Abstracts Available
LOCA-like Embrittlement of Zr-1Nb Cladding

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Development of an embrittlement criterion for Zr1%Nb cladding applicable to loss-of-coolant accident in LWRs and comparison with zircaloy.

To establish an embrittlement criterion for Zr1%Nb cladding applicable to hypothetical loss-of-coolant accident (LOCA) in light-water reactors (LWRs), the available information, mainly from Germany, Russia and Hungary, was reviewed. The results of isothermal steam-oxidation tests performed between 1000 and 1200°C show that, despite a very slightly lower weight gain than for zircaloy:

- The oxygen-stabilised α phase layer thickness and the cumulative thickness of the oxide and α phases layers are larger than for zircaloy ;
- The oxygen content in the β phase, deduced from hardness measurements, is higher than for zircaloy ;
- To summarise, oxygen is more uniformly distributed than for zircaloy ;
- Under unlimited steam supply conditions, the hydrogen pick-up is significantly higher than for zircaloy.

All these parameters are known to be embrittlement factors for zirconium alloys. The results of ring compression tests and tensile tests, conducted at several load temperatures from these steam-oxidised specimens, show that the nil ductility temperature can be very well linearly correlated with the weight gain or equivalent oxidation rate ECR. The application of the 1973 ECCS Rule making-hearing methodology to these results lead to a provisional criterion for the total oxidation limit of 6 percent of the wall thickness associated with the use of the Bochvar Institute's weight gain correlation, compared to 17 percent associated with the use of the Baker-Just correlation for zircaloy. The difference comes mainly from the hydrogen pick-up. As for zircaloy, the most limiting phase is the post-quench phase of the LOCA under hydraulic, seismic or handling loadings ; the quench phase at the Leidenfrost temperature is not limiting when the thermal shock loading is applied, without additional axial constraints.

Thermal Shock Tests for Hydrided Zircaloy Cladding Tube

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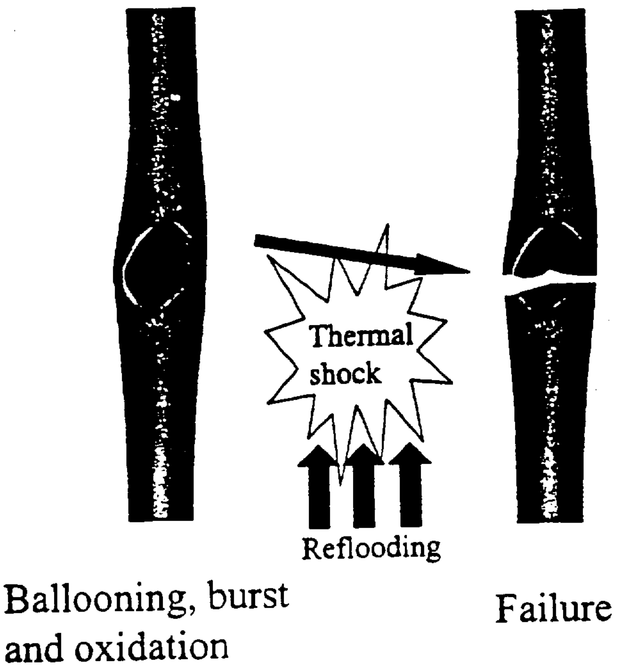
Outline of presentation

