



HAL
open science

A new experimental setup for high temperature creep test on Zircaloy-4 fuel rods internally pressurized

Damien Campello, Nicolas Tardif, Anne Maynadier, Marie-Christine Baietto, Michel Coret, Jean Desquines

► To cite this version:

Damien Campello, Nicolas Tardif, Anne Maynadier, Marie-Christine Baietto, Michel Coret, et al.. A new experimental setup for high temperature creep test on Zircaloy-4 fuel rods internally pressurized. ICEM17, Jul 2016, Rhodes, Greece. hal-01863168

HAL Id: hal-01863168

<https://hal.science/hal-01863168>

Submitted on 28 Aug 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

A NEW EXPERIMENTAL SETUP FOR HIGH TEMPERATURE CREEP TEST ON ZIRCALOY-4 FUEL RODS INTERNALLY PRESSURIZED

D. Campello, N. Tardif, A. Maynadier, M.-C. Baietto, M. Coret, J. Desquines

Université de Lyon, CNRS, INSA-LYON, LaMCoS UMR 5259, 20 Avenue Albert Einstein, F69621 Villeurbanne Cedex, France

Abstract: Custom experimental setup has been designed to investigate the secondary creep behavior of Zircaloy-4 cladding under Loss Of Coolant Accident (LOCA) conditions. Creep test are ran at elevated temperatures (from 700 to 900 °C) and the fuel rods are internally pressurized from 10 to 50 bars. The proposed setup induces a non-uniform axial temperature profile. At such temperatures the creep behavior is known to be strongly dependent on the temperature. Two dimensional Digital Image Correlation (2D-DIC) is performed using a custom optical system to compute kinematics data along the axial direction. Near Infra-Red (NIR) method has been developed to measure the temperature distribution. The correlation between the kinematics and thermal profiles is a good way to experimentally determine creep behavior parameters such as activation energy or stress exponent. The setup, its associated methods and results are detailed in this paper.

1. Introduction

During a hypothetical LOCA a break appears in the primary loop of a Pressurized Water Reactor. The water is depressurized and a hoop loading stress is then applied to the fuel rods. The cladding temperature is quickly increasing at the same time. To representatively simulate the entire LOCA, lots of parameters are needed. High temperature creep behavior of Zircaloy-4 internally pressurized is here investigated. The experimental setup designed by Tardif et al. [1] is upgraded to test Zircaloy-4 claddings in inert atmosphere. The non-uniform temperature distribution is measured and three hoop stress loadings are applied in a single creep test. The bench is fitted to perform 2D-DIC [2] and NIR measurements [3]. These digital image techniques capitalize the thermal and kinematics distribution to experimentally reach creep parameters.

$$\dot{\epsilon}_{ss} = A \cdot \sigma^n e^{-\frac{Q}{R \cdot T}} \quad (1)$$

As explained by Hayes et al. [4], high temperature creep behavior of Zircaloy-4 can be modeled using eq. (1). The steady-state strain rate $\dot{\epsilon}_{ss}$ depends on the true stress σ and the temperature T. The stress exponent n, the activation energy Q and the multiplicative coefficient A have to be determined.

2. Results

Specimens are cut off from Zr-4 cladding tubes by electro discharge machining. They are 90mm long, 0,57mm thick and their outer radius is 4,75mm. The experimental setup designed heats the specimen using an induction device¹. Argon flushing is maintained inside an enclosure during the whole test to lower metal oxidation. Three hoop stress loadings are successively applied. The Region Of Interest (ROI) is observed by 2 cameras performing 2D-DIC and 2 others performing NIR measurements. Processing has been developed to compute steady-state

¹ 6 kW induction CELES generator.

creep-rate and the temperature along the ROI. A radiometric model is calibrated using the heating data from thermocouples and cameras. Temperature distribution is plotted versus axial position in Fig. 1.a.

