TESTING OF CREEP AND RELAXATION FUEL CLADDING AT THE MECHANICAL TESTING LABORATORY IN STUDSVIK

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ABSTRACT

Equipment for testing of creep and relaxation properties of irradiated cladding has been developed and used at the Studsvik mechanical test laboratory. The tests are performed by pressurizing tube samples up to maximum 1000 bar. Temperatures of 300-400°C are used. At creep testing the pressure is kept constant while the diameter increase due to creep is monitored. At relaxation testing the diameter is increased with a certain strain rate up to a certain strain, where it is then kept constant by decreasing the internal pressure. The diameter is measured by laser scanning equipment. The creep testing provides data for different materials at different temperatures and pressures, which are used for determining long term properties for dry storage. The relaxation testing provides data which are used as a basis for constitutive material models, used for determining the impact of power transients in power plant operation.

1. Introduction

1.1 Creep and Relaxation

Testing of creep and relaxation properties in cladding materials are closely related to each other, but there are principal differences between the methods, see Fig. 1.

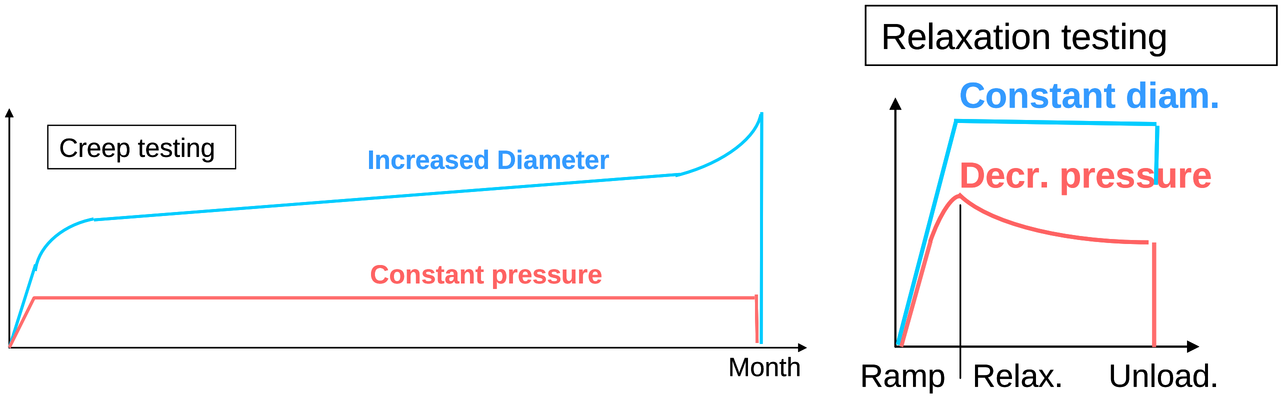


Fig. 1 Principals of Creep testing and Relaxation testing

In creep testing the material is exposed to a constant pressure during a long period of time (weeks-months), while the increasing diameter is measured. This gives data on primary, secondary and tertiary creep properties. At relaxation testing the diameter is increased during the short "ramp phase" (seconds – hours) up to a certain diametral strain, after which the diameter is kept constant during a couple of days. The constant diameter is obtained by decreasing the pressure.

For the relaxation testing the results are normally presented as hoop stress vs. hoop strain, where the stress is evaluated from the pressure and sample geometry, and the strain is evaluated from the diametral change. See Fig. 2 Principal curve for Hoop Stress vs Hoop Strain for relaxation test

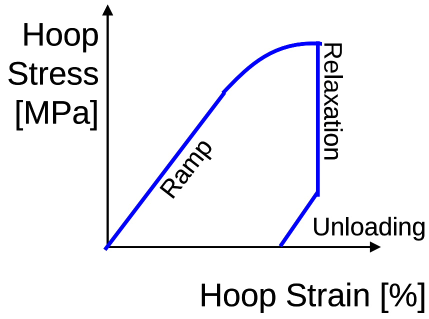


Fig. 2 Principal curve for Hoop Stress vs Hoop Strain for relaxation test

1.2 Purpose of testing

The creep properties are needed as a basis for defining operational limits for dry storage of spent fuel. The relaxation tests aim for getting data used as a basis for modelling fuel behaviour at for example power transients at reactor operation.