- **Objective**
- **Experimental method**
- **Results**
- **Summary**

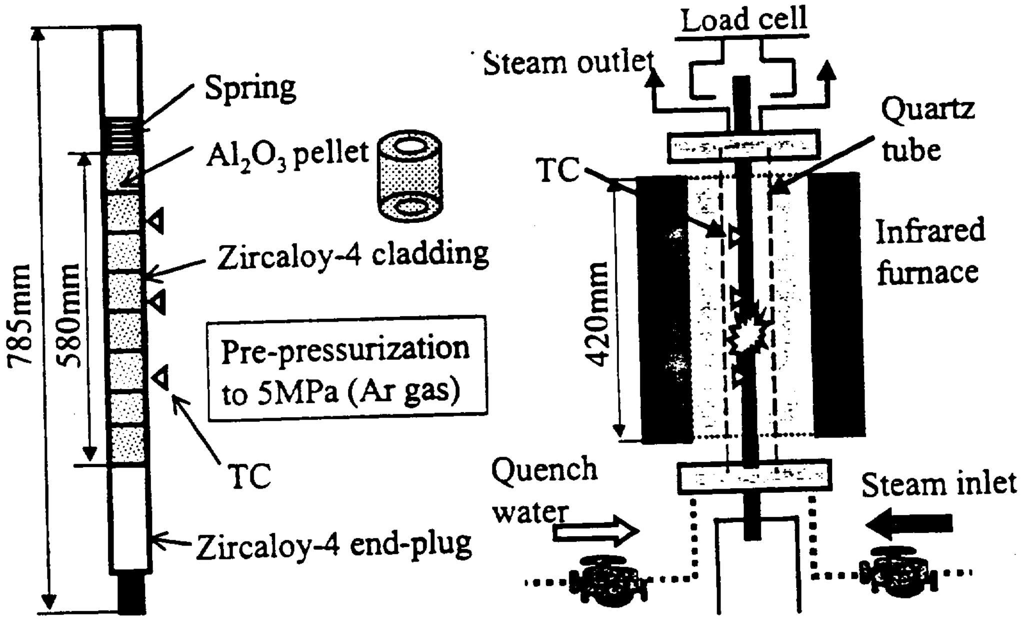
Objective

To investigate failure-bearing capability of the cladding during thermal shock taking into account of the whole LOCA sequence

including rod-burst, oxidation and reflooding.



