Aspects of working with manipulators and small samples in an $\alpha\beta\gamma$-box

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Abstract
The Laboratory for Materials Behaviour, operator of the Hotlab and part of the Paul Scherrer Institute (PSI) is studying corrosion- and mechanical phenomena of irradiated fuel rod cladding materials. To improve the options for mechanical tests, a heavy shielded ($\alpha\beta\gamma$) universal electro-mechanical testing machine has been installed. The machine is equipped with an 800°C furnace. The furnace chamber is part of the inner α-box and can be flushed with inert gas. The specimen can be observed by camera during the tests. The foreseen active specimens are very small and can not be handled by hand. Before starting active tests, tools and installations had to be improved and a lot of manipulator practise had to be absolved. For the operational permit, given by the authorities (Swiss Federal Nuclear Safety Inspectorate, HSK), many safety data concerning furnace cooling, air pressure and γ-shielding had to be collected. Up to now various inactive tests have been performed. Besides the operational and safety features, results of inactive mechanical tests and tests for active commissioning are presented.

Keywords: Mechanical testing, handling, safety, results

1. INTRODUCTION
The Group for Core Materials Safety and Performance, a part of the Laboratory for Materials Behaviour at PSI operates a heavy shielded $\alpha\beta\gamma$-box, equipped with manipulators (see figure 1) . The inner α-glove box is combined with a universal testing machine (yellow frame) and a furnace (see figure 2).
The furnace can be flushed with air, argon, nitrogen and helium or it can be set under slight vacuum. It can be driven at a maximum temperature of 800°C.
Specimens are observed by a long distance microscope during the whole test procedure. With a digital camera photos can be taken at every moment of the test. Theses photos can be used for the determination of various, mainly geometric parameters.
It is foreseen to do mainly fuel cladding samples testing in the $\alpha\beta\gamma$-box. The device is a very complex and sophisticated system. However, it is versatile enough for multi purpose mechanical testing, e.g. tensile, creep, fracture toughness and for special, cladding behaviour relevant tests (e.g. dry storage).
The $\alpha\beta\gamma$-box needs approval given by the authorities (Swiss Federal Nuclear Safety Inspectorate, HSK). Therefore safety tests had to be done.

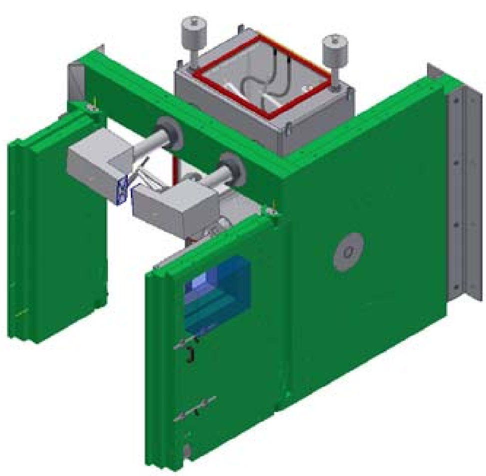

fig.1 $\alpha\beta\gamma$-box with open doors

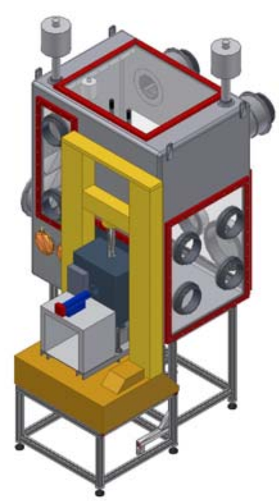

fig.2 α-box, furnace and universal testing machine

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2. SPECIFIC SAMPLE PREPARATION

Up to now, only inactive tests have been performed. Everything could be handled manually and very easily. But at an early stage it was quiet clear that work with active material leads to an involvement of different groups and methods.
Also the design of the original specimen holders had to be changed and improved.

2.1. CROSS-CUT ACTIVITIES OF GROUPS AND METHODS

Following groups were engaged with specimen preparation:

- "Hot Cell Experiments":
  Cutting of the fuel pins, which stem mainly from Swiss nuclear power plants (pieces of. 90 mm length).
  Defueling of the cut pieces by drilling out the fuel.
  Raw cutting of the specimens (15 mm) after dissolution of the remaining fuel.
- "Isotope and Elemental Analysis":
  Dissolving of the remaining fuel in the special dissolution box
- "Surface and Solid state Analysis":
  Cutting the specimens with a diamond saw to a length of 12 mm (fine cutting), cutting the notches (length 1.5 mm) when necessary.
- "Core Materials Safety and Performance":
  Making initial fatigue Cracks when necessary.

