21A-006

Creep model and experimental data for CrAl–ODS–Zr alloy ATF cladding

Jong-Dae Hong[a*], Hongryul Oh[a], Jae Yong Kim[a]

[a] *Nuclear Fuel Safety Research Division, Korea Atomic Energy Research Institute, Daejeon, 34057, Rep. of Korea*

E-mail: jongd@kaeri.re.kr

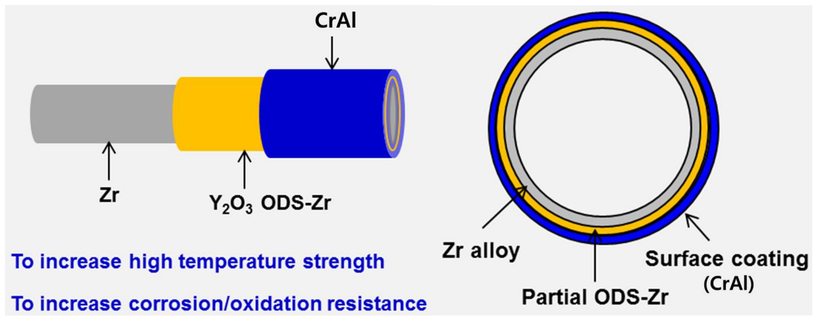
KAERI 한국원자력연구원 Korea Atomic Energy Research Institute

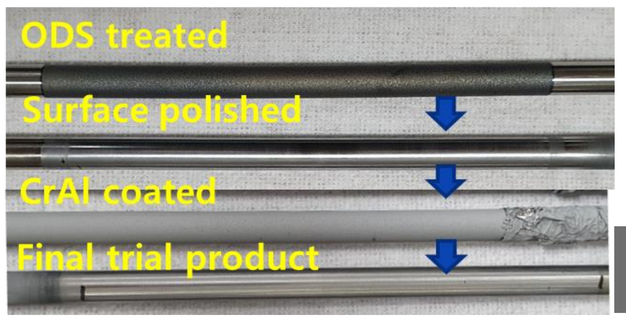
사단법인 한국원자력학회 KOREAN NUCLEAR SOCIETY

추계 학술대회
Oct 21-22, 2021
On-line

Introduction

- CrAl–ODS–Zr alloy ATF cladding [1]
  - Surface modified Zr cladding concept in KAERI
  : CWSR Zry–4 cladding
    + Partial ODS treatment using Y_2O_3 particles by laser beam scanning (LBS) process
    + CrAl coating by arc ion plating (AIP) method



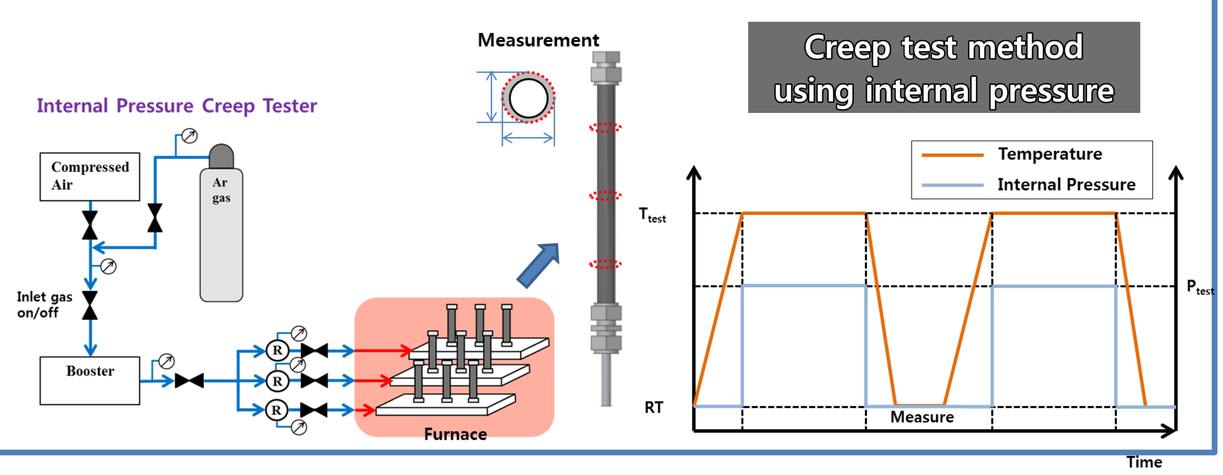


Structure of CrAl-ODS-Zr alloy cladding and manufacturing process

- Creep
  - One of the governing mechanisms inducing cladding deformation during the nominal LWR operation
  - Effect of improving the strength of the ODS layer greatly also in creased the creep resistance
- In this regard, the development of a creep law for CrAl–OD S–Zr alloy ATF cladding was based on experimental results obtained from tests by modification of FRAPCON creep mod el. Also, additional creep tests for CrAl–ODS–Zry–4 ATF cla dding were performed and test results were compared with modified FRAPCON creep model.

