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Industry LOCA Oxidation Test Plans

NRC LOCA Public Meeting

Washington DC

September 24, 2008

LOCA Oxidation Test - Background

- Motivation for test
  - ANL work focused on testing at 1200°C
    - Test data have shown ECR accumulated at lower temperatures are not as detrimental to ductility

Oxidation Temperature (°C)	Measured ECR	RT Offset Strain
1,000	22.4	3.2
1,100	20.3	4.8
1,200	20.8	0.5

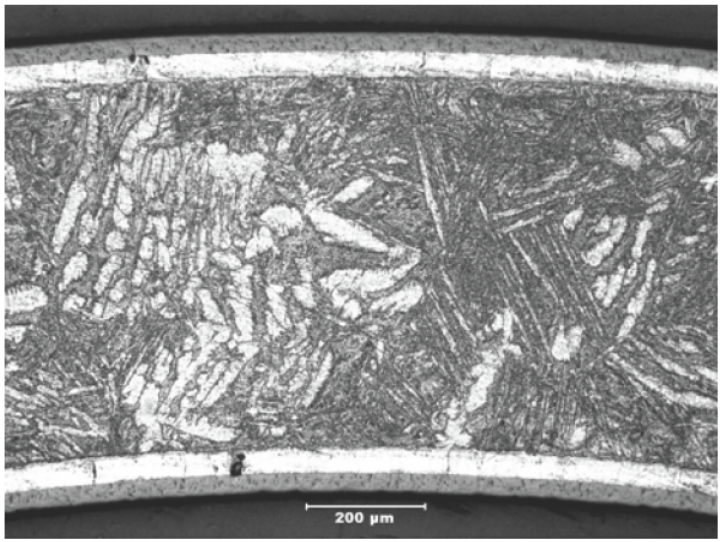
    - Since most fuel rods will not reach 1200°C during LOCA it may be appropriate collect data in support alternative LOCA criteria not tied only to 1200°C PCT
  - Effect of cooling and quenching temperatures on ductility not well understood
    - Significant differences in ductility results from different international laboratories
      - Quench from temperature
      - Cooling rates
      - Quench temperatures
    - Oxygen diffusion
    - Role hydrogen plays

LOCA Oxidation Test - Background

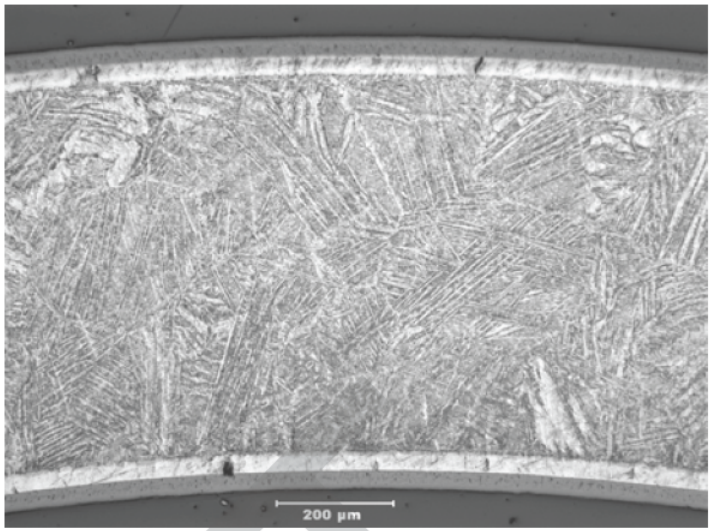
- LOCA oxidation test goals
  - Develop a mechanistic understanding of embrittlement mechanisms
    - Evaluate entire ranges of relevant oxidation temperatures and hydrogen contents
      - 800 to 1200°C
      - As-built to 800 ppm hydrogen
    - Full characterization of test samples (in addition to RCT)
      - Oxygen, hydrogen, micro-hardness, prior-beta and oxygen stabilized alpha phases thickness measurements and localized oxygen stabilized phases
  - Generate sufficient test data to propose alternative criteria

LOCA Oxidation Test - Background

- Important factors to be evaluated
  - Oxygen diffusion during heat-up and cool-down
    - Does oxygen diffuse out of prior beta to form localized oxygen stabilized alpha during cooling? Is this behavior modified by hydrogen?