2.2. SPECIMEN HOLDER AND TOOLS

2.2.1. SPECIMEN HOLDER AND HALFCYLINDERS

The loading system, which comprises specimen holders and half cylinders as counterparts, is designed to simulate inner pressure onto the samples by inducing transversal forces. The handling of the original specimen holders and (load inducing) half cylinders (see figure 3 and 4) was without any problems for inactive specimens. The material used for the holders and the half cylinders is MARM247cc, a Ni based creep resistant alloy (for e.g. turbine blades).
But there are some disadvantages and exclusions for the work with active material as for e.g.:

- During a test the specimen is only observable from one side.
- It is not possible to insert the half cylinders into the cladding tube specimen and to place the half cylinders in the right position with manipulators.
- The half cylinders can fall out the specimen easily.
- The half cylinders fit too tight in the specimen holder.
- The specimen could fall out of the holder or change its position while placing the holder in the load line.

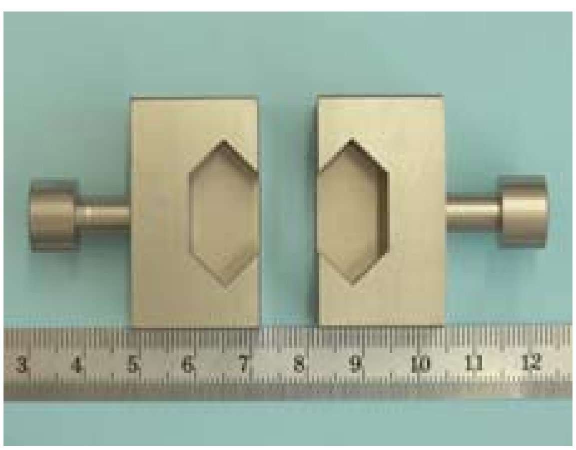

fig.3 Original specimen holders

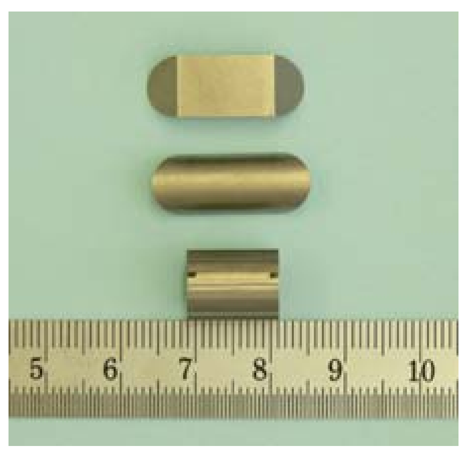

fig.4 Original half cylinders and cladding tube sample

2.2.2. NEW DESIGN OF SPECIMEN HOLDER AND HALF CYLINDERS

With the new design (see figure 5 and 6) the above mentioned disadvantages are solved:

- The specimen is observable from two sides and the holders are still stable.

- The half cylinders are pressed against the inner tube wall with a spring. The position of the half cylinders does not change and they do not fall out during manipulator handling.
- The diameter of the half cylinders is slightly reduced (more play).
- A plate screwed on the holders avoids a falling out of the specimen during manipulator handling.

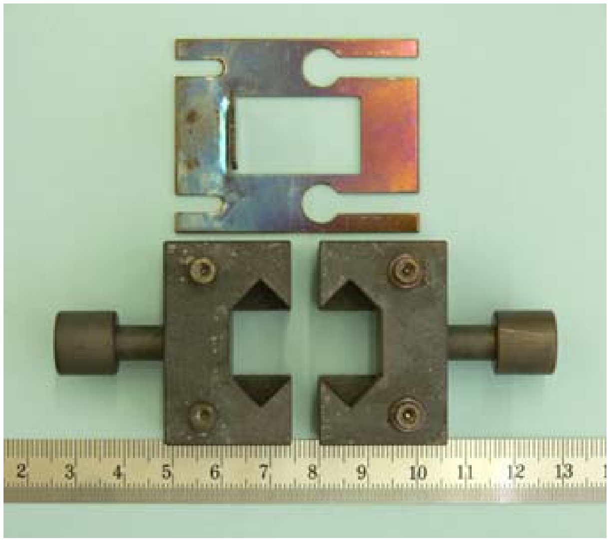

fig.5 Newly designed specimen holders

fig.6 Newly designed half cylinders

2.2.3. SPECIAL MOUNTING UNIT AND TOOLS

Adequate tweezers had to be found and modified for the use with manipulators. A mounting unit (see figure 7) had to be designed, machined and tested. With the found solution the mounting is easy after a certain time of practise with the manipulators:

- Placing the half cylinders always at the right position into the cladding tube specimen and aligning the notches correctly (see figure 8).
- Placing the specimen with inserted half cylinders into the holders without canting.

Also new pulling roads had to be machined. It had to be avoided that the junctions are too close to the furnace center. In the original design, different rod materials screwed in the hot region were affected by cold welding.

fig.7 Mounting unit with specimen

fig.8 Placing the half cylinders into the specimen

3. Safety aspects

For the comissioning of the αβγ-box an approval given by the authorities was needed. Therefore many tests of the whole system had to be done as for e.g.

