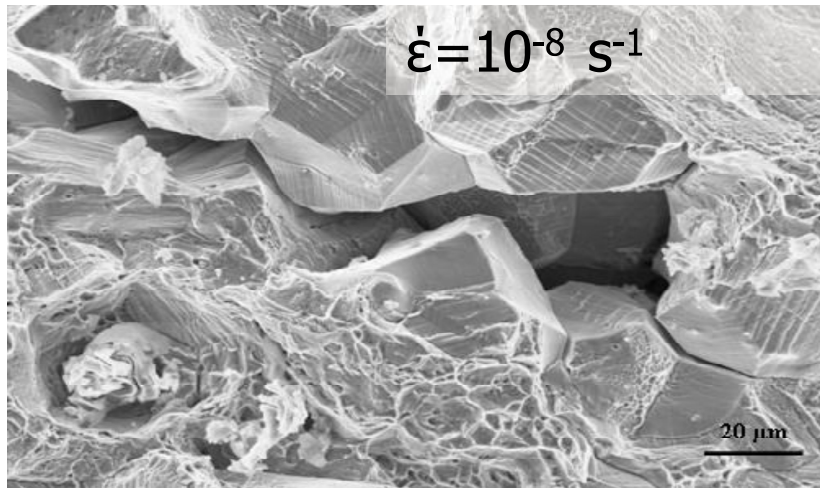
Cyclage mécanique et/ou environnemental

*PhD Thesis: V.Garat, J.Deleume, B.Ter Ovanessian, B.Max, F.Galliano
INPToulouse*

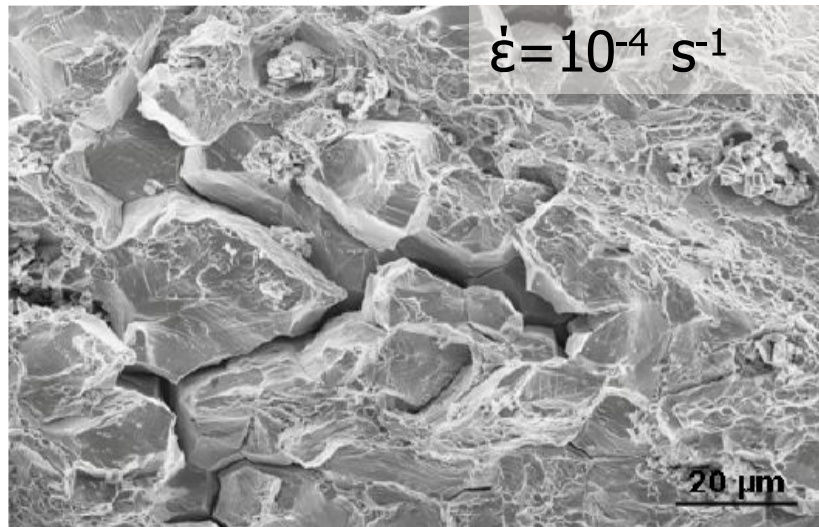
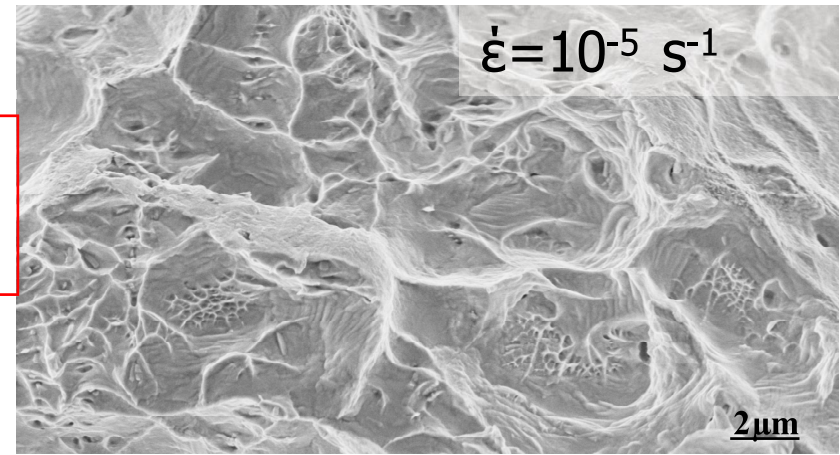
Vieillessement dynamique et instabilités type PLC
(cyclage subi)



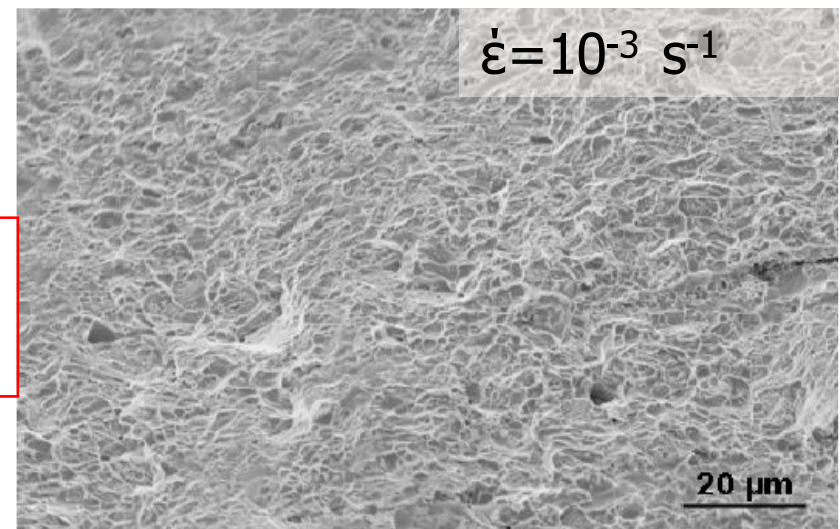
Corrélations comportement et endommagement.