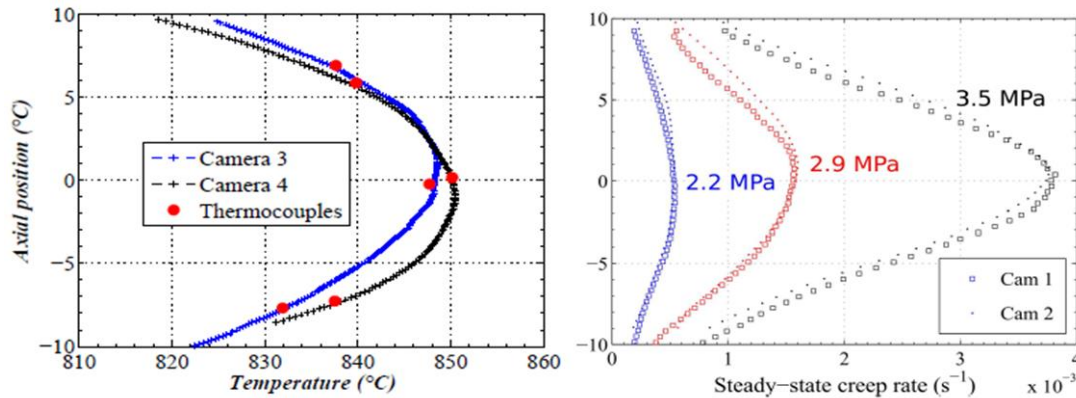


Figure 1: Thermal distribution using NIR method updated by thermocouples measurements on the left (1.a) and steady-state creep-rate distribution calculated from 2D-DIC. The results gathered from two cameras are superimposed in both thermal and kinematics figures. The results are consistent with an axisymmetric assumption.

Kinematics fields are calculated using the internal software Ufreckles developed by J. Réthoré à LaMCoS. The equation of the optical flow is solved using a non-linear least square method relying on a finite element basis. Creep-rates results of a single test ran at internal pressures of 2.2 MPa, 2.9 MPa, and 3.5 MPa are plotted versus axial position in Fig. 1.b. The creep-rates results and the determined creep parameters are extremely consistent with the literature data [5].

3. Conclusions

The custom experimental setup is validated by comparing creep-rates determined to literature data. Moreover a single test leads to the determination of creep parameters such as stress exponent and activation energy at a first order. The rich kinematics and thermal data will be capitalized in further work using a FEMU based on the Levenberg-Marquardt algorithm to accurately determine behavior laws. The test will be simulated with the commercial Abaqus software using an axisymmetric model.

Acknowledgements

The study was performed in the framework of the PERFROI ANR project (n° ANR-11-RSNR-0017-01). The authors would like to acknowledge all the participants of the project: EDF, IRSN-SEREX, LEMTA, Ecole Centrale of Paris.

References

- [1] N. Tardif, M. Coret, A. Combescure, Experimental study of the fracture kinetics of a tubular 16MnNiMo5 steel specimen under biaxial loading at 900 and 1000°C. application to the rupture of a vessel bottom head during a core meltdown accident in a pressurized water reactor, *Nuclear Engineering and Design* 241 (3) (2011) 755 – 766.
- [2] M. Sutton, W. Wolters, W. Peters, W. Ranson, S. McNeill, Determination of displacements using an improved digital correlation method, *Image and vision computing* 1 (3) (1983) 133–139.
- [3] F. Meriaudeau, E. Renier, F. Truchetet, Temperature imaging and image processing in the steel industry, *Optical Engineering* 35 (12) (1996) 3470–3481.
- [4] T. A. Hayes, M. Kassner, Creep of zirconium and zirconium alloys, *Metallurgical and Materials Transactions A* 37 (8) (2006) 2389–2396.
- [5] H. E. Rosinger, P. C. Bera, W. R. Ciendening, The steady-state creep of Zircaloy-4 fuel cladding from 940 to 1873 K, *Tech. rep.*, Atomic Energy of Canada Limited (1978).