- water coolant and low-pressure system leaks,
- water in the α-box,
- electrical power cuts,
- dose rates outside the shielding especially at the door hinges, etc.

In any imaginable case the whole system had to fall automatically in a safe mode. All these points were checked by the HSK (Swiss Federal Nuclear Safety Inspectorate) during an on location inspection. It could be demonstrated that in case of a water coolant leak at 750°C the outside temperature on the furnace does not exceed 50°C. Further a handbook for the furnace and the whole device was written.

4. Inactive tests

Many inactive tests have been done. Temperature calibration was an important work. The temperature measured directly at the specimen surface is lower than at the measuring points in the heating zone. This is caused by the cooled pulling rods and the windows in the heating chamber. Mainly following test were carried out:

- Hydride reorientation tests with cladding tube samples at different starting temperatures, with one or three heat cycles at a starting temperature of 400°C and constant load of 230 N. The cooling rate was 0.5°C.
- Fracture toughness tests with plates and cladding tubes samples at room temperature and up to 350°C (see figure 9). For every test initial fatigue cracking was done.
- Delayed hydride cracking tests have been carried out, too.

All the tests showed a well functioning and reliable system that is ready for active testing now.

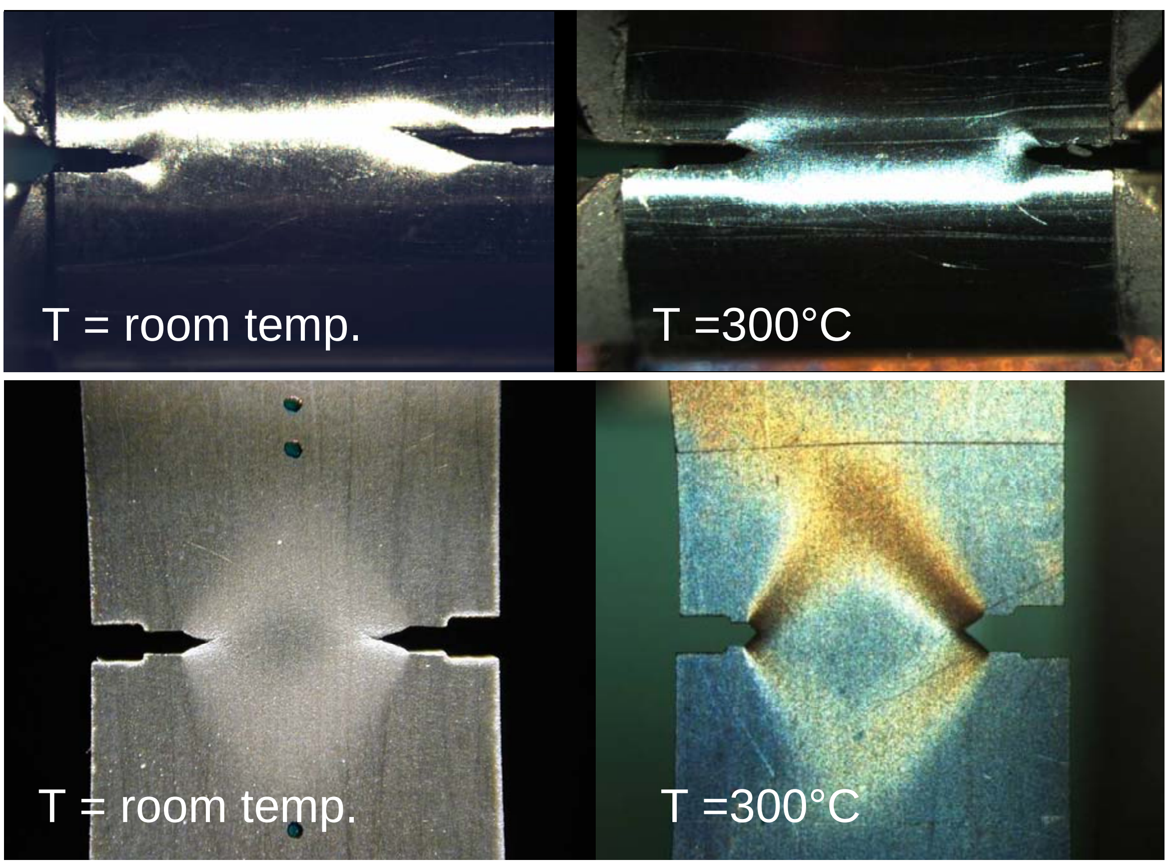

fig.9 Comparison tube (above) and plate (below) with wall thickness 0.6 mm, sample width 12 mm, notches approx. 0.8 mm; the pictures were taken during tensile testing at comparable displacement.