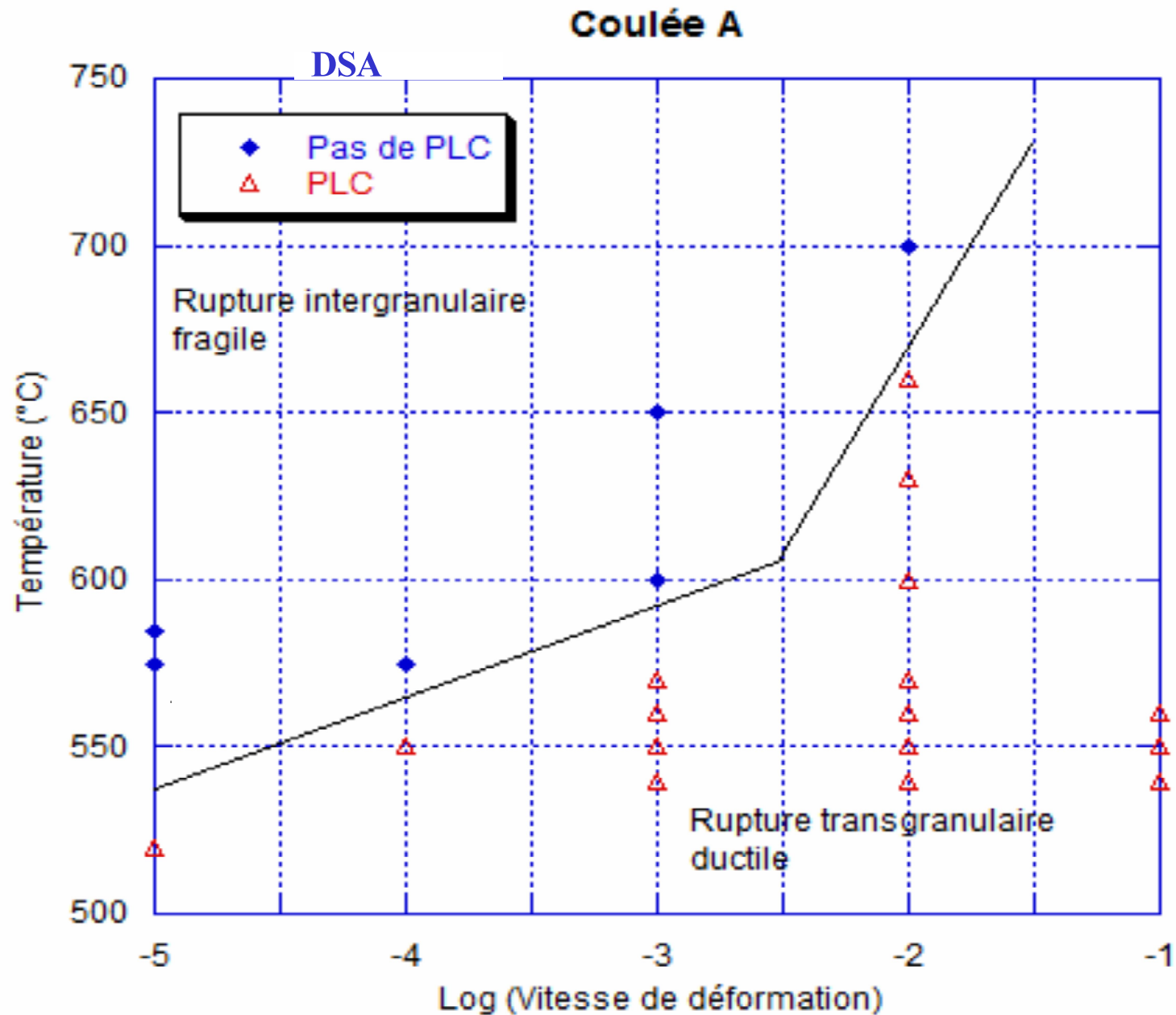
350° C
EAU



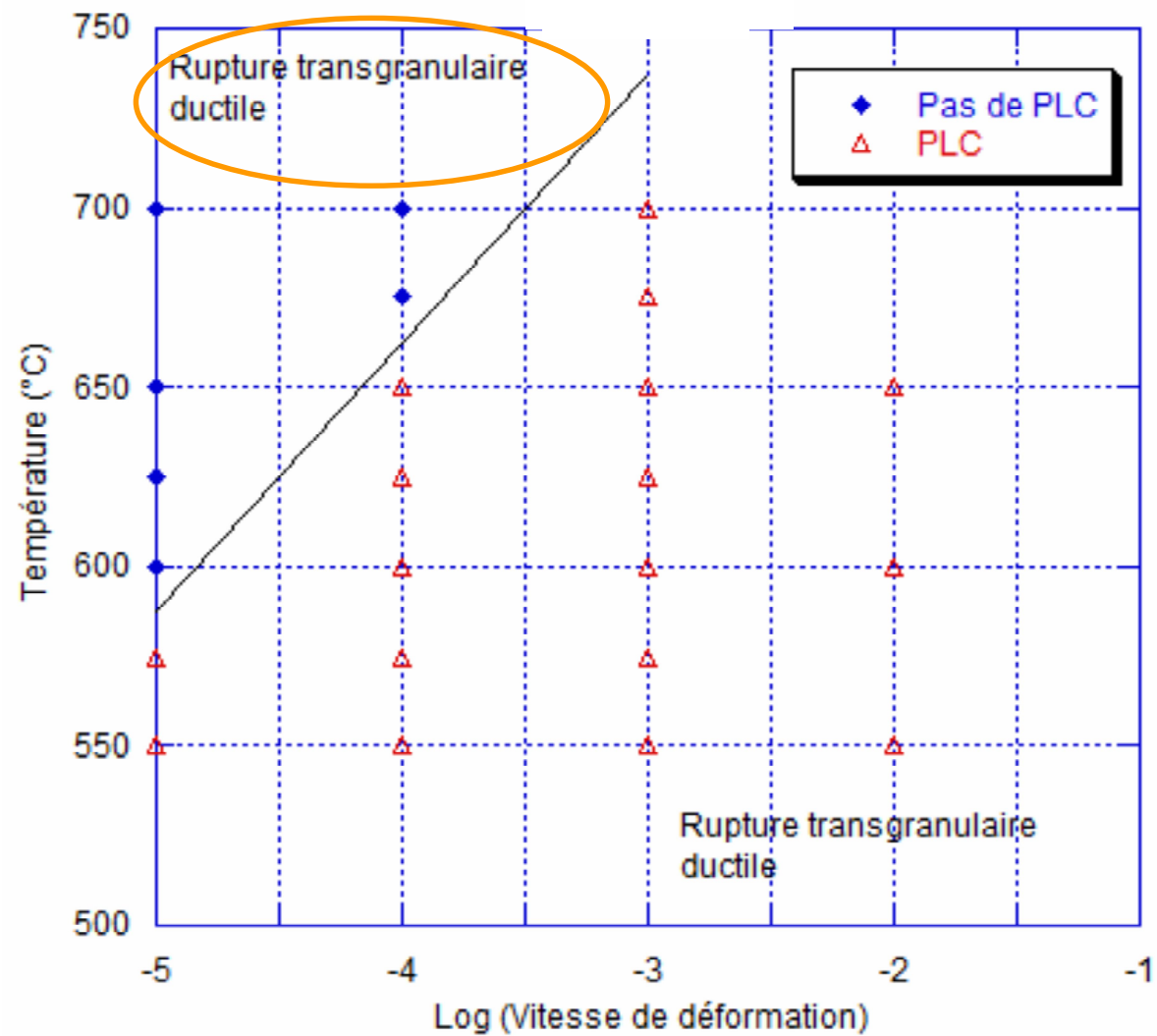
650° C
AIR



Tensile tests under air testing conditions:



