Investigation of mechanical and micro structure properties of the QUENCH-L0 claddings near to burst regions

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17th QUENCH Workshop, KIT, Karlsruhe, 2011

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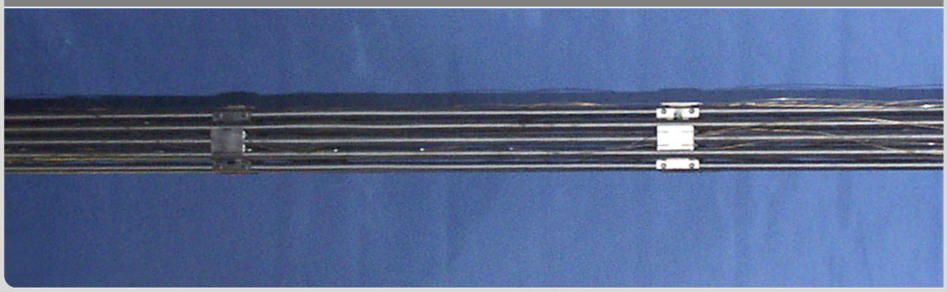
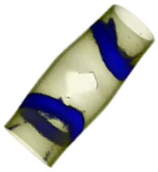


Outline

- Motivation
- Secondary Hydration
- XRD
- TEM
- Micro hardness
- Conclusions

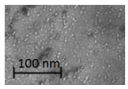
Motivation

- Secondary hydration next to the bust openings



- Influence on local mechanical properties

- Investigation of the presence of zirconium hydrides

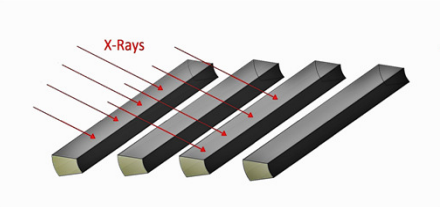


Secondary Hydriding

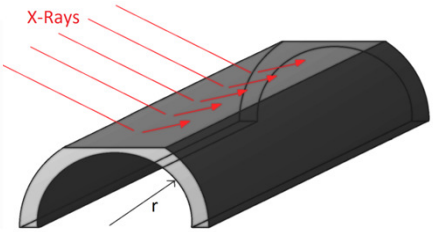
- Hydrogen released during the steam oxidation of the cladding
- $Zr + 2H_2O \leftrightarrow ZrO_2 + 2H_2$
- As the bursts occurs, steam reaches the inside of the cladding and oxidizes the inner side of the burst.
- Since the diffusion of H trough ZrO_2 is very slow, it gets concentrated at the boundary of oxidized area.

XRD

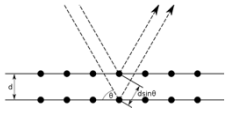
- Samples extracted from internal rods QL0-#3 and QL0- #8 and reference Zry-4
- Different samples because of rod geometry and band location
- Phase identification