5. RESULTS

5.1. TENSILE TESTS

The tensile tests show an increase of local displacement and load drop at higher temperature (increased plasticity, "chewing gum effect", see figure 11 and 12). At the same time the crack propagation slows down; more displacement is needed for the same crack length increase. This effect is stronger for flat samples than for the tube sections.

If the crack resistance curves are calculated according to ASTM standard 1820E (the standard requirements are only partially met), complex dependencies on displacement, load, temperature and geometry are revealed.

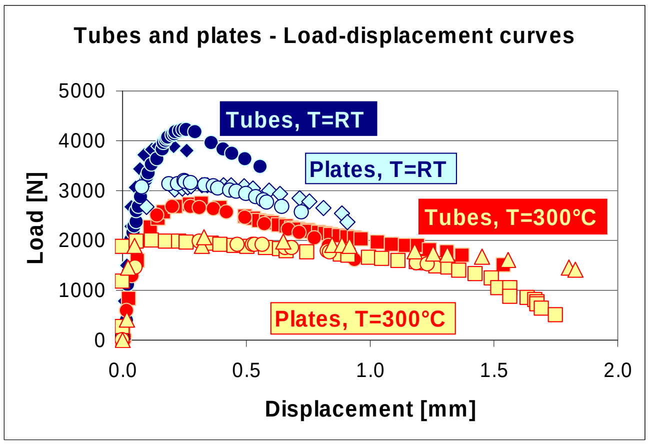

fig.11 Load-displacement curves for plate and tube specimens.

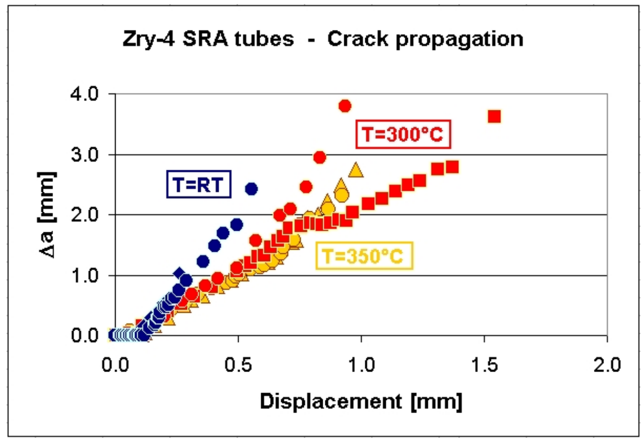

fig.12 Crack propagation dependency on temperature.

5.2. HYDRID REORIENTATION TESTS

The metallographic examinations showed clearly how the hydride bands change from circumferential into a radial orientation. It is typically localized at the places with the highest stress during the test (see figure 13).

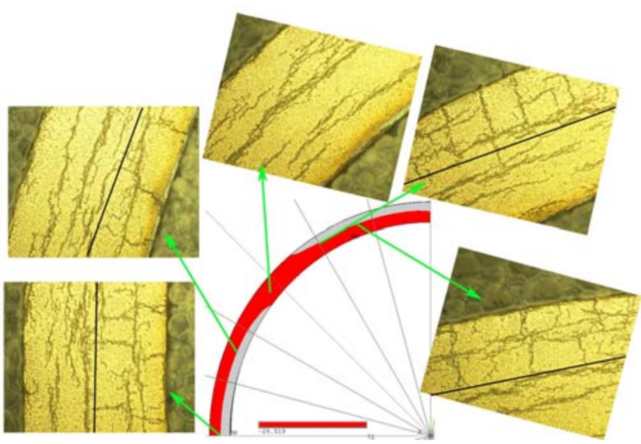

fig.13 highest stress at gray parts

6. PLANNED ACTIVE TESTS

We will start with active test, in the middle of October 2007. We will use cladding tube samples from fuel pins irradiated in the Swiss nuclear power plants KKL (Leibstadt) and KKG (Gösgen). The foreseen tests are:

- Hydride reorientation
- Fracture toughness with initial fatigue crack
- Delayed hydride cracking

The specimens from the hydride reorientation and delayed cracking tests will further be examined by metallography.

7. CONCLUSION

We are well equipped with a state of the art mechanical testing device for scientific research and service work. It is appropriate for highly active fuel cladding samples and thus a contribution to investigate mechanical behaviour questions with respect to high burn-up and intermediate dry-storage conditions.

8. OUTLOOK

New supporting inactive equipment, as a new MTS universal testing machine, is ordered. The inactive machine shall help to validate improved testing procedures and sophisticated equipment like high temperature capacitive extensometer, strain gages and a potential drop measurement system. A direct implementation of these devices into the active tests would require a too big effort, whereas the forthcoming active testing should be as robust as possible.

9. ACKNOWLEDGEMENT

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