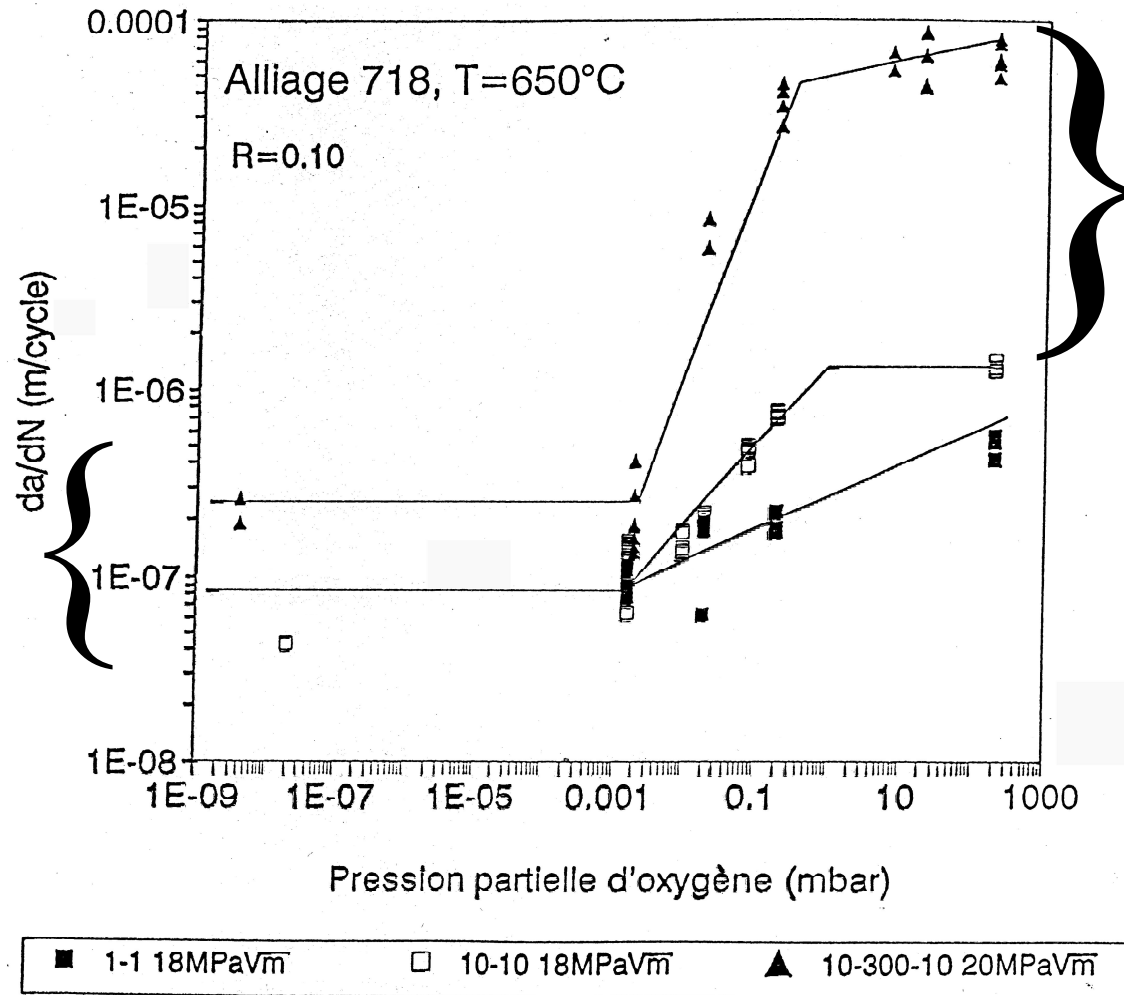
Low carbon alloy



Cyclage environnemental et mécanique
« Fatigue mécano-chimique »

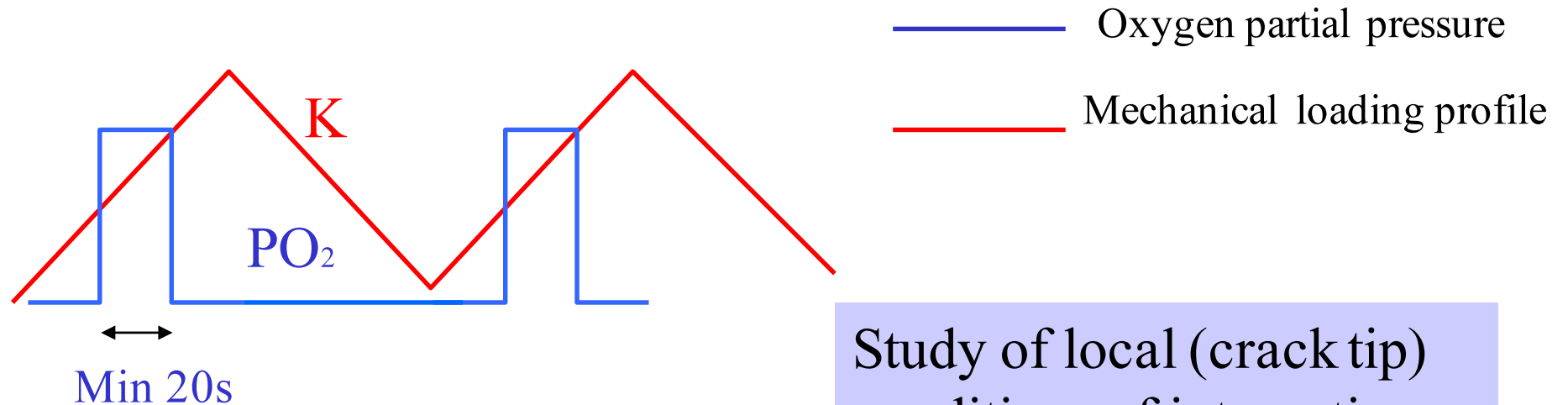
Effect of the oxygen partial pressure on the crack growth rate under constant ΔK .

