MULTI-LAYER COATED CLADDING BEHAVIOUR DURING LOSS OF COOLANT ACCIDENT

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To study the high temperature creep behavior of coated zirconium alloys, a series of ballooning and burst tests was performed. The main focus was on comparing the time to burst and deformation of samples with various types of coating and reference uncoated samples.

Multi-layer Coated Cladding Behaviour during Loss of Coolant Accident

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1. Introduction

During Loss-of-coolant accident the nuclear fuel is exposed to **high temperatures** and **high internal pressure**. This leads to **thermal creep**, i.e. time-dependent plastic deformation. Fuel cladding experiences **ballooning** which may lead to **burst** (failure). [1]

In recent years a lot of research has been focused on various concepts of **Accident Tolerant Fuel (ATF)**, which should have reduced oxidation rade and reduced creep rate (longer time to burst and smaller deformation) during accident conditions. So far, one of the most promising concepts is the deposition of **protective chromium layer** on conventional Zr alloy cladding outer surface. [2-4]

To prevent the interdiffusion of Cr and Zr and their eutetic reaction, it is possible to add an **interlayer of CrN**, as it leads to the creation of ZrN (as depicted in Fig.1), which acts as a diffusion barrier [5].

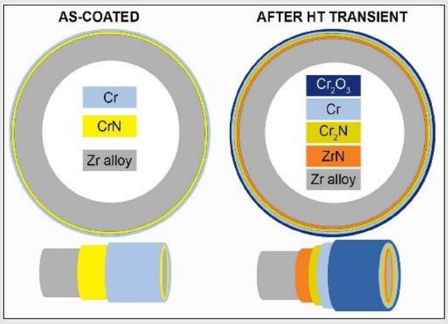

Fig. 1: Multi-layered coating [5]

2. Experimental

2.1 Material

- ❑ Reference uncoated Zr alloy samples
- ❑ Cr coated samples (coating thickness 18.6 μm)
- ❑ Cr coated samples (17 μm)
- ❑ substoichiometric Cr90N10 coated samples (18.2 μm)
- ❑ CrN+Cr coated samples (22.6 μm)
- ❑ CrN+Cr coated samples (16.7 μm)
- ❑ CrN+Cr coated samples with Cr interlayers in CrN (17.6 μm)

2.2 Internal pressure high temperature creep tests

- ❑ Isothermal tests at 750 °C and 950 °C
  - sample heated to high temperature and then pressurized
  - internal pressures 2–10 MPa for 750 °C, 0.9–1.5 MPa for 950 °C
- ❑ Thermal ramp tests at 6 °C/s
  - pressurized sample heated to 360 °C, then temperature increased by 6 °C/s up to the failure of the sample
  - internal pressures 2–10 MPa
- ❑ After the tests the samples were measured in diameter in different places to evaluate their deformation

Fig. 2: Sample before burst test

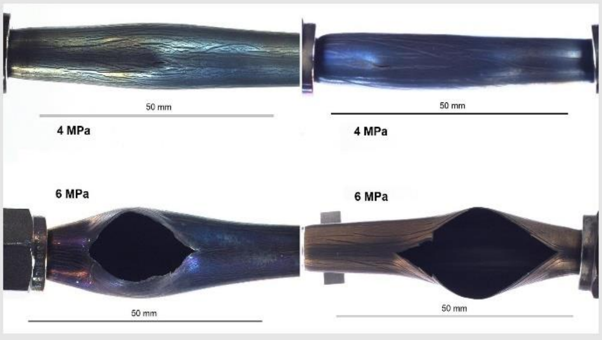

Fig. 3: Samples after burst tests: left – Cr90N10 coated, right – CrN+Cr coated

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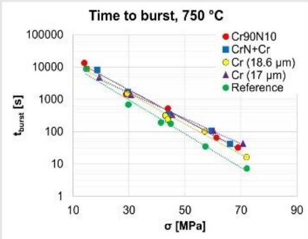
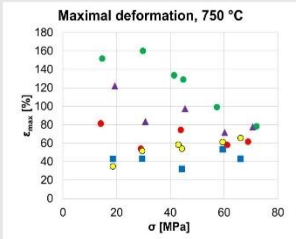
3. Results and discussion

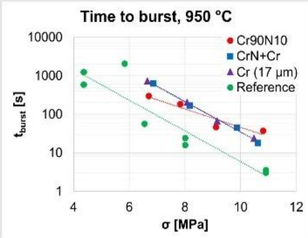
3.1 Isothermal tests at 750 °C

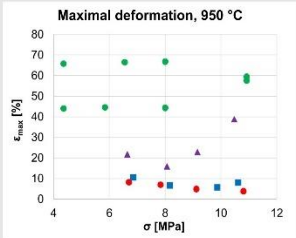




The charts show time to burst and maximal deformation of the sample in relation to hoop stress in the cladding wall. It is clear that coated samples have **longer times to burst** as well as **smaller maximal deformations** than reference uncoated samples. The longest times to burst were in Cr90N10 and CrN+Cr coated samples. The smallest deformations were in Cr (18.6 μm) and CrN+Cr coated samples. These results show the **benefit of coating** in accident conditions, since it leads to less fission gas being released into the reactor pressure vessel area and less flow blockage for water from emergency cooling systems.

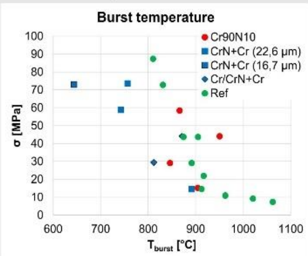
3.2 Isothermal tests at 950 °C

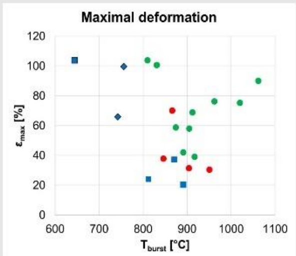




At 950 °C coated samples tended to **fail later** and had **smaller maximal deformations** than reference uncoated samples, which is consistent with results at 750 °C. The benefit of coating has been proved at 950 °C as well.

3.3 Thermal ramp tests





The charts show the relationship of burst temperature and stress in the cladding wall and the maximal deformation. It can be observed that coated samples failed at lower temperatures, which suggests that coated samples **failed earlier**. This is the opposite of what was observed in isothermal tests. This can be explained by the formation of **cracks in the coating** (seen in Fig. 3), which leads to the thinning of the sample wall and concentration of stress in areas around the cracks. However, the maximal deformations are still smaller in coated samples. The benefit of coating in thermal ramp tests is not very straightforward.

4. Conclusions

In isothermal tests the coated samples failed later than reference uncoated samples and had smaller maximal deformations, which means that coated samples have a lower creep rate. Coating has a positive effect on the results of isothermal tests. On the other hand, in thermal ramp tests coated samples failed earlier than reference samples, possibly due to the presence of cracks in the coating, thinning of the cladding wall and concentration of stress in those areas.

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