(a) As-received

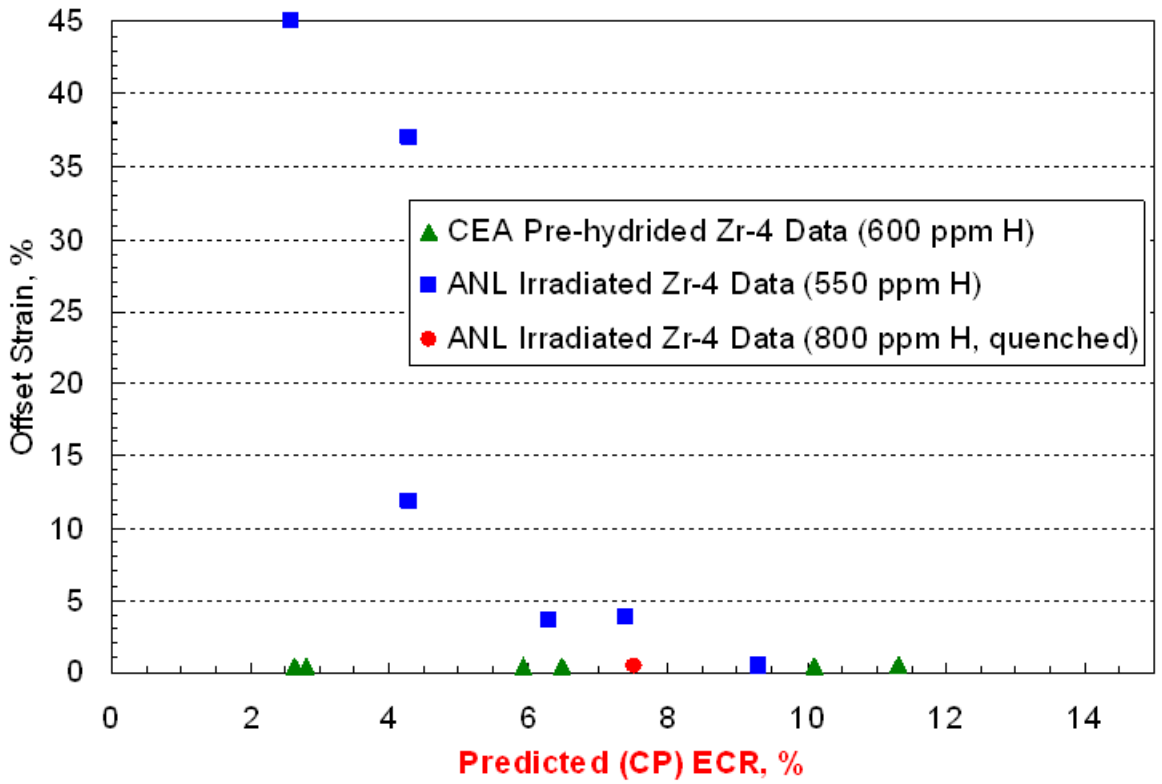


(b) 600-wppm hydrogen

  - Oxygen solubility limit modified by hydrogen?