- Trangranular fracture
- Selective oxidation of chromium

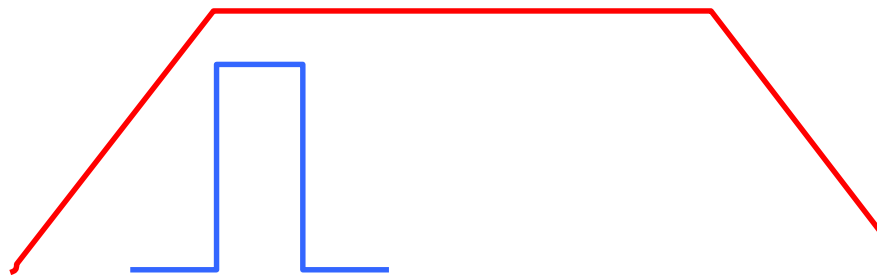


- Intergranular fracture
- The first oxide to grow is: (Ni,Fe)O
- Cationic growth process
- high oxide growth rate (transient regime)

Types of experiments carried out on several nickel base superalloys



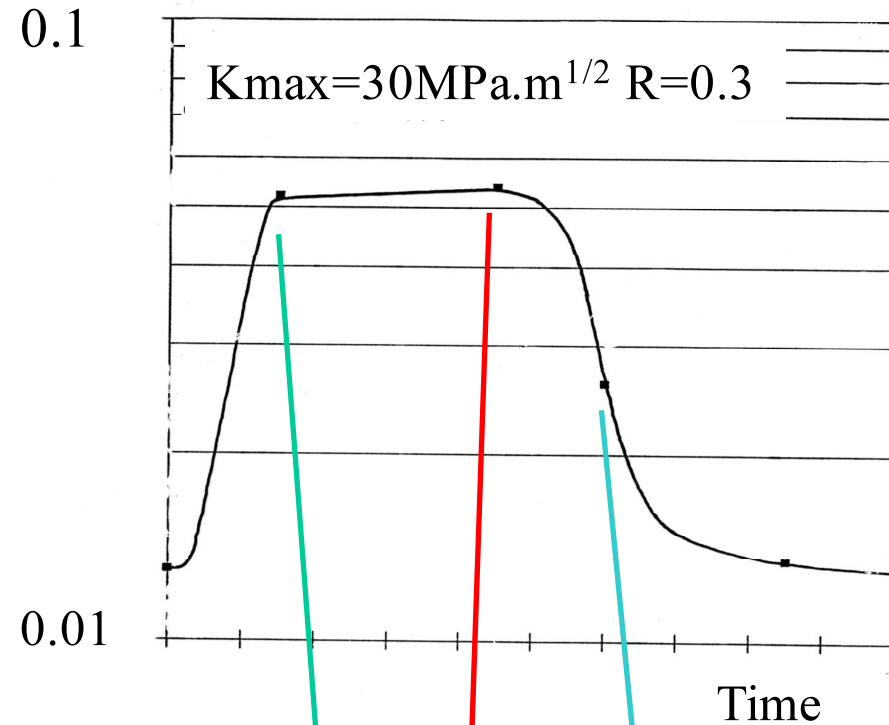
Study of local (crack tip) conditions of interaction between oxidation and deformation



Creep-fatigue

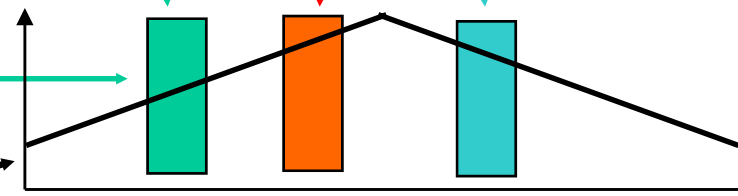
Effect of the relative position of an oxygen pressure cycle on the fatigue crack growth of alloy 718 at 650° C

Fatigue crack growth rate (mm/cycle)

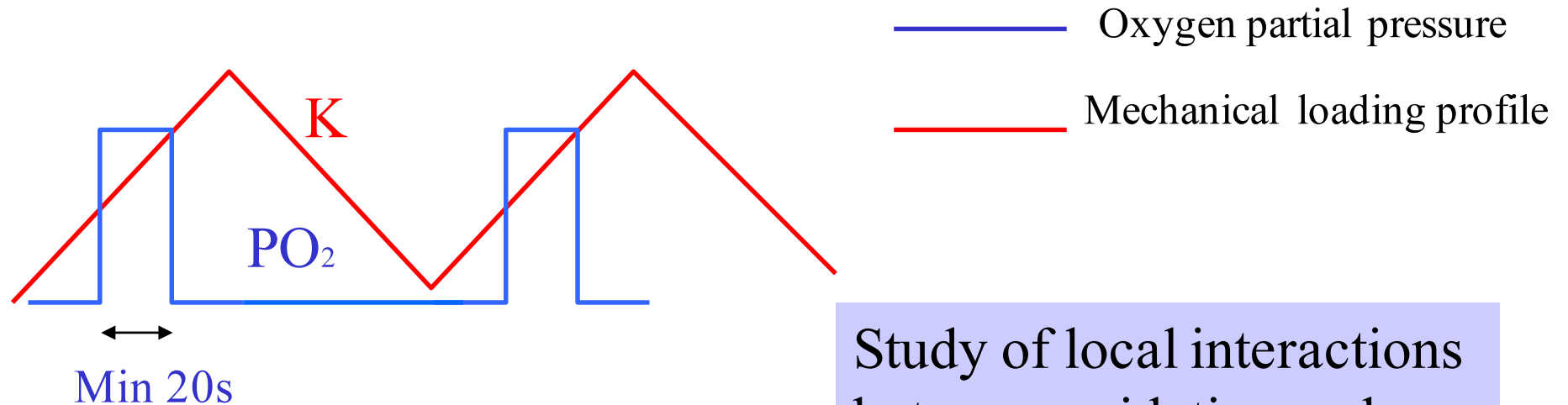


Pressure cycle (10^{-1}Pa - 10^2Pa (20s))

Fatigue cycle (180s-180s)



Types of experiments carried out on several nickel base superalloys



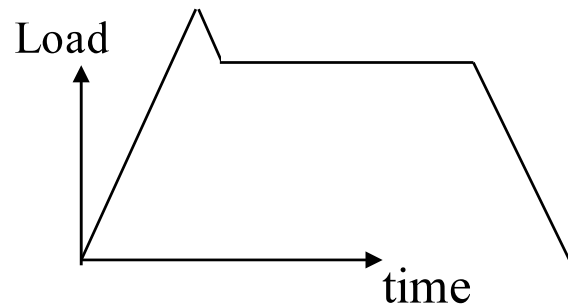
Study of local interactions between oxidation and deformation at a crack tip



Creep-fatigue

Is there a way to stop Oxidation Assisted Cracking?