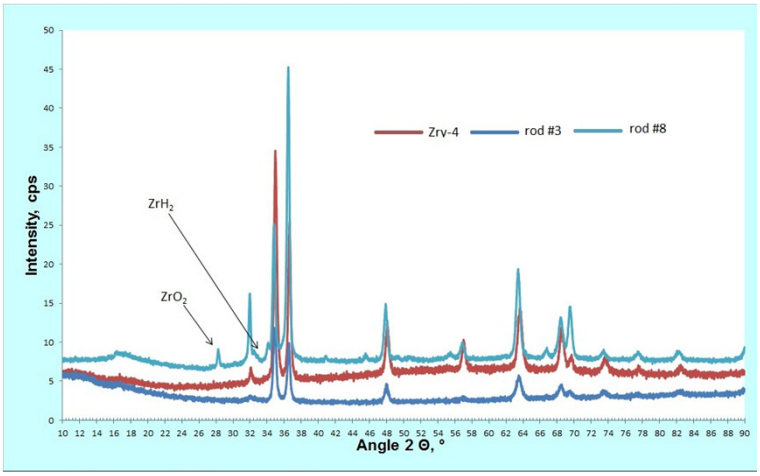
rod#3



rod#8

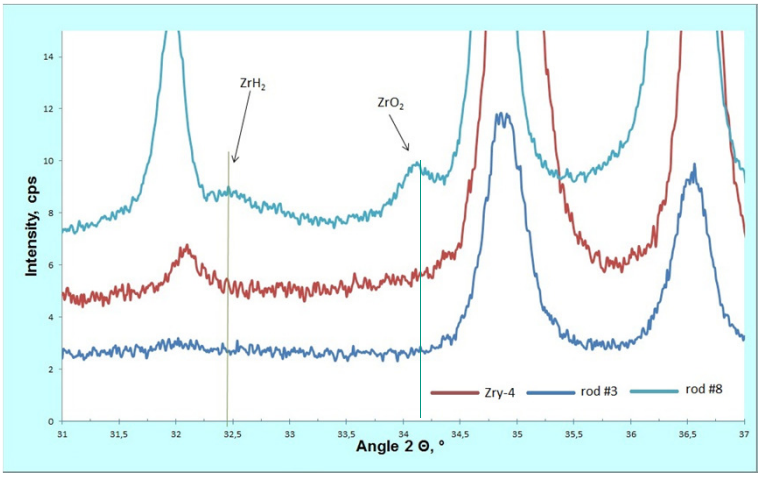


XRD - Results



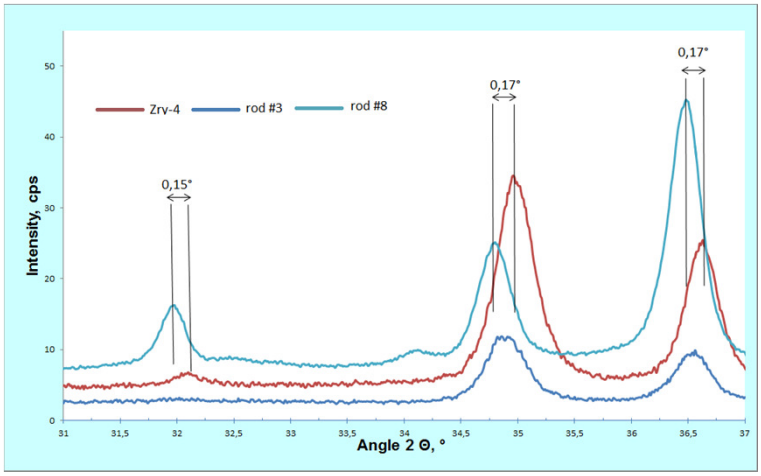
Overall view of the spectrum, generally in good accordance with pure Zr

XRD - Results



The peak around 32.4° has a small shoulder, which correlates well with ZrH_2

XRD - Results



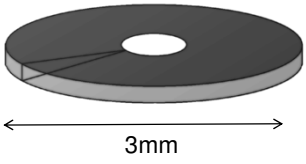
Shift of about 0.17° between Zry-4 as received and hydrided rod#8

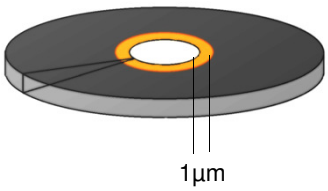
XRD - Conclusions

- Weak signal related to ZrH_2
- Peaks are shifted roughly by 0.2° which can´t be attributed to equipment precision.
- Spectrometer is equipped with parallel beam optics, so the error commonly caused by sample shift is eliminated.
- Other calibration procedures were executed.
- Second Zry-4 probe verification.
- *The crystal structure is in part distorted because of dissolved hydrogen.*