Experimental

- Creep test
  - Test material : CrAl–ODS–Zr alloy ATF cladding
  - Internal pressurization method with 150–mm long specimens
  - 350° C and 70/90/120 MPa of hoop stress for 3800 hours
  - Creep strain : from the average outer diameter measurement using a micrometer with a 0.0001–mm resolution



Creep test method using internal pressure

Results and Discussion

- FRAPCON creep model
  - given by Limbäck and Andersson (Thermal +Irraidation creep)

Parameter	Units	Values for SRA Cladding
A	K/MPa/hr	1.08E9
E	MPA	1.149-59.9*T
a_i	MPa^{-1}	650{1-0.56[1-exp(-1.4E-27*$\Phi^{1.3}$)]} Φ = fast neutron fluence (n/cm²)
n	unitless	2.0
Q	kJ/mole	201
R	kJ/mol-K	0.008314
C_0	$(n/m^2\text{-}s)^{-C1}$ MPa^{-C2}	4.0985E-24
C_1	unitless	0.85
C_2	unitless	1.0
f(T)	unitless	T<570K 0.7283 570<T<625K -7.0237+0.0136T T>625K 1.4763

FRAPCON creep model (CREPR) [3]

Secondary rate

$$\dot{\varepsilon}_{th+irr} = \dot{\varepsilon}_{th} + \dot{\varepsilon}_{irr}$$

$$\dot{\varepsilon}_{th} = A\frac{E}{T}\left(\sinh\frac{a_i\sigma_{eff}}{E}\right)^n \exp\left(\frac{-Q}{RT}\right)$$

$$\dot{\varepsilon}_{irr} = C_0 \cdot \phi^{C_1} \cdot \sigma_{eff}^{C_2} \cdot f(T)$$

$\dot{\varepsilon}_{th}$ = thermal strain rate (in./in./hr)
$\dot{\varepsilon}_{irr}$ = irradiation strain rate (in./in./hr)
T = temperature (K)
σ_{eff} = effective stress (MPa)
R = universal gas constant (0.008314 kJ/mol-K)
ϕ = fast neutron flux (n/m^2-s)

Saturated primary strain

$$\varepsilon_p^s = 0.0216 \cdot \dot{\varepsilon}_{th+irr}^{0.109}\left(2-\tanh\left(35500\cdot\dot{\varepsilon}_{th+irr}\right)\right)^{-2.05}$$

Total thermal strain

$$\varepsilon_H = \varepsilon_p^s\left(1-\exp\left(-52\cdot\sqrt{\dot{\varepsilon}_{th+irr}\cdot t}\right)\right) + \dot{\varepsilon}_{th+irr}\cdot t$$

