"CEDRIC EXPERIMENT: ON LINE ELONGATION MEASUREMENT OF A HIGH TEMPERATURE SPECIMEN UNDER DRIVEN STRESS IN THE OSIRIS REACTOR",

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Abstract – *The CEDRIC irradiation experiment is dedicated to SiC/SiC cladding performance evaluation. The JHR and OSIRIS teams have jointly worked on the design of a specific irradiation device which can perform an irradiation in the OSIRIS core of a SiC/SiC mini composite at a high level of temperature between 600 and 1000°C. During irradiation, a pneumatic monitored bellows applies an axial strength on the sample, furthermore an on-line elongation system measures the resulting creep deformation.*

I - OSIRIS reactor.

OSIRIS is a research reactor with a thermal power of 70 MW. It is a light-water reactor, open-core pool type (see figure 1), the main aim of which is to carry out tests and irradiate the fuel elements and structural materials of nuclear power plants under a high flux of neutrons, and to produce radioisotopes [1]. Located within the French Atomic Energy Commission (CEA) centre at Saclay, it is close to many research teams and inspection laboratories and has a large-scale technological infrastructure.

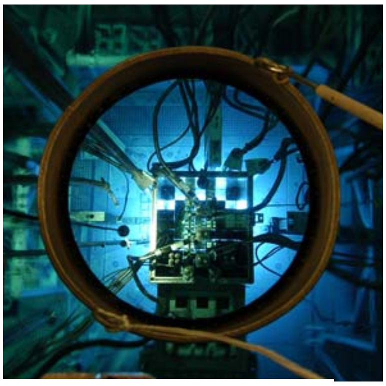

Fig. 1. View of the OSIRIS core.

II - The CHOUCA device

The irradiation device that has been chosen to host the CEDRIC experiment is the CHOUCA. It is a device dedicated to the irradiation of materials in the core or on the periphery of the reactor.

It consists of 2 concentric tubes delimiting a gas gap, which is used:

- to adjust the temperature inside the internal tube depending on the position and the sample load by modifying the nature of the gas it contains,
- to control the leak from either one of the tubes ensuring the containment of the samples.

Electric heating elements are placed on the internal tube, quenched by a spray of metal particles gauged by further finishing. This heating system ensures fine tuning of the temperature of the samples throughout the irradiation by responding instantaneously to variations in heating from the reactor.

Sample-holders are inserted inside the capsule to receive the samples. They are specific to each type of experiment. The experiments carried out in CHOUCA systems typically relate to fuel cladding materials, materials for the internal structures of various types of reactors or neutron-absorbing materials.

The main characteristics of this device are:

- Effective diameter: 24 mm
- Height under flux: 600 mm
- Fast neutron flux (E > 1 MeV): up to 2.10^{18} $n.m^{-2}.s^{-1}$
- Acceptable gamma heating: up to 13 $W.g^{-1}$.
- 12 thermocouples on the CHOUCA rig and 18 on the sample-holders,
- Activation foils for dosimetry to access the neutron fluence received by the samples,
- Pressure pick-ups and dimensional measurement for certain specific experiments.

III - The CEDRIC experiment

III.a - The aim of the irradiation

SiC-based materials are candidates for the cladding of high-temperature gas-cooled reactors. However, these ceramics materials are brittle and one serious issue to address is how to accommodate the large fuel swelling predicted at high burn-up. Irradiation creep, if large enough, could be part of the answer to this problem and this is a strong motivation for its study.

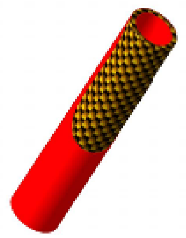

Fig. 2. Pin concept for GFR reactors.

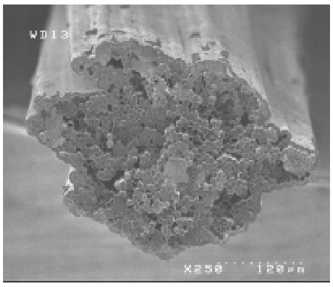

Fig. 3. Section of a mini-composite as used for CEDRIC. Typical "diameter" is 0.5 mm.