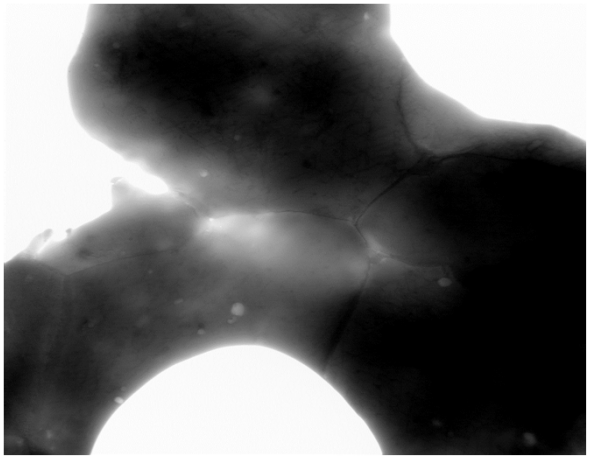
TEM – Sample Preparation

- Selection of extraction area
- Cut and grind sample
- Electrochemical polishing with Perchloric acid and Glacial Acetic acid
- QL0 rods #3, #8 and reference Zry-4
- Small analyzable area



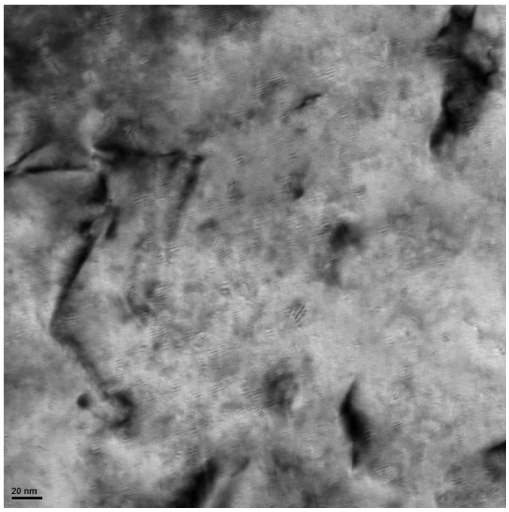


TEM - Results



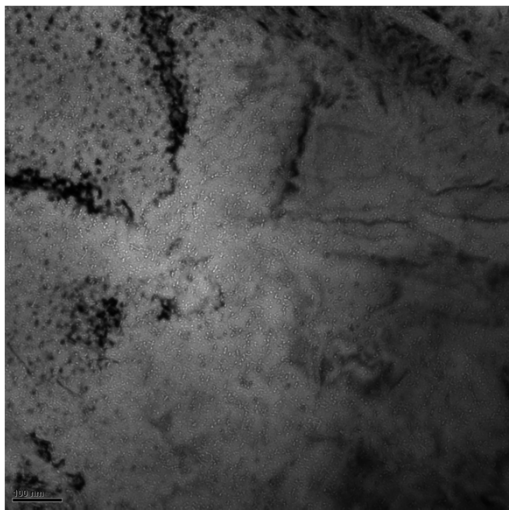
Zircaloy 4, as received

TEM - Results



rod #3

TEM - Results



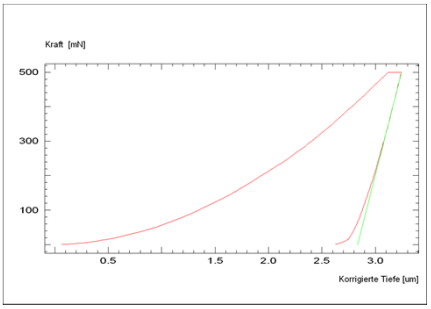
rod#8

TEM - Conclusions

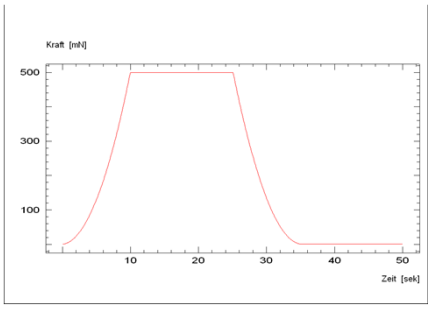
- Great number of not chemically identified precipitations
- Do not contain any detectable alloying element such as Cr, Ni or Fe.
- Same chemical spectra is obtained analyzing the particles or surroundings.
- Particles with different orientations measuring 10~20nm.
- Chemical analysis (EDX HAADF)?
- Electron Diffraction?