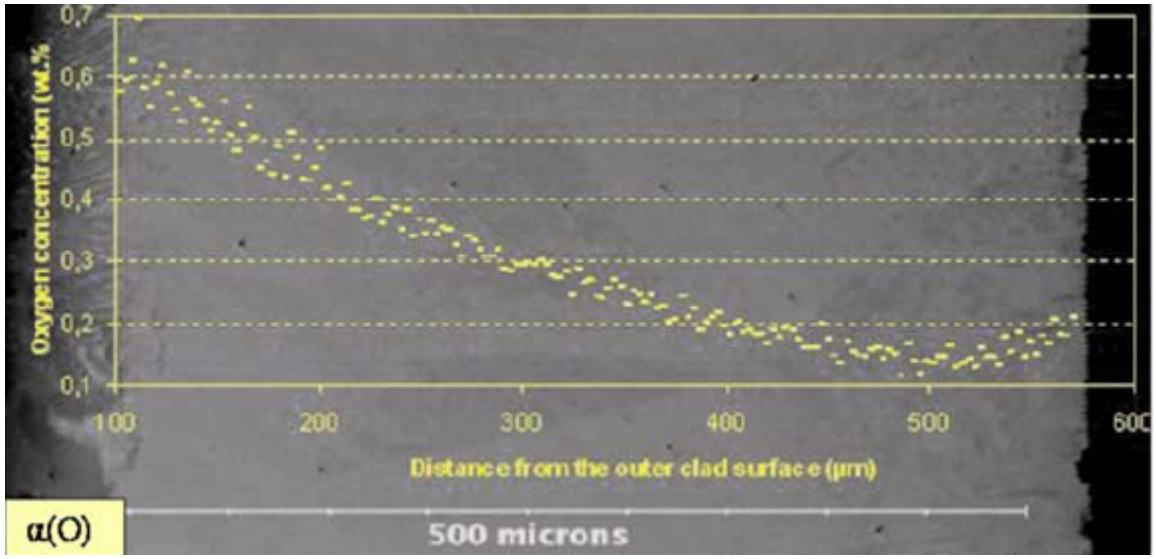
LOCA Oxidation Test - Background

- Quench effects
  - CEA results of samples quenched from temperature show zero ductility
    - Oxygen trapped at solubility limit or micro-structural differences?



LOCA Oxidation Test - Background

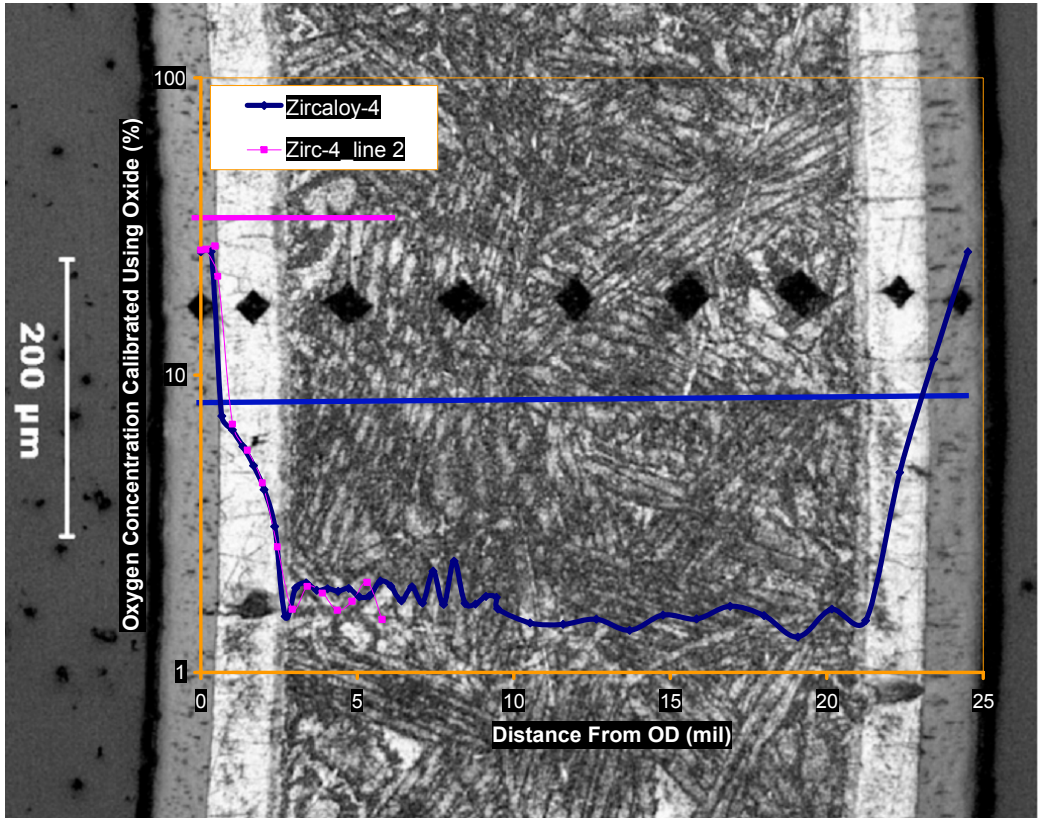
- Oxygen distribution across as-quenched Zircaloy-4 clad wall
  - 110s at 1250°C



