PO4D12

ODS Cladding Burst test using DIMAT and Transient Analysis with FRAPTRAN−KATF

KAERI 한국원자력연구원 Korea Atomic Energy Research Institute

JaeYong Kim*, ChangHwan Shin, HongRyul Oh, HyoChan Kim

Nuclear Fuel Safety Research Division, Korea Atomic Energy Research Institute, Daejeon, 34057, Republic of Korea

E-mail: kjykjy@kaeri.re.kr

사단법인 한국원자력학회 KOREAN NUCLEAR SOCIETY

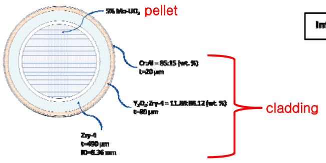
추계 학술대회

Oct. 21-22, 2021

On-line

Introduction

- **Oxide dispersion strengthened (ODS) Zry-4 cladding**
  - One of the candidates for ATF in KAERI
  - A laser beam scanning (LBS) has been employed.
  - Effective way to increase the strength of Zry-4 cladding
- **Ballooning phenomenon of multi-layered cladding**
  - Analysis by using creep strain has been performed to evaluate the cladding large deformation.
  - Creep strain rate is described in the form of the Arrhenius equation.
  - Coefficients of a multi-layered cladding are hard to measure by using conventional test methods.



Internal pressure case ($\sigma_r = 0, \sigma_\theta = 2\sigma_z$)

$$\dot{\varepsilon}_\theta = A_\theta \exp\left(-\frac{Q}{RT}\right)\sigma_\theta^n$$

$$A_\theta = \left(\frac{F+G}{4}+H\right)^{\frac{n-1}{2}}(0.5F+H)(F+G)^{-\frac{n+1}{2}}A_z$$

$$\sigma_\theta = \sigma_{\theta,0}\exp\left(\left(\frac{0.5G+H}{0.5F+H}+1\right)\varepsilon_{\theta,true}\right)$$

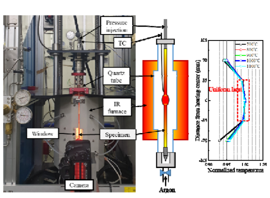
Axial creep

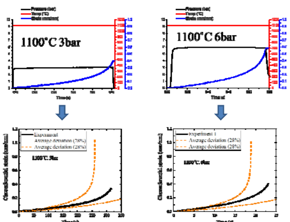
$$\dot{\varepsilon}_z = A_z \exp\left(-\frac{Q}{RT}\right)\sigma_e^n$$

- **DIMAT burst tests are performed and the creep coefficients of a ODS cladding are derived.**
- **These coefficients are applied to FRAPTRAN-KATF which creep-based large deformation module is installed and compared with ODS test results.**

Coefficients of multi−layered cladding by using DIMAT

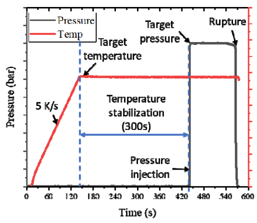
- **DIMAT**
  - Steady-state creep test and tube burst test could be performed by using DIMAT (Deformation In-situ Measurement Apparatus by image-analysis Technique).
  - During tests, deformed shape and dimensions of a cladding could be measured in real-time.





- **Anisotropic and creep coefficients**
  - Anisotropic (F, G, H) and creep coefficients (A_z, Q, n) of a multi-layered cladding could be obtained by using steady-state creep tests. (A_θ is measured)

▪ Steady-state creep experiment



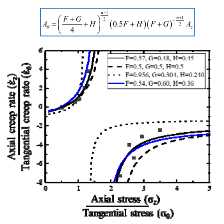
α-phase

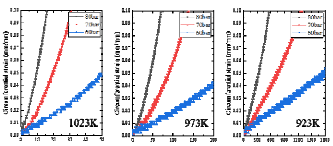
Temperature [K]	Pressure [bar]
923	80
	70
	60
973	80
	70
	60
1023	80
	70
	60