Micro hardness

- Continuous measurement of load and depth
- Hardness, reduced elastic modulus, creep
- Mapping of mechanical properties

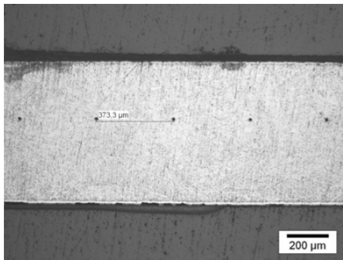


Elastic modulus ~ derivative of the unloading curve

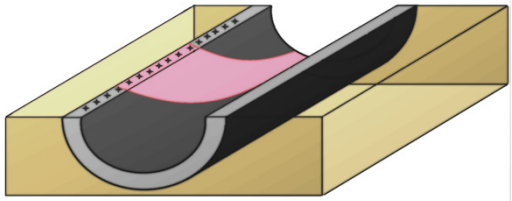


Load applying cycle

Microhardness



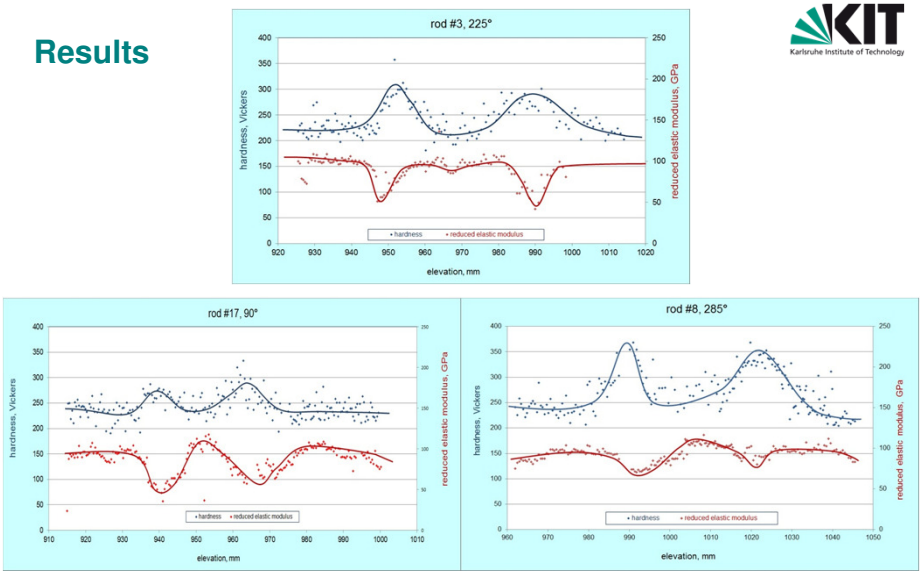
Indentation marks



Mapping along axial direction

Distance between measuring points: 350 µm along 100 mm

Results



Micro hardness - Conclusions

- Clear identification of the affected zones
- Up to 350 HV at hydrogen band, compared to the regular 210 HV
- Simultaneous decrease of elastic modulus down to 60 GPa

Summary

- Most of the hydrogen is dissolved in the matrix
- Clear influence on local mechanical properties
- Further TEM analysis is required

Outlook

- Small-angle neutron scattering (SANS)
- Single rod experiments

Acknowledgements

Dr. S. Schlabach IAM/WPT

Dr. H. Leiste IAM/AWP

Dr. M. Klimenkov, Ms. U. Jäntsch IAM/AWP

Thank you for your attention

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