Thermal shock test

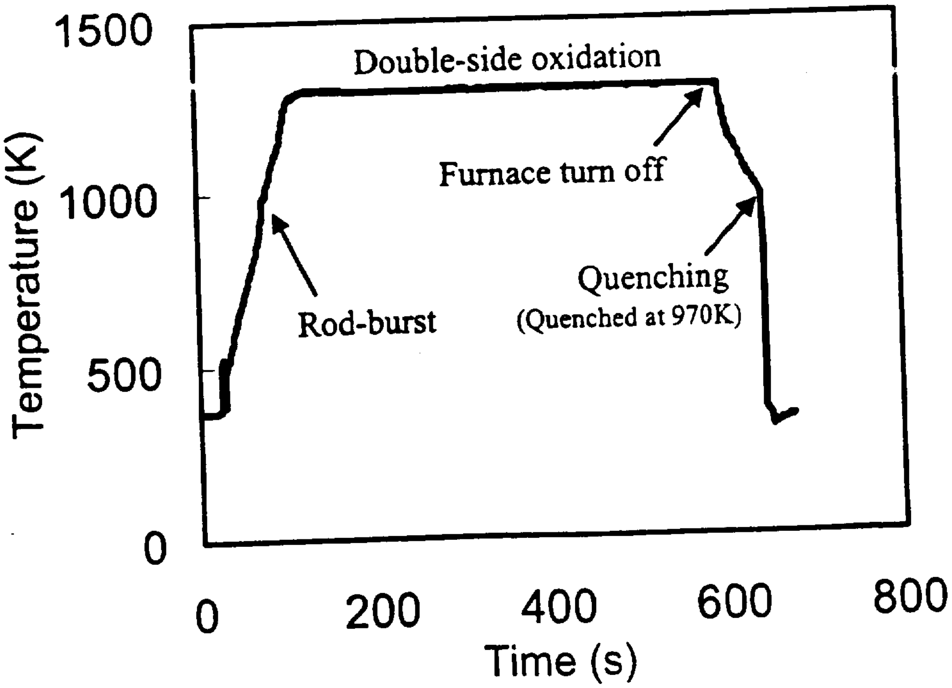


Sample and oxidation condition

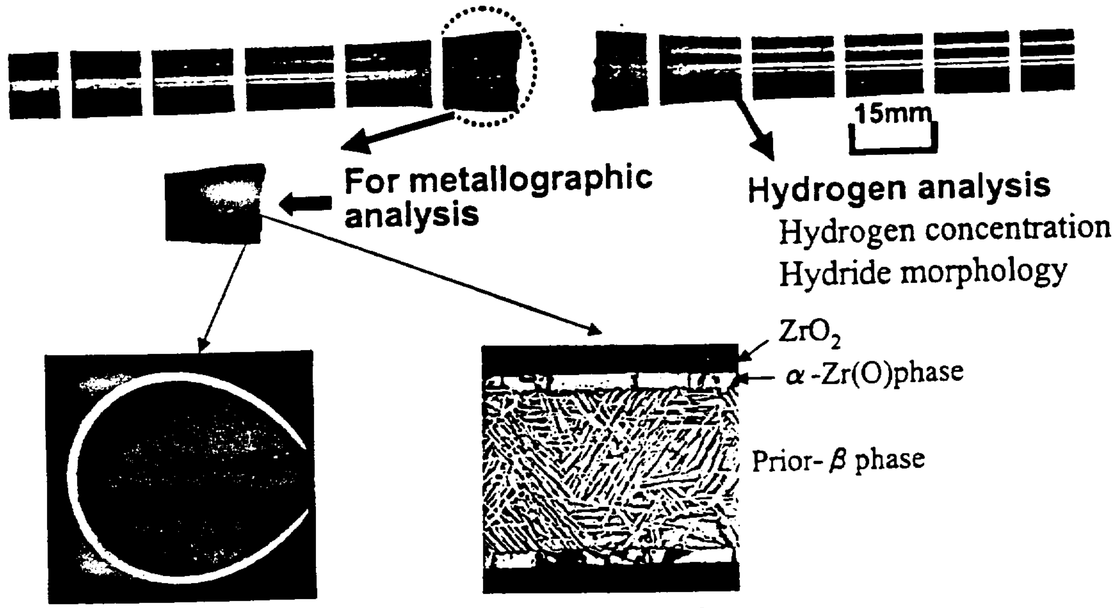
Parameters	Present test condition	Plan
Cladding (Wall thickness, pre-oxidation, pre-hydriding, irradiation)	Unirradiated Zircaloy-4 PWR cladding, 0.57mm thick As-received Pre-hydrided :400~600wtppm	Irradiated cladding Thinned cladding BWR cladding
Oxidation temperature	1050K−1550K	
Oxidation time	100s−7500s	
Oxidation amount	5−65% ECR*	

* ECR : Equivalent Cladding Reacted (Proportion of oxide layer thickness assuming that all of absorbed oxygen forms stoichiometric ZrO_2)

History of cladding temperature



Post-test examination



For metallographic analysis

Hydrogen analysis

Hydrogen concentration

Hydride morphology

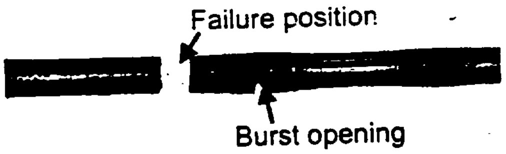
Circumferential length,
Cross sectional area

Thickness of
each layer

➡ Evaluate oxidation amount, radial expansion, axial profile of hydrogen concentration.