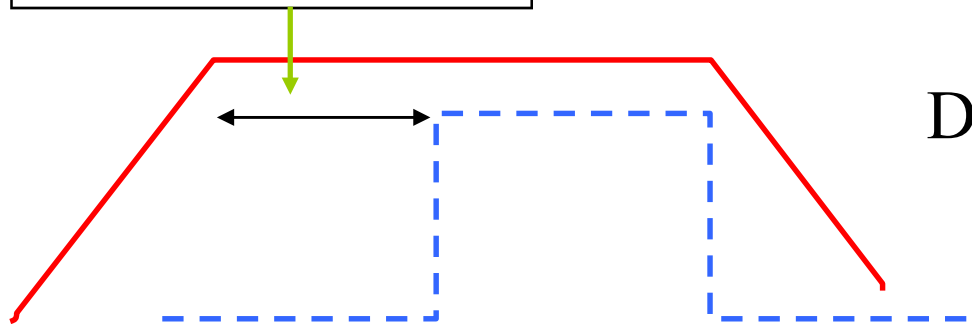
For creep resistant alloys (Ni based superalloys)



Unloading between 5 and 10%

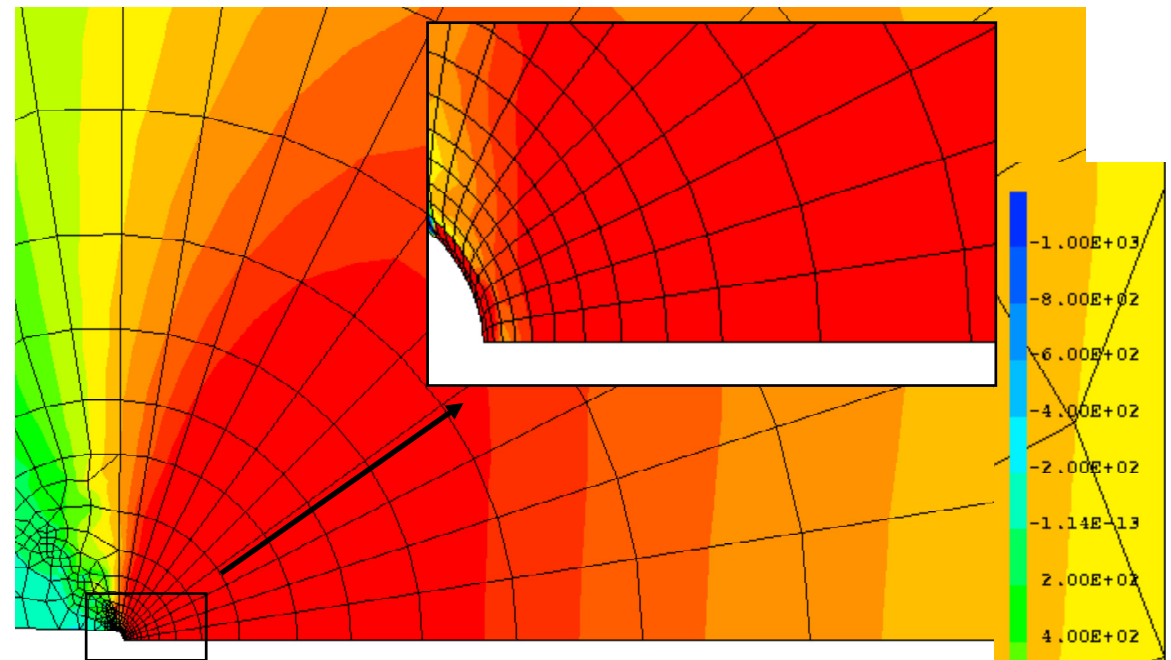
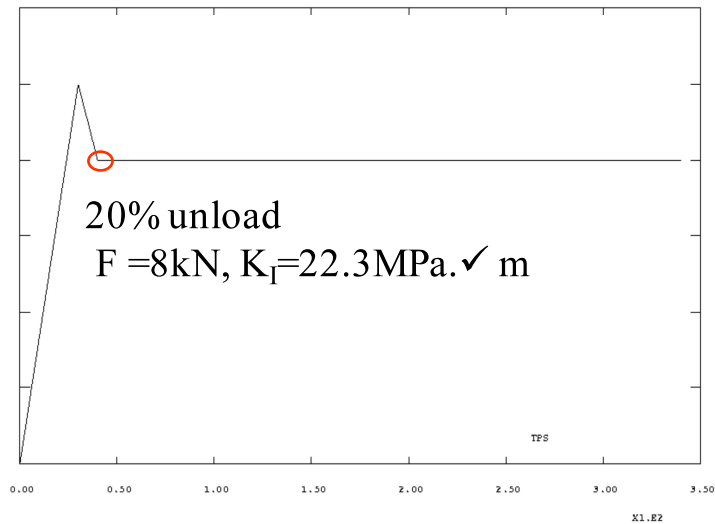
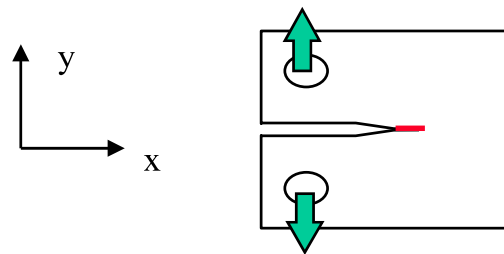
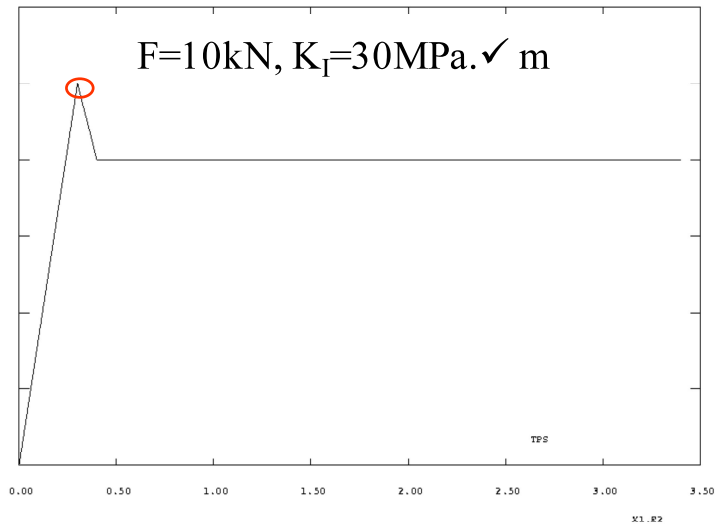
Compression stresses at the tip of the crack