* J.C. Brachet et al, Journal of ASTM International, Vol. 5, No. 5

LOCA Oxidation Test - Background

- Oxygen distribution of cooled and then quenched Zircaloy-4
  - CP-equivalent 166s at 1200°C
    - No significant oxygen gradient across metal wall, evidence of localized oxygen segregation



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LOCA Oxidation Test – Apparatus

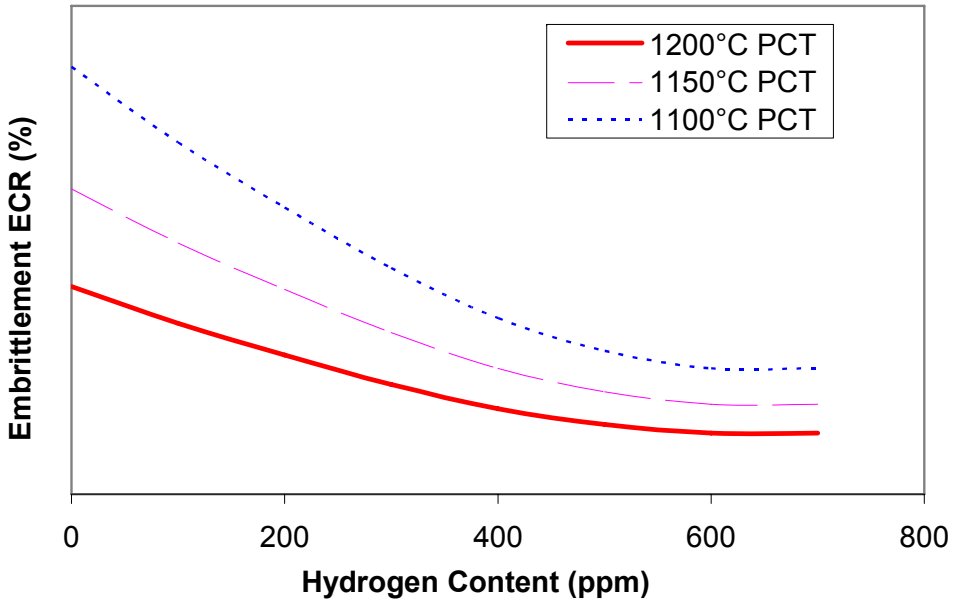
- Electric resistance furnace
  - Center core quartz tube
  - Heat furnace up to set temperature and then insert samples
    - Initial inert gas atmosphere is possible
  - Excellent temperature repeatability
  - Cooling scenarios
    - Slow cool – turn off power and let furnace cool
    - Intermediate cool – remove quartz tube from furnace
    - Fast cool - remove quartz tube from furnace and forced cooling with fan
    - Quench – drop sample into a water tank
- Sample evaluation
  - RCT, Metallography, WDX and EDS with oxygen standards

LOCA Oxidation Test – Scope

- Test divided into three subsections
  - Evaluate oxygen diffusion coefficients
    - Samples quenched from oxidation temperatures
    - Focuses on 1100 and 1200°C
    - 3 ECRs and 5 levels of hydrogen
  - Evaluate cooling effects
    - Micro-structural and oxygen distribution evaluation at different oxidation temperatures, cooling rates and quench temperatures
  - Evaluate metallurgical conditions at critical embrittlement ECR
    - Different combinations of oxidation temperatures, hydrogen content, cooling rate and quench temperatures

LOCA Oxidation Test

- Ultimate goals
  - Generate sufficient data to determine the feasibility of developing an embrittlement model
  - Two potential pathways
    - Allowable ECR dependent on both hydrogen concentration and peak clad temperature
      (1) Maintain ductility based on model predictions
      (2) A family of ECR vs Hydrogen curves with different peak clad temperatures



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