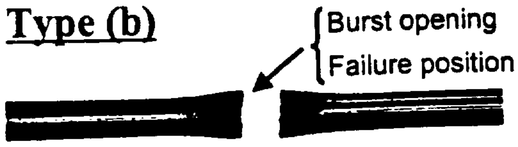
Post-test appearance

Type (a)



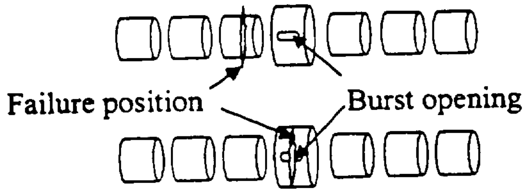
Indicating large influence of significant hydrided by inner surface oxidation

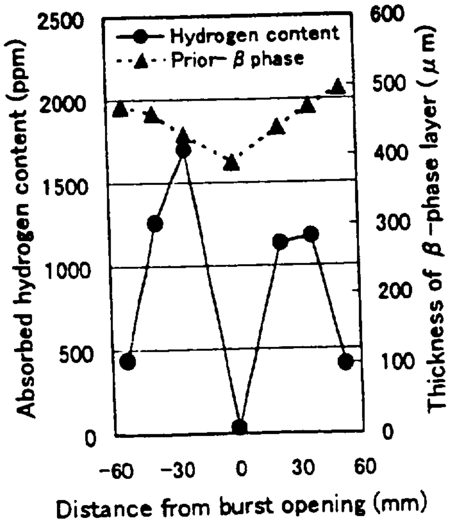
Type (b)



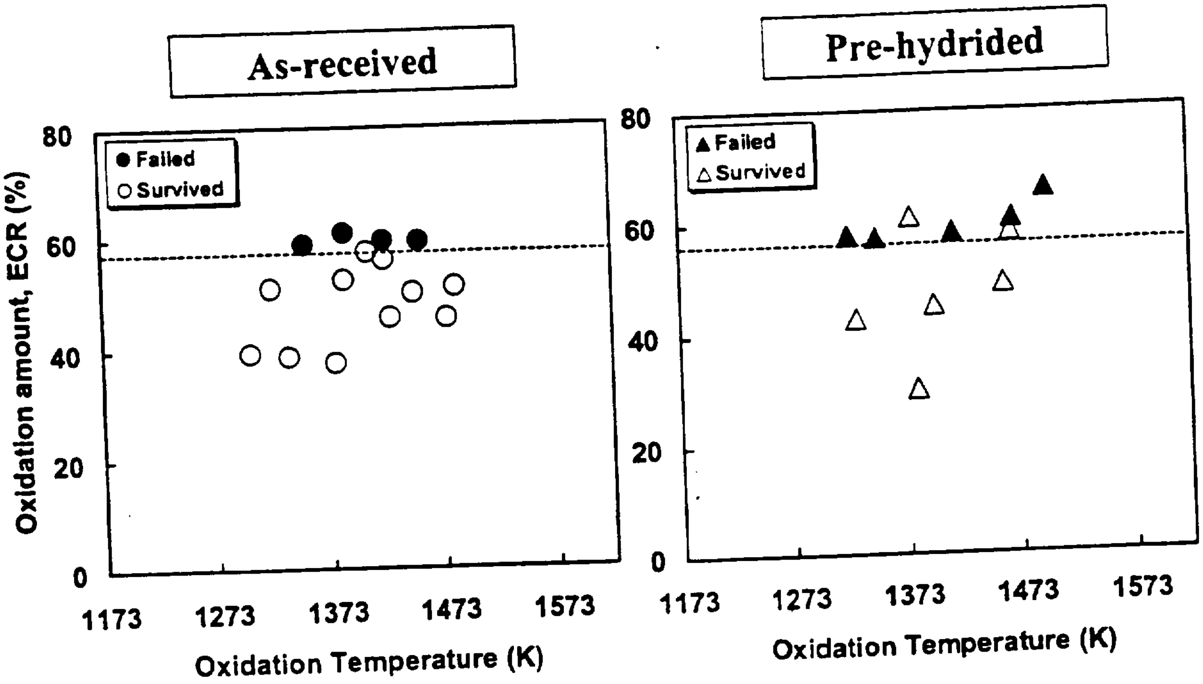
Suggesting influence of reduction of cladding wall thickness and double side oxidation