The scientific goal of the CEDRIC[1] experiment in the OSIRIS reactor is to acquire first quantitative data on SiC/SiC irradiation creep, up to 4 dpa, and at two temperatures representative of GFR working conditions (600 and 1000°C). Easier interpretation of the creep data as well as the space constraints typical of high flux irradiation positions fostered the decision to use in CEDRIC a mini-composite SiC/SiC wire instead of a sample of the "real" composite envisioned for GFR cladding (see figure 2). Indeed, such a mini-composite with its SiC fiber/interphase/SiC matrix structure retains in a simpler 1-D geometry most of the properties of the real composite.

[1] Creep Experimental Device for Research on Innovative Ceramics

III.b - The sample design

A specific irradiation device and sample have been conceived jointly by OSIRIS and JHR teams to reach the targets of the experiment. In the CEDRIC design, the mini-composite sample is about 0.5 mm in diameter (figure 3) and its free length is 40 mm. To be easily handled in hot cells, it is housed in a hollow SiC cylinder. Both ends of the sample are bonded to SiC end pieces, the lower one being tied to the cylinder, and the upper one being free in translation, hooked to a pneumatic loading system and to an elongation measurement system (figures 4 and 5).

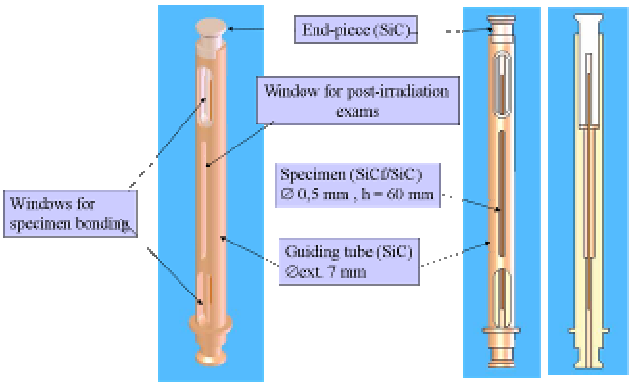

Fig.4. SiC housing of the SiC/SiC mini-composite. Top movable end-piece is hooked to a pneumatic loading unit (see next figure).

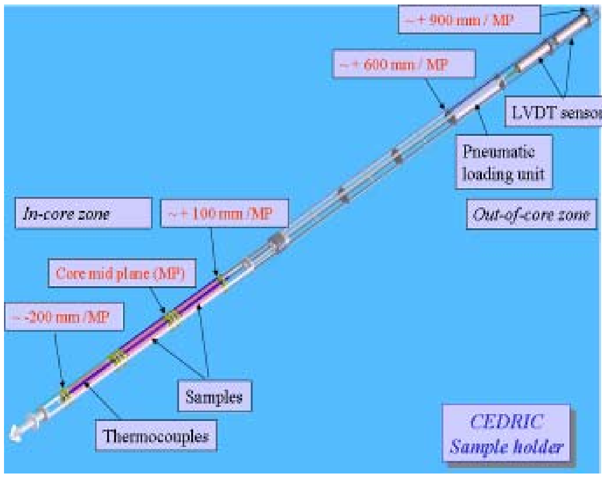

Fig. 5. Schematic view of the lower part of the CEDRIC irradiation rig, showing the LVDT sensors, the loading system and the two samples.

A specific irradiation experiment, named CROCUS [2] has been previously performed at high neutron flux and high level of temperature in OSIRIS reactor, in order to choose and qualify the best bonding system between SiC fibers and end pieces.

III.c - Sample holder mechanical design

The materials of the lower part of the sample holder have been chosen because of their good behavior under high temperature (nickel alloys, niobium, silicon carbide).

The specific bellows used for loading of the specimen was studied and qualified previously out of pile (see figure 6).

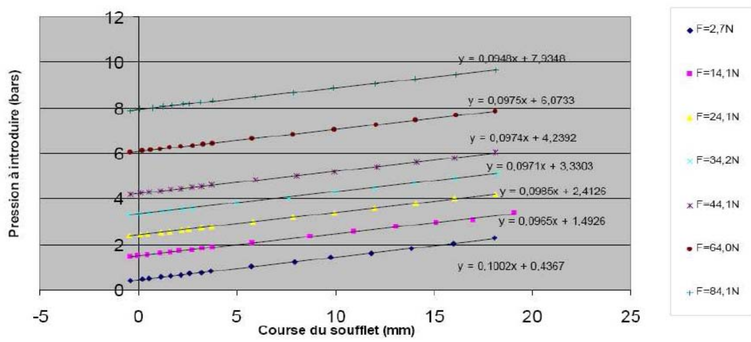

Fig. 6. Out of pile characterization of the pneumatic bellows.

