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

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

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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.

$$\dot{\varepsilon}_{ss} = A.\sigma^{n} e^{-\frac{Q}{R.T}} \tag{1}$$

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 $\dot{\varepsilon}_{ss}$ 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 device[1]. 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.

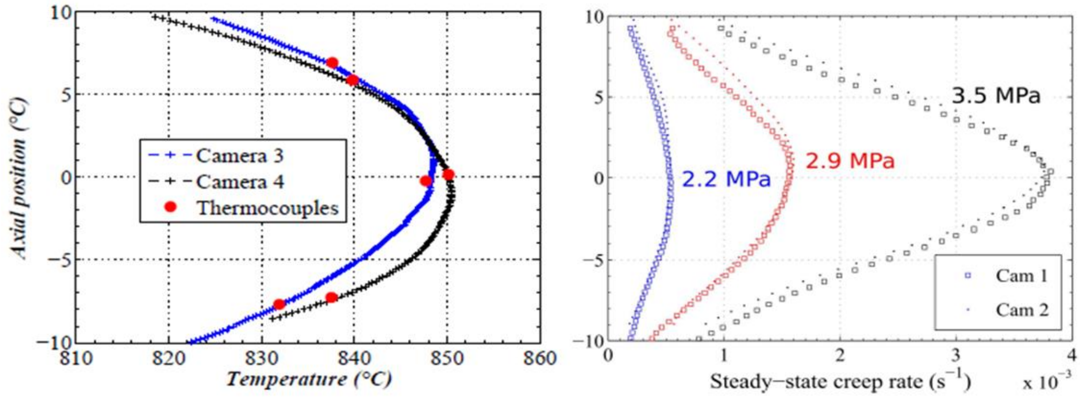

Figure 1: Thermal distribution using NIR method updated by thermocouples measurements on the left (1.a) and steady-state creep-rate distribution calculated from 2D-DIC. The results gathered from two cameras are superimposed in both thermal and kinematics figures. The results are consistent with an axisymmetric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

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