As-received



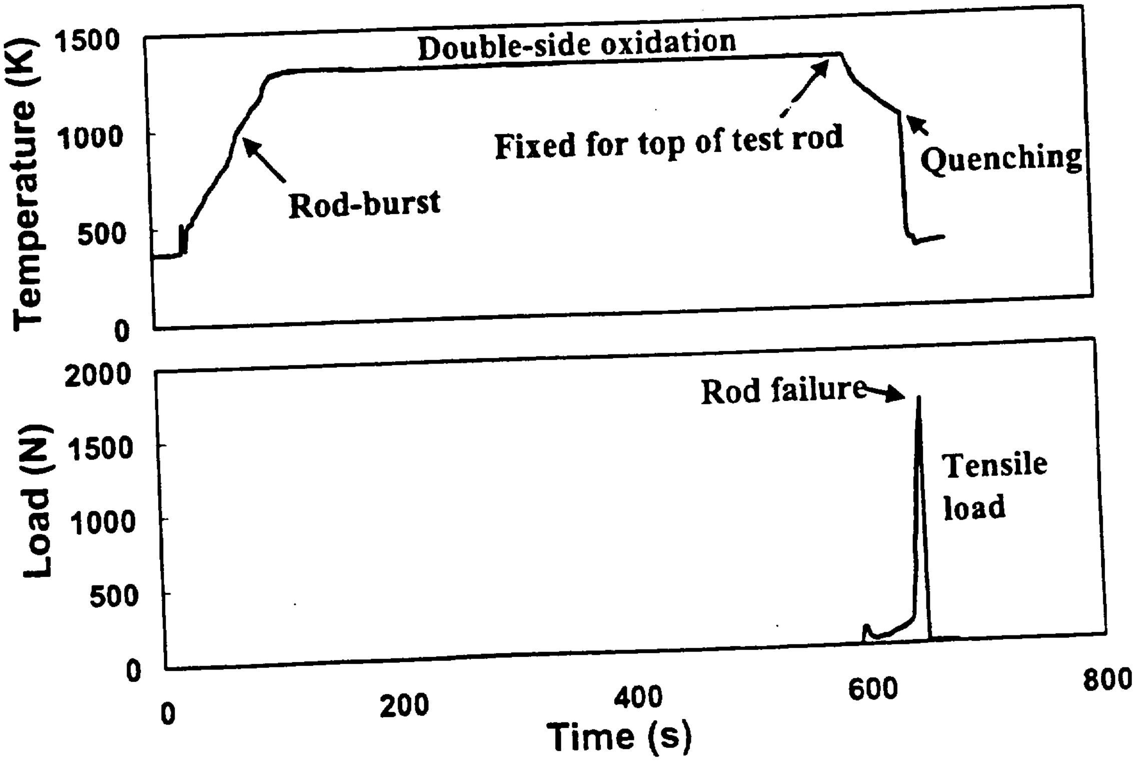


Failure map(1/2) -No restraint condition-

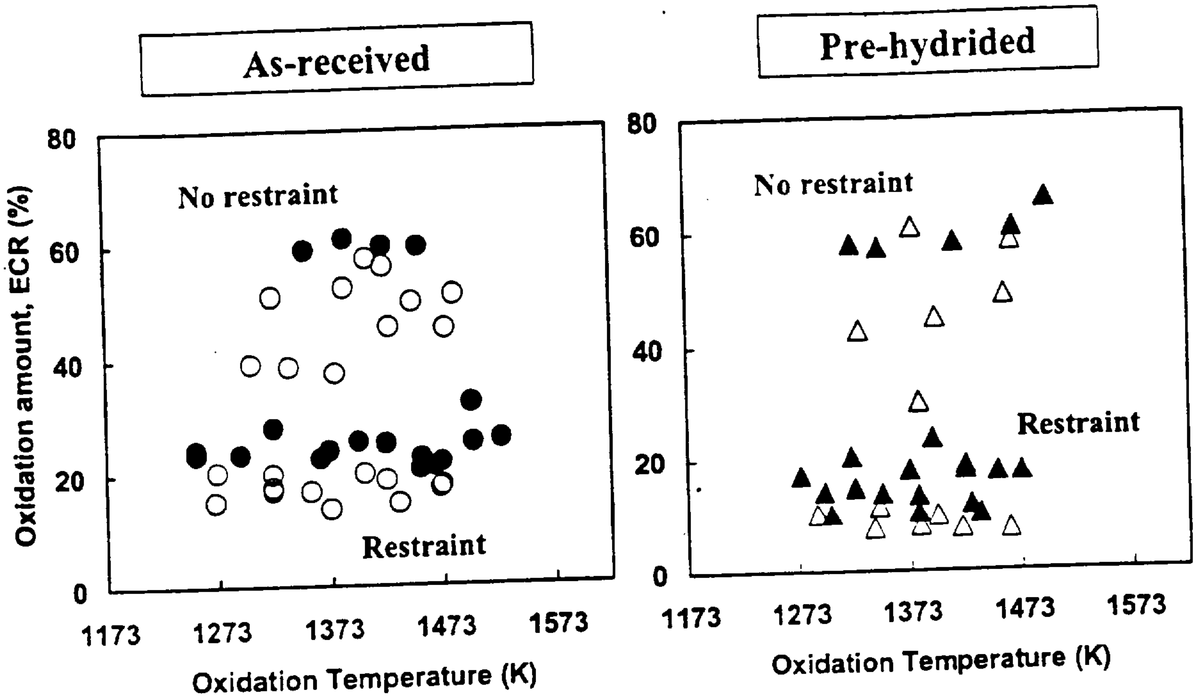


ECR was calculated with the Baker-Just equation taking account of double sided oxidation after rupture and increase of circumference by ballooning.