2. Experimental equipment

2.1 Specimens

An example of a specimens for creep and relaxation testing is shown in Fig. 3. A cladding piece is TIG-welded to an upper and a lower end plug. Inside the cladding there is a “filler” with slightly smaller diameter than the cladding ID. The purpose is to reduce the gas volume in the sample during testing. Support rings are mounted on the welds, with the purpose to limit the “active length” of the sample to the range inside the HAZ (Heat Affected Zone) and to support the HAZ. The bottom end plug is connected to a pressure supply system.

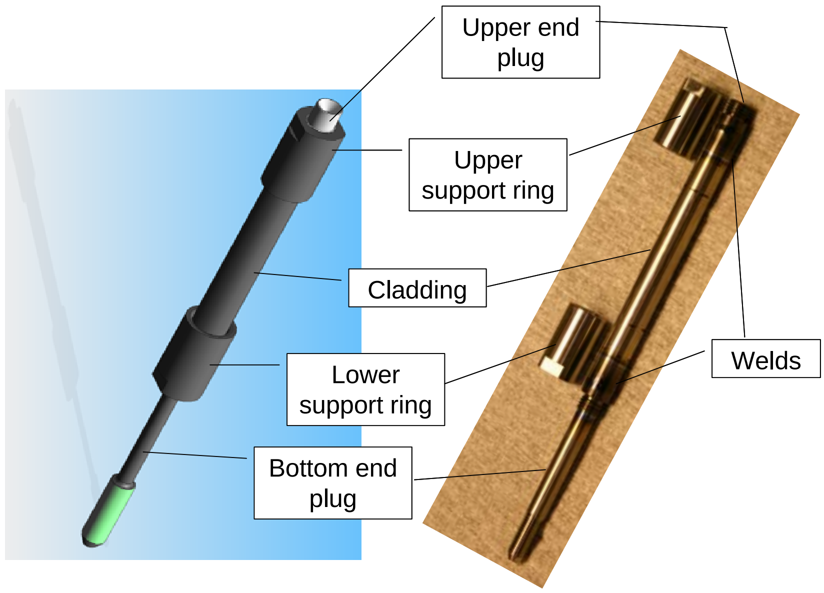


Fig. 3 Specimen for Creep or Relaxation testing. The right picture shows the specimen before mounting the support rings

2.2 Test cell

The creep and relaxation tests are performed inside steel cells, shown in Fig. 4. Cell 1 to the right is the high pressure cell (up to 1300 bar) used for relaxation testing. The next three cells (cell 2, 3, 4) with lower pressure (up to 350 bar) are used for creep testing. To the right the so called profilometry cell is shown, where the diameter of the samples can be mapped along and around the cladding.

The cells are supplied with pressurized Argon, cooling water, cooling air etc. through the bottom, and the samples are fed into the cell through the lid.

Fig. 4 Test cell 1 to 4 and profilometry cell

2.3 Furnace

Fig. 5 shows the test equipment before mounting in the cell. In the center a furnace tube is seen and around the furnace is the shielding with isolation inside. The furnace lid is turned towards the position for loading the sample into the furnace.

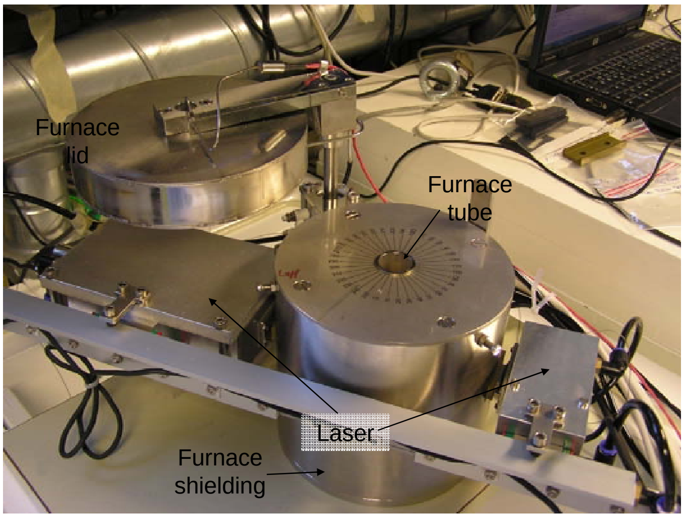


Fig. 5 Test furnace

The protractor on the upper surface is used for keeping track of the angular orientation of the sample.

2.4 Pressure supply systems

The samples are pressurized with Argon. The gas is pressurized with boosters in two steps, first to 320 bar, used in cell 2, 3 and 4, and then to 1300 bar used in cell 1.