Before construction of the irradiation device, a mock-up of the lower part of the sample holder has been tested out of pile in a specific electrical furnace in order to assess the global performance of the measurement system at high temperature.

The design took into account the post irradiation operations in hot cells, for instance unloading of specimen after an irradiation phase or loading of new samples for a further experiment (see figure 7). Specific tools dedicated to the hot cells have been manufactured.

The high stiffness of SiC-based materials (typ. 400 GPa) and the expected low level of creep under irradiation put severe requirements on the measurement capabilities of the experiment.

Online elongation is measured with a LVDT sensor designed by IFE Halden. Expected sensitivity is 2 µm. To improve the consistency of the measurement, several precautions were taken:

- A second identical LVDT, with a fixed plunger has been added just above the active one (see figure 5) in order to perform an online correction for its eventual drift, assuming that both LVDTs would have similar drifts in a similar environment,
- A second identical mini-composite has been added just below the main one, with no connection to the pneumatic unit, in order to do an (offline) correction of the swelling under irradiation,
- A slit has been added in the housing, to check after irradiation, but with a high precision, the true drift of the main LVDT.

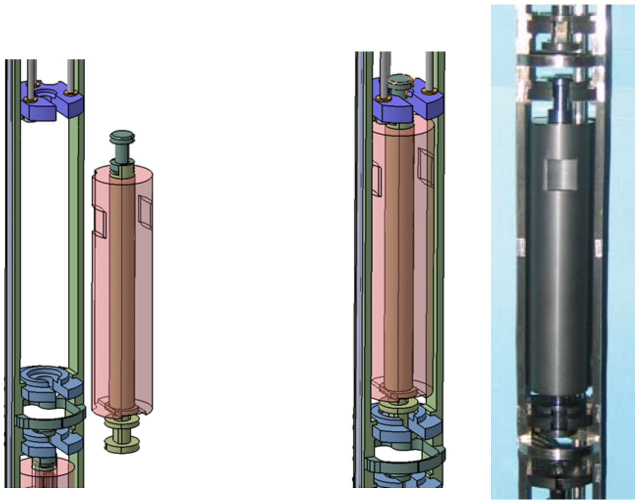

Fig 7 : Positioning of SiC sample on the CEDRIC device.

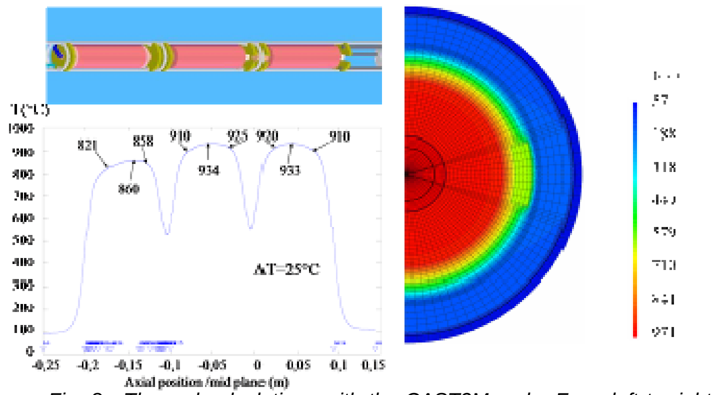

Fig. 8. Thermal calculations with the CAST3M code. From left to right, the fake sample for temperature monitoring, the unstressed reference sample and the sample under stress. In this calculation (corresponding to a configuration close to the actual one), upper thermocouples (858°C) are about 75°C below the temperature of the middle of the mini-composites.

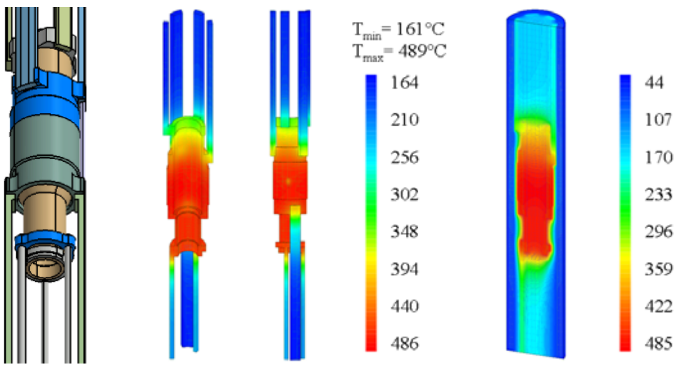

Fig 9 : Thermal calculation on structural pieces.