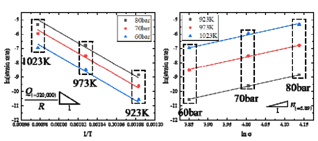
β-phase

Temperature [K]	Pressure [bar]
1373	3
	6
	6

▪ Anisotropic coefficients are obtained



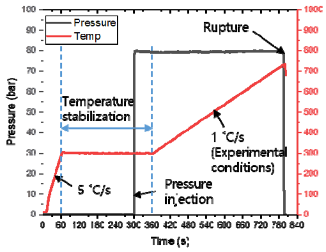




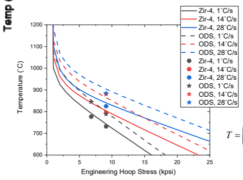
$$\ln\dot{\varepsilon}_\theta = -\frac{Q}{RT} + \ln A_\theta + n\ln\sigma_\theta$$

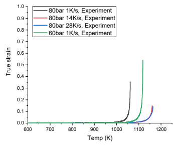
$$\ln\dot{\varepsilon}_\theta = n\ln\sigma_\theta + \ln A_\theta - \frac{Q}{RT}$$

Burst tests using DIMAT and transient analysis



Pressure [bar]	Heating rate [K/s]	Burst Temperature [°C]
80	1	789
	14	880
	28	885
60	1	845



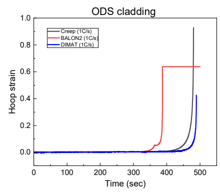


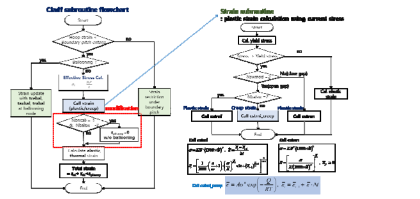
Parameter	Zircaloy-4	ODS
A_z [$Mpa^{-n}s^{-1}$]	19400	22900
n [-]	5.89	6.60
Q/R [K]	38487	44861

$$T = \left(3960 - \frac{20.4\sigma}{1+H} - \frac{8510000\sigma}{100(1+H)+2790\sigma}\right)\times 1.075$$

$$\left[H = \frac{Heating\ Rate}{28}\right]$$

- **Burst tests and creep coefficients of ODS cladding**
  - It is assumed that F, G, H are 0.5, because more random microstructure is formed than as-fabricated claddings during ODS manufacturing process.
  - The creep coefficients of a ODS cladding is estimated by using the measured real-time data.
  - The rupture occurs at the temperature about 1.075 times higher than the Zry-4.
  - It is needed to obtain anisotropic coefficents with uniform ODS claddings if possible.
- **Transient analysis of ODS cladding using FRAPTRAN-KATF**
  - The large deformation evaluation module based on the creep model, Mo thermal conductivity, CrAl oxidation models and ODS mechanical properties are applied to FRAPTRAN-2.0 for ATF safety evaluation.
  - FRAPTRAN strain limits are used to predict failure in ballooning.
  - Creep-based large deformation model is more consistent with the physical phenomenon than original FRAPTRAN large deformation module, BALON2.





Conclusion

- To obtain the creep coefficients for ODS cladding, DIMAT tests were performed.
- Creep-based large deformation module with them was well simulated a ODS cladding burst test.
- As a result of the analysis, although the time of failure is delayed, the strain according to time is well predicted.
- In the future, it is needed to establish stress and strain limits for ATF claddings.

Acknowledgements & References

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

[1] H.-G. Kim et al, Top fuel 2017.
[2] H.-G. Kim et al, Addit. Manuf. 22 (2018) 75-85.
[3] D.-H. Kim et al, Mater. Today Comm. 27 (2021) 102210.
[4] G.-H. Choi et al, Nucl. Eng. and Des. 370 (2020), 110859.
[5] D. Powers et al, NUREG-0630, S. NRC, 1980.
[6] G.-H. Choi et al, KAERI/TR-8338/2020, (2020).
[7] C.-H. Shin et al, KAERI/TR-8595/2021, (2021).