Cladding temperature and load at fracture under Restraint condition

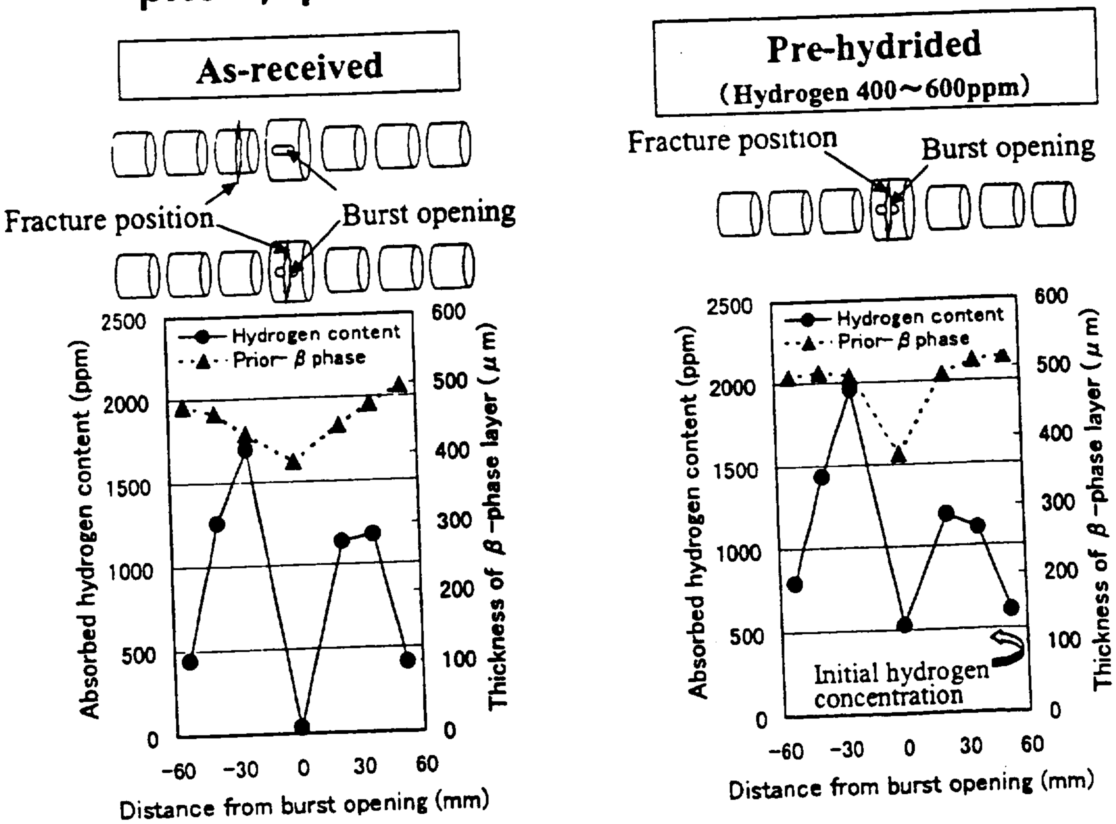


Failure map(2/2) -Restraint condition-

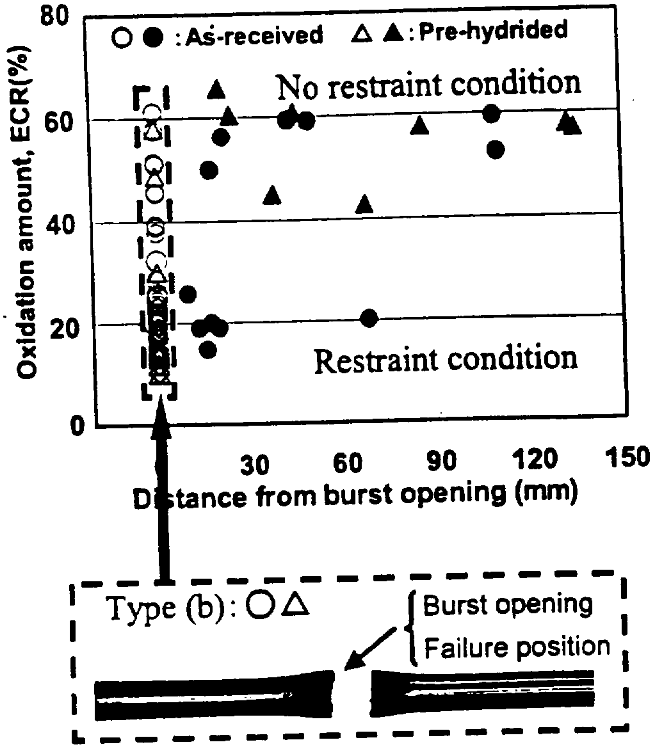


ECR was calculated with the Baker-Just equation taking account of double sided oxidation after rupture and increase of circumference by ballooning.

Axial profile of hydrogen content and thickness of prior-β phase under Restraint conditions