Time spent under vacuum



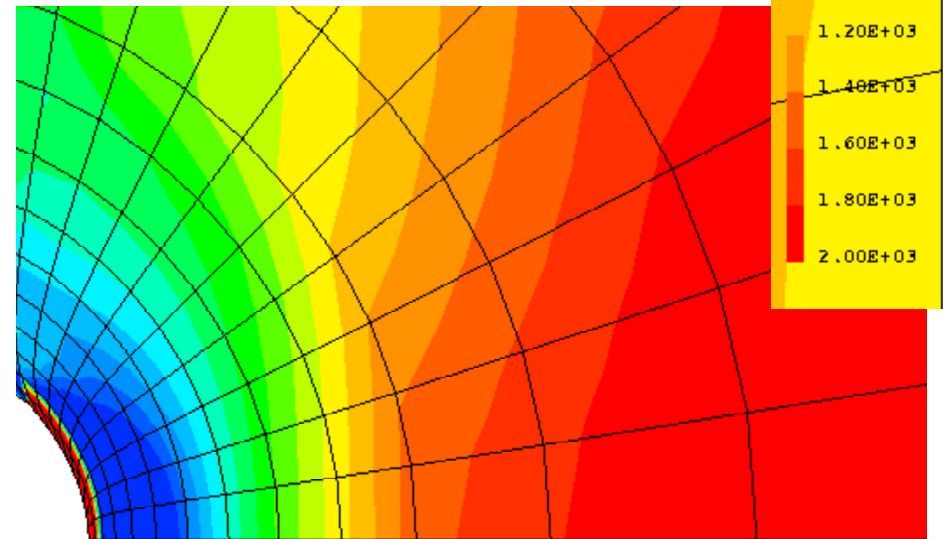
Delaying the oxidation effect

i_{local} is reduced



CT specimen (FEM 2D & plane strain)
 Stress at the crack tip

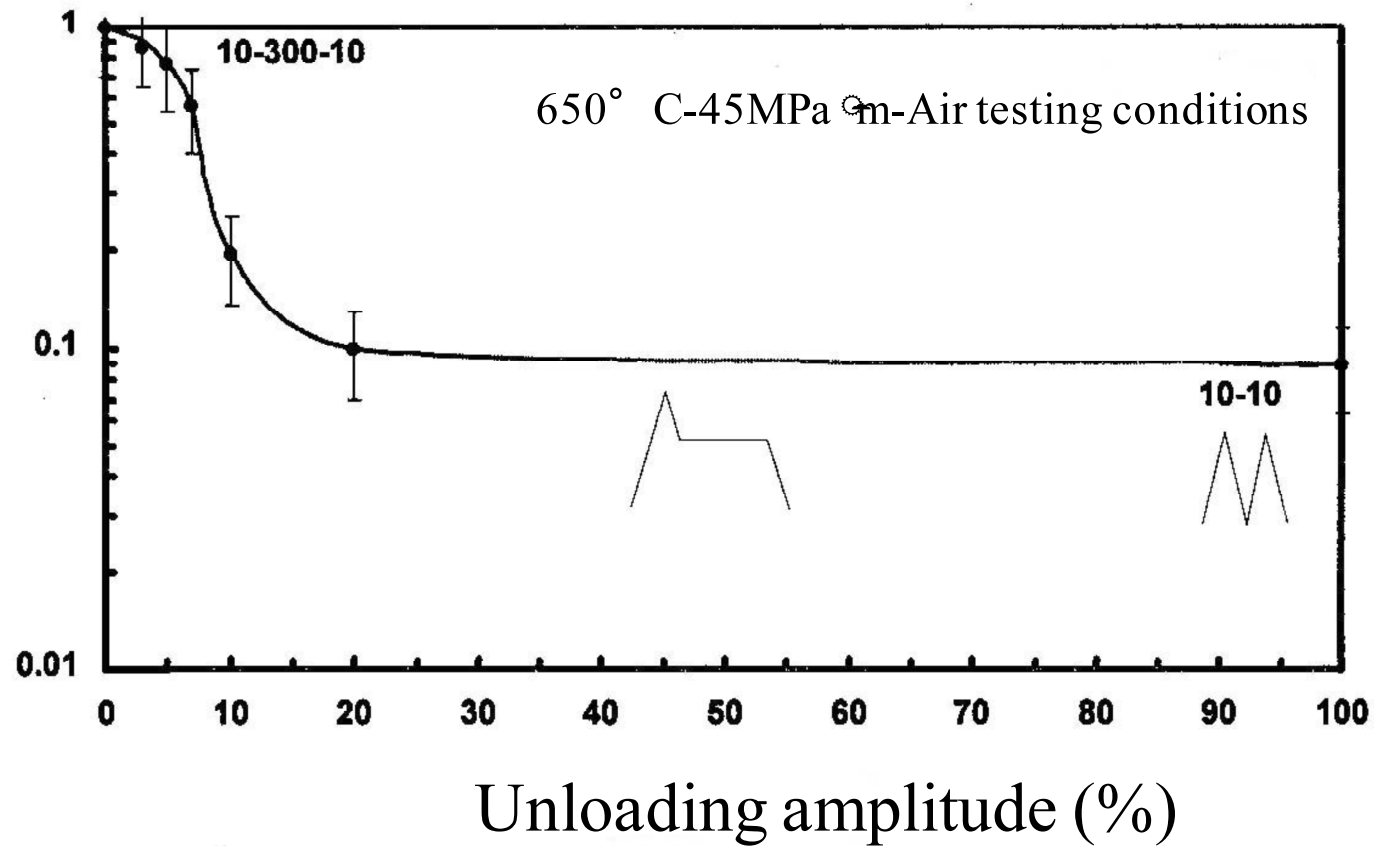
σ_{yy} (MPa)