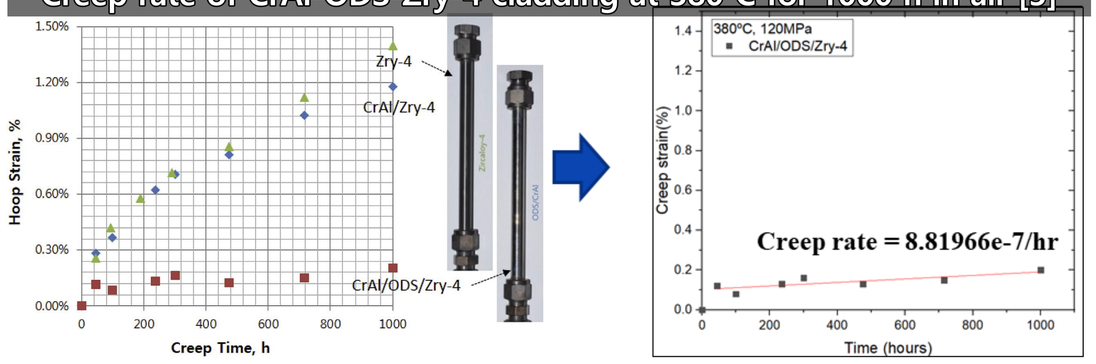
Primary / Secondary

Total thermal strain rate

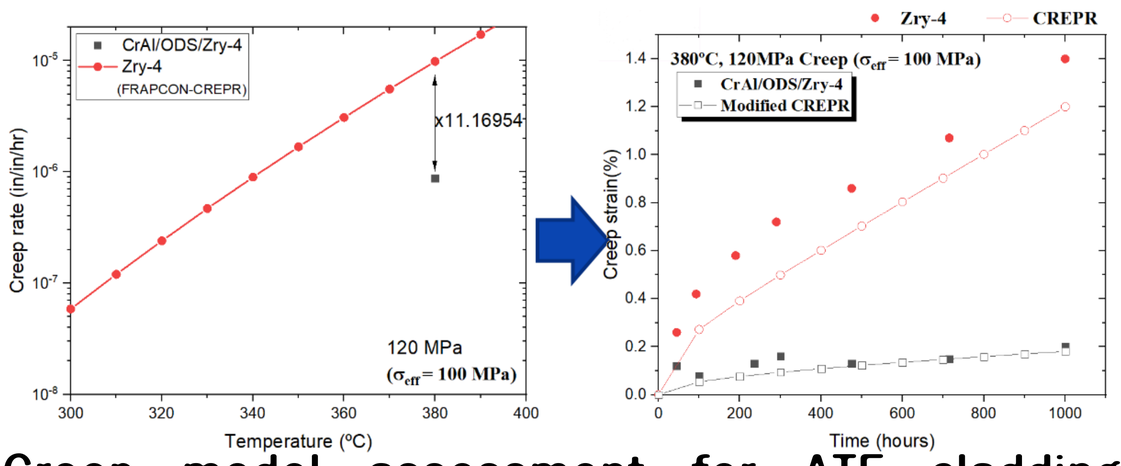
$$\dot{\varepsilon}_H = \frac{52\cdot\varepsilon_p^s\cdot\dot{\varepsilon}_{th+irr}^{1/2}}{2\cdot t^{1/2}}\exp\left(-52\cdot\sqrt{\dot{\varepsilon}_{th+irr}\cdot t}\right) + \dot{\varepsilon}_{th+irr}$$

- Modified FRAPCON creep model for ATF cladding
  - Modify FRAPCON creep model using existing data
    - 11.17 times lower than that of Zry–4
  - Greatly reduced compared with the uncoated Zry–4
  - Same trend to have same effects of temperature and stress with Zr–alloys are assumed due to limited data
    => Parameter "A" modified

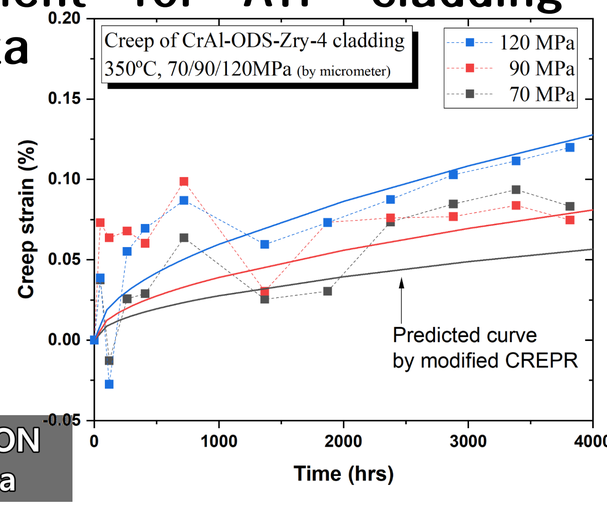
Creep rate of CrAl-ODS-Zry-4 cladding at 380°C for 1000 h in air [5]



Modified FRAPCON creep model for CrAlODS-Zry-4 cladding



- Creep model assessment for ATF cladding versus experimental data
  - Compared with additional test data
    - Scattered test data with very small strain
  - Good agreement with the trends and magnitude



Prediction curve by modified FRAPCON creep model with experimental data

Conclusion

- To evaluate creep deformation of CrAl–ODS–Zry–4 ATF cladding, the FRAPCON creep model for Zr–alloy cladding was modified based on the existing experimental data
- For a comparison, additional creep tests were performed and additional data are good agreement with the trends and magnitude of predictive curve, although measured data are widely scattered with large uncertainties

Acknowledgments & References

- This work has been carried out under the Nuclear R&D Program supported by the Ministry of Science and ICT. (NRF–2017M2A8A5015064)

[1]] J.–D. Hong, J.Y. Kim,, 2021 KNS spring meeting
[2] J.–D. Hong et al, Nucl. Technol. 203 (2018) 282–292
[3] FRAPCON 4.0, PNNL–19418 Vol.1 Rev.2
[4] M. Limbäck, T. Andersson, ASTM STP 1295. pp. 448–468, 1996.
[5] H.–G. Kim et al., J. Nucl. Mater. 510 (2018) 93–99