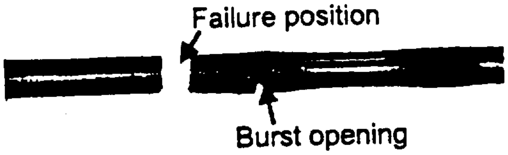


Failure position

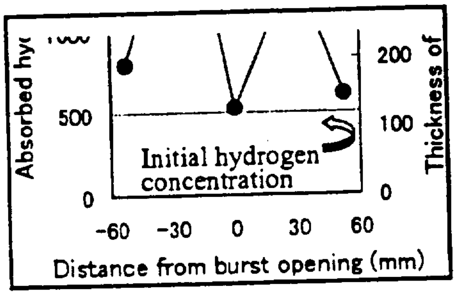


Suggesting influence of thinner cladding wall

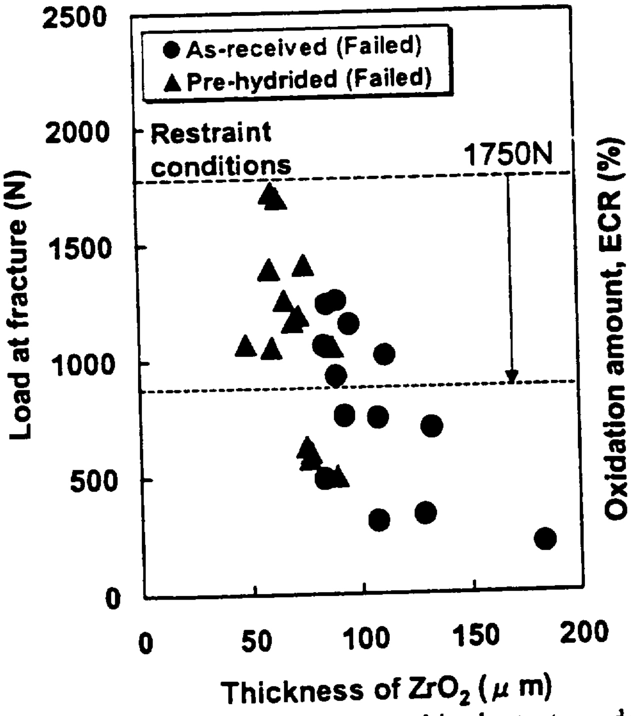
Type (a): ●▲



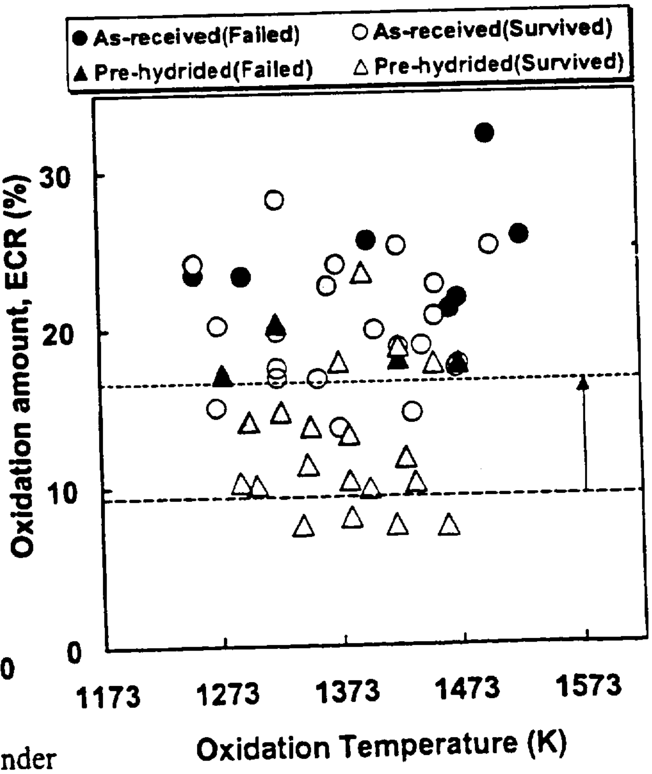
Indicating large influence of significant hydrided by inner surface oxidation



Influence of axial restraint on failure boundary



Load fracture measured in the tests under restraint condition as a function of ZrO_2 thickness.



Summary

- Integral thermal shock tests have been performed with as-received and pre-hydrided (400~600 wtppm) Zircaloy-4 claddings, simulating rod-burst, double-side oxidation and quench by reflooding.
- Following information was obtained on thermal shock failure behavior including
  - Position of rod failure on quench
  - Axial hydrogen profile
  - Load at fracture under full restraint condition
  - Oxidation condition of thermal shock failure
- Influence of axial restraint during quench became larger in pre-hydride cladding.