2 μm : compression

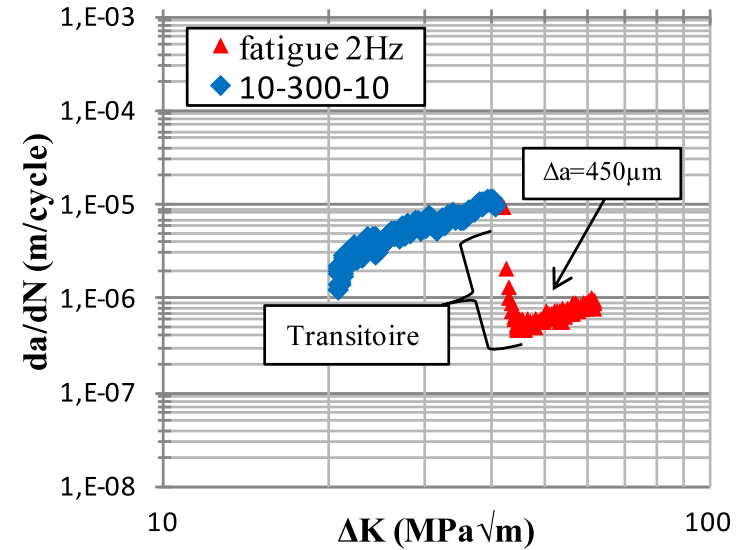
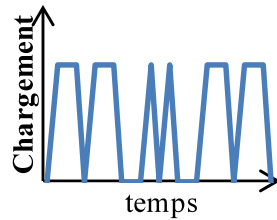
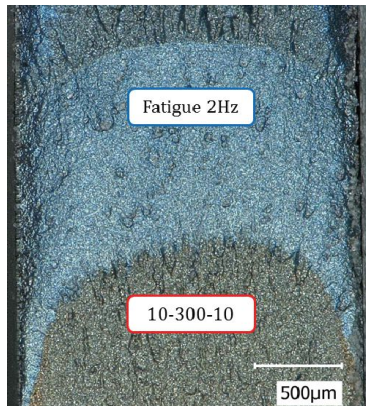
Effect of an unloading at the beginning of the hold time at K_{max} on the creep-fatigue cracking resistance of N18

Normalized crack growth rate



Effet de microstructure

Aspect des fronts de fissure



Résultat des marquages mécaniques :

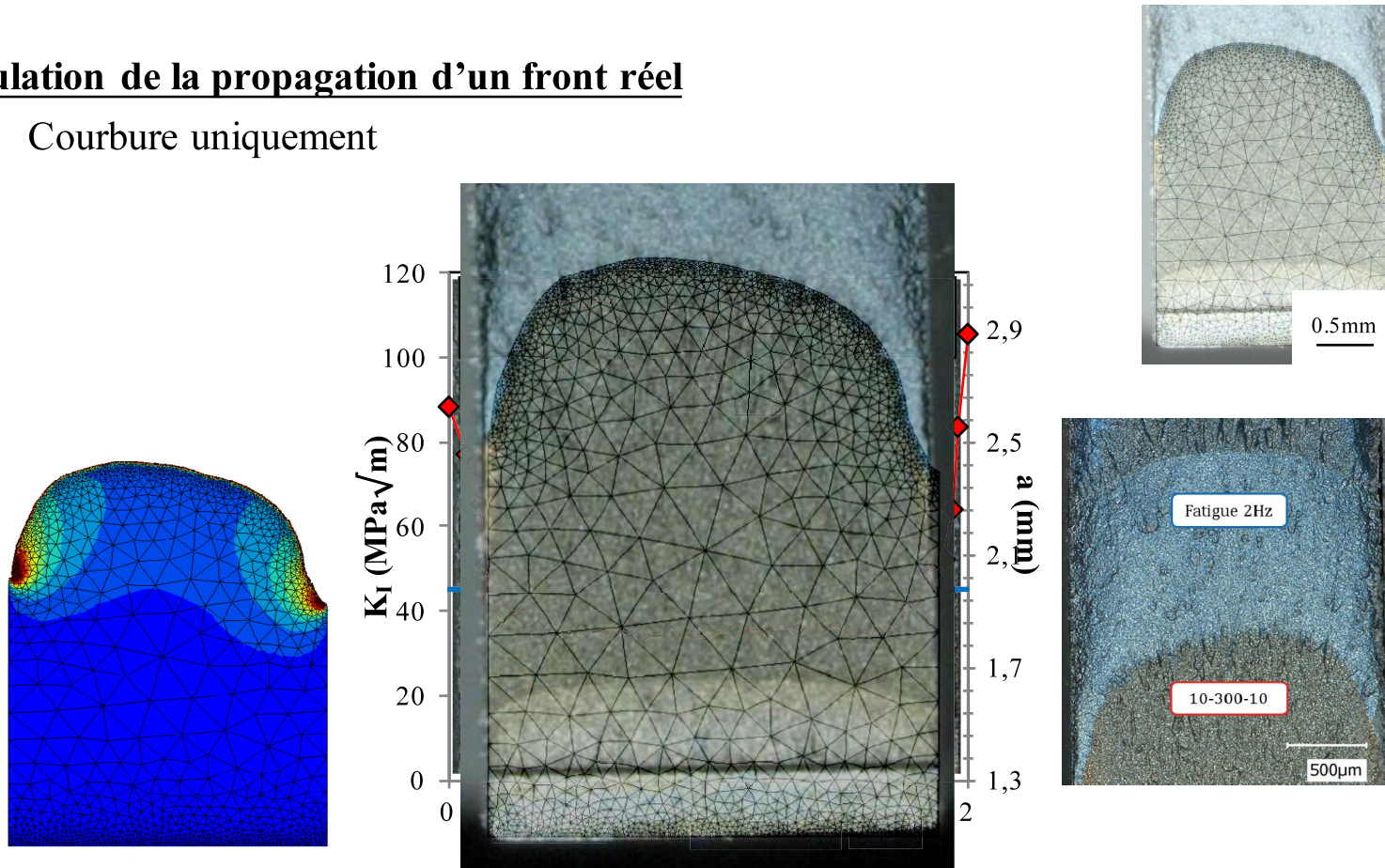
- Les cycles de fatigue pure « dépliant » la courbure et la tortuosité
- Transitoire de vitesses : effet de l'environnement et/ou géométrique ?