2.5 Diameter measurement

The diameter is measured with a laser equipment. One way of measuring the diameter is shown in Fig. 6. In order to achive a stable signal the laser beams are led through glass pieces on both sides of the sample.

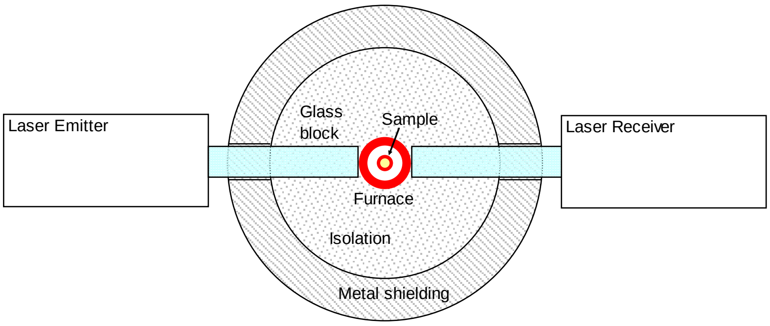
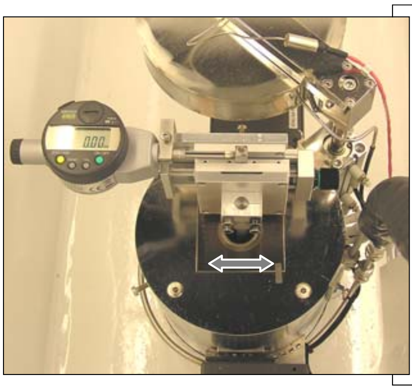


Fig. 6 Diameter measurement of the cladding sample

The diameter measurement has sometimes exhibited sensitivity for the lateral position of the sample in the furnace. Therefore a “side-way” check is regularly performed.



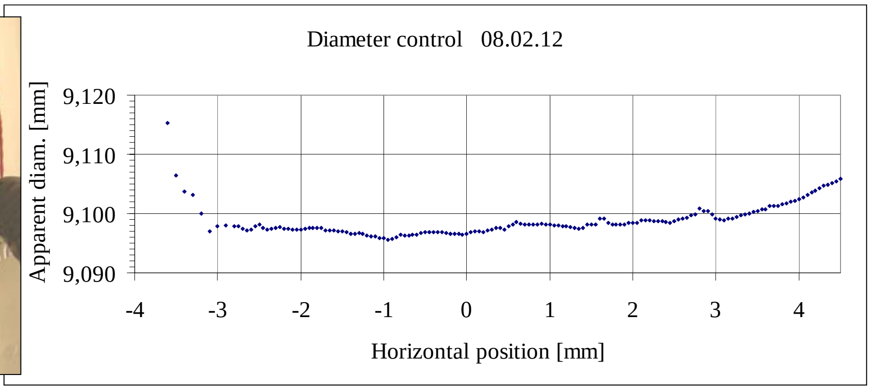


Fig. 7 Side-way check of the stability of apparent diameter

Before every creep or relaxation test the measurement equipment has to stabilize at the test temperature.

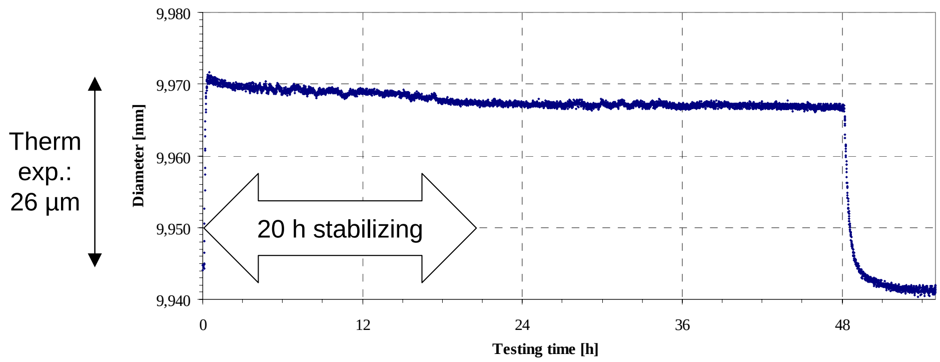


Fig. 8 Test of long term stability of the laser signal

2.6 Temperature control

It is of great importance for the results and interpretation of those that the temperature is constant along the specimen. To obtain an even temperature along the sample the furnace consists of four heating coils which are individually set. The appropriate furnace coil temperatures are determined by a measurement with a sample, identical with the real sample, but with a number of calibrated thermo couples welded on the cladding. A thorough adjustment of the four coils temperatures give a temperature variation along the sample of less than +/- 0,5degC.