III.d - Thermal design

Nuclear heating management is a critical issue for CEDRIC. The initial design was optimized by 2D and 3D thermal simulations, using the CAST3M thermo-mechanical code. The two required working temperatures are obtained in a simple way, by adding (or removing) a SiC heater around the sample.

Thermal calculations for the “hot configuration” are presented on figure 8. They show a good uniformity of the temperature along the mini composite: their centre (933/934°C) is less than 25°C above their ends (910/920°C).

These calculations were also required to monitor the temperature of the SiC/SiC specimen. The small dimensions of the mini-composite preclude the direct measurement of its temperature with thermocouples. A fake SiC sample, able to house 4 thermocouples (two at each end for redundancy) was added just below the two SiC/SiC samples (see figure 5). Online temperatures of the mini-composites are derived from these thermocouples, by applying the correction deduced from the calculated on-axis temperature profile (about +60 °C in the eventual design).

Thermal simulations were also done on structural pieces of the device which are submitted to a high level of neutron flux and temperature, to assess their mechanical strength (see figure 9).

III.e - Neutron fluence

Activation foils (copper, iron and niobium) for dosimetry have been placed on the sample holder to access the neutron fluence received by the samples. Those activation foils are removed in hot cells for measurement at the end of the irradiation phase.

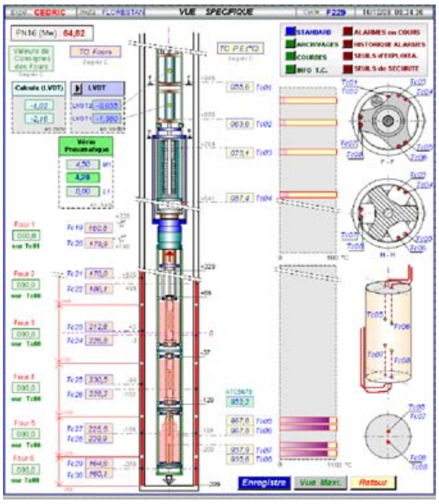

Fig 10 : CEDRIC visual.

III.f - Experiment monitoring

The CEDRIC irradiation device is connected to an out of pile instrumentation and control system for:

- Monitoring of the pneumatic pressure of the bellows (loading and unloading of the sample)
- Monitoring of the sample temperature
- Recording of the LVDT output signal (elongation of the sample)

All parameters are recorded on a computer system (acquisition rate 1Hz) for a further analysis. The control system has a visual interface to help the monitoring during irradiation phases (see figure 10).

III.g - CEDRIC first results

The irradiation started in October 2008 and should be carried on during one year. The raw elongation results of the first week of irradiation at 2.10^{18} $n/m^2/s$ under an estimated stress of 150 MPa are reported on figure 11.

Measured temperature (about 1000°C) is in very good agreement with the calculated one. The displacement measurement has been in accordance with the expectation (figure 11) and all the instrumentation has been functioning correctly since the beginning.

Final results will not be available before the post irradiation exams. Beside the corrections and checks mentioned above, the stress-force relationship implies the knowledge of the true section of the mini-composite. This section will be measured by a destructive examination of the sample.

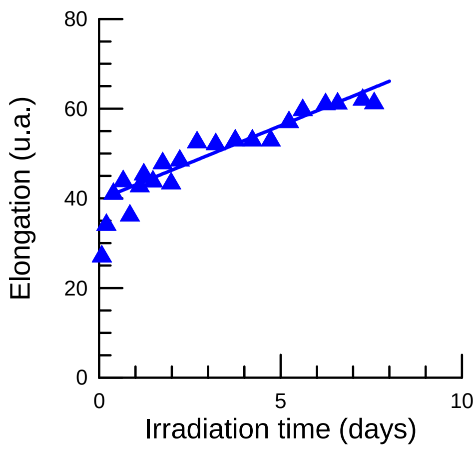

Fig. 11. First raw results of the first week of irradiation of CEDRIC.

IV – Conclusion

In the perspective of offering this kind of service in the next future the OSIRIS teams in association with JHR one continues the conception of sample holders and devices that allows online accurate measurement and stress driving for material sample in a large scale of temperature. The next step is the MELODIE experiment that will involve biaxial stress and measurement [3].

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