PhD : Emmanuel Fessler

Prise en compte de la courbure sur le chargement local

Simulation de la propagation d'un front réel

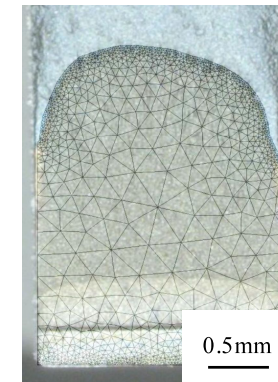
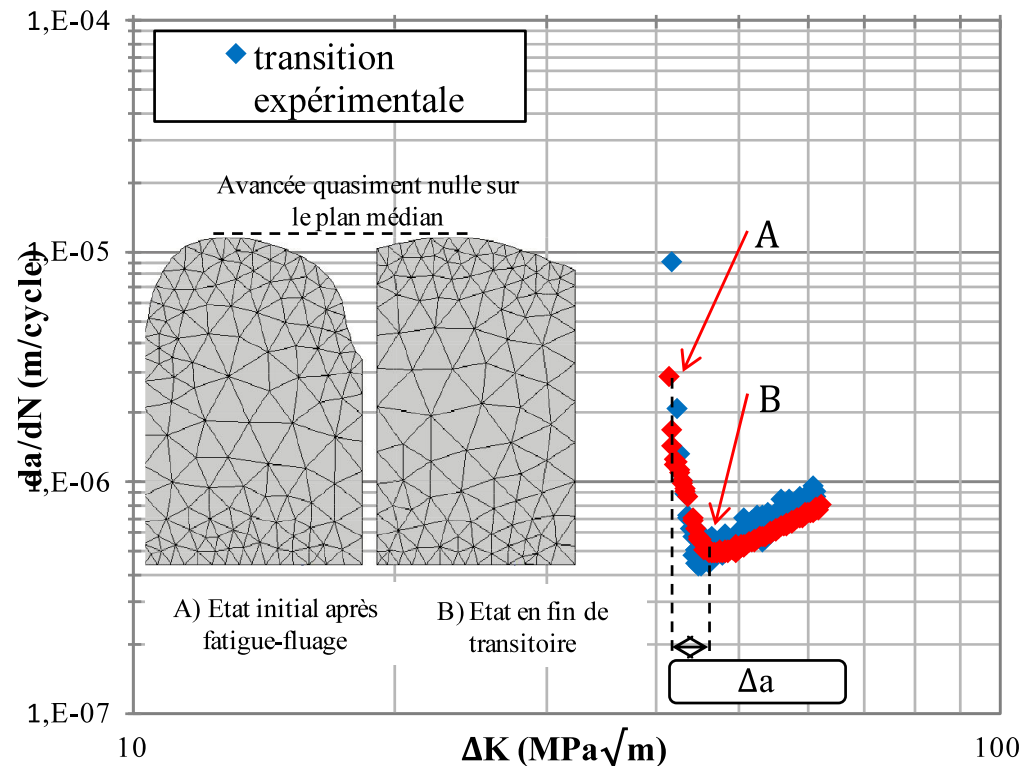
- Courbure uniquement



Effet de la courbure sur les vitesses de propagation

Simulation de la propagation d'un front réel

- Effet de la courbure
- Accord entre simulation et expérience

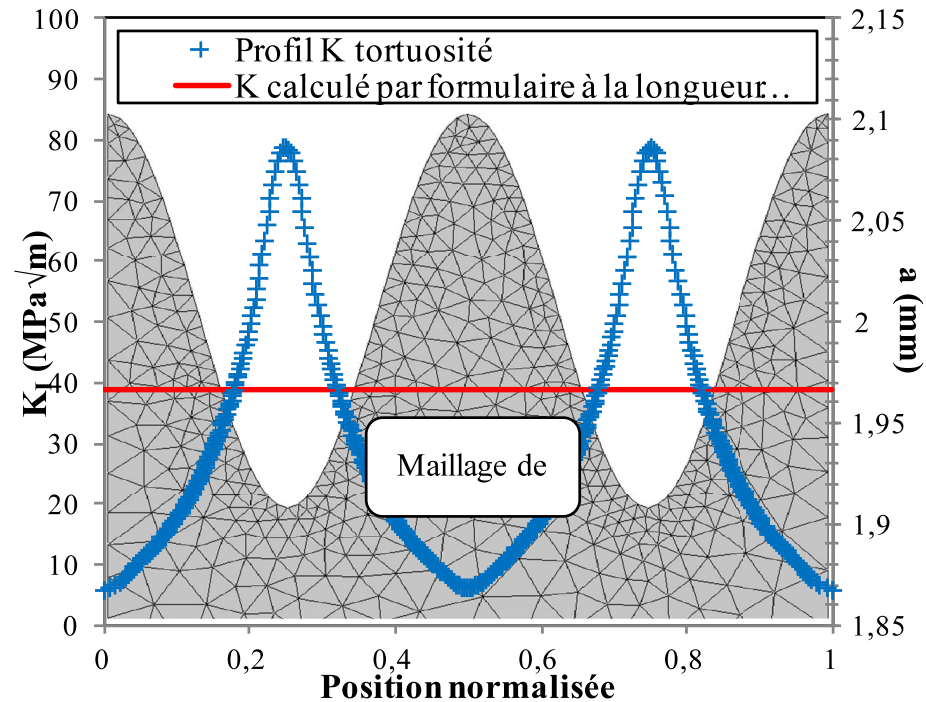
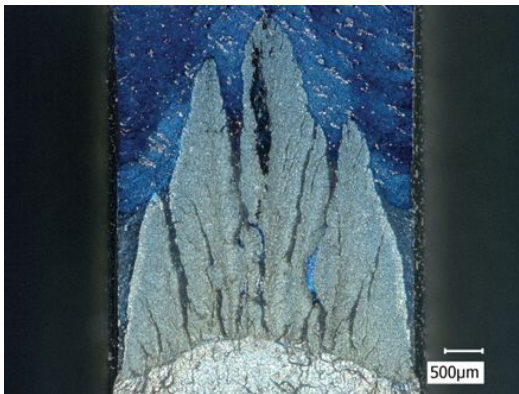


Effet majeur de l'évolution de front de fissure (courbure) sur le comportement en propagation

Prise en compte de la tortuosité sur le chargement local

Simulation de la propagation d'un front tortueux

- Propagation jusqu'à dépliement partiel



PhD: Emmanuel Fessler

Perspectives et enjeux

Développer de nouvelles expériences utiles à la validation de modèles (DFT, Dynamique moléculaire, Monte Carlo, Champs de phase...) et de modèles de comportement intégrant les couplages multiphysiques.

Caractériser les gradients de propriétés induits par les réactions d'oxydation

Accroître les bases de données dans ce domaine des Sciences

Développer des matériaux en anticipant les conséquences de ces mécanismes de dégradation