Fig. 9 Sample for adjustment of temperature of the furnace coils.

3. Some results

3.1 Creep test results

Fig. 10 shows that the creep rate for irradiated cladding is dependent on the temperature and the pressures. Further it shows a strong impact of the irradiation.

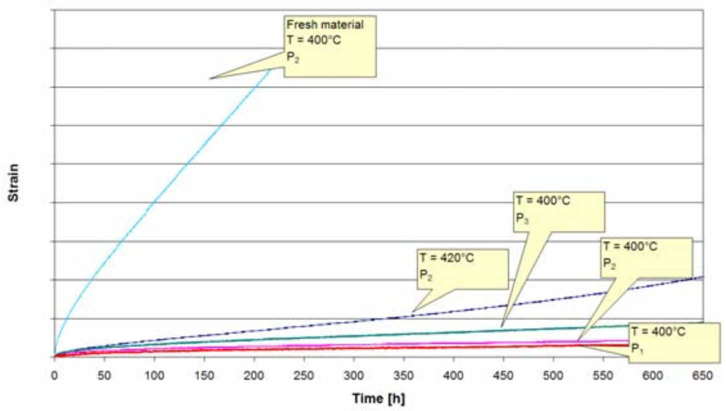


Fig. 10 Creep test results for two materials at different temperatures and pressures.

3.2 Relaxation test results

Fig. 11 shows results from four consecutive relaxation tests of an unirradiated sample. All four test were performed with different strain rates in ramps up to 0.6% strain, after which they were kept at 0.6 % for 24 hours.

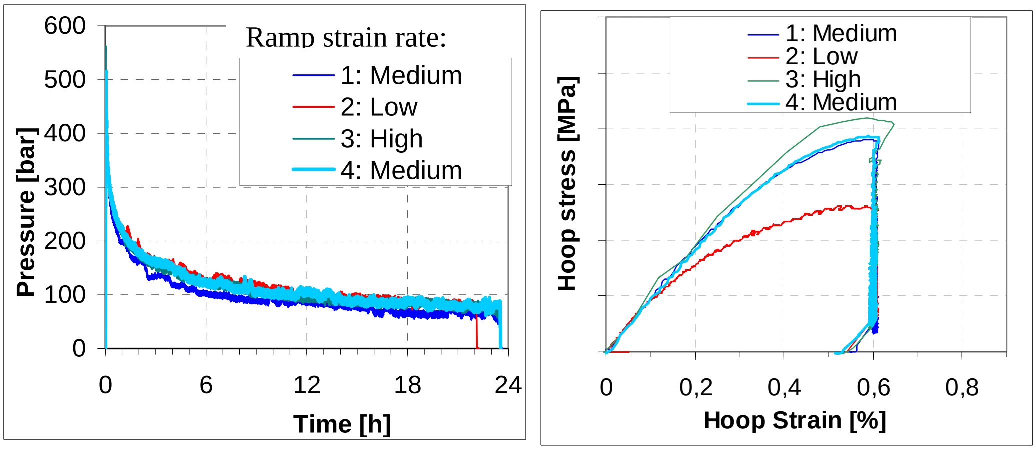


Fig. 11 Results from relaxation measurement at different strain rates in the ramp phase.

The tests show that the maximum stress after the ramp phase (right picture) is lower at lower strain rates. It means that relaxation has time to occur already during the ramp phase. After the differences during the ramp phase the pressure graphs (left picture) agree for the different ramp strain rates. The stress – strain graphs also show that the relaxation ends up at the same stress, and that the residual strain is about the same.

4. Conclusions

At Studsvik mechanical test laboratory there are facilities for testing creep and relaxation properties. A number of different materials have been tested so far and the results are used for development of materials models.

5. Acknowledgement

The test equipment has been developed, designed and built by Robert Jakobsson, Johan Flygare, Francesco Corleoni and Kananizadeh Fariborz. Vanja Liljedal has manufactured the test samples at the Hot Cell laboratory, and Johanna Hjorteen and Max Lundström have performed the testing at the Mechanical Test Laboratory. Fruitful discussions and support has been given by Gunnar Lysell, Hot Cell Laboratory.