Background

The development of an Accelerator Driven System (ADS), such as the demonstrator MYRRHA, for the transmutation of high level nuclear waste, necessitates a dedicated R&D program for the development and qualification of structural materials. Assure fuel element cladding tubes structural integrity is a particular challenge owing to high stress, high temperature, high heat flux and high coolant velocity. The choice of cladding material is of critical importance both from economic and safety viewpoints. The cladding material should exhibit:

a) reproducible fabrication, workability and weldability;
b) mechanical resistance: sufficient strength with limited degradation of ductility and fracture toughness under irradiation in liquid metal;
c) dimensional stability: resistance to irradiation-induced swelling and/or creep;
d) heat resistance: limited decrease of strength and toughness with temperature;
e) compatibility with LBE coolant.

These fundamental properties are very sensitive to service conditions, in particular to temperature, irradiation (flux and dose), stresses (tensile, fatigue, creep), LBE coolant chemistry and velocity. Such operational conditions are very challenging issues for a material to be selected from the existing material database for nuclear applications, in order to comply with all the requirements.

Objectives

The objective of the present work is to develop a methodology to qualify the cladding tubes that are being developed in the framework of the FP6-EUROTRANS project and in collaboration with FZK/Germany and IPPE/Russia within the ISTC#2048 contract. Keeping in mind the fact that actual technical specifications for ADS-cladding tubes do not exist yet, an effort is being made to develop in-house methods based on the standard approach in use to qualify the actual cladding materials for the light water reactor [ASTM B-811]. Thus, the obtained cladding tubes will be controlled in terms of:

- Dimensional control, chemical analysis, defect and flaw detection, microstructure by optical and electronic microscopy;
- Burst test at room temperature and at 300°C;
- Tensile test (strength, yield and elongation) at room temperature, 300°C and at 500°C;
- Creep resistance determination with or without irradiation;
- Oxide layer thickness measurements (if tubes require a surface oxide) by microscopy;
- Hydrostatic or non destructive electric test (as eddy current).

This report, describe the qualification of the burst testing method in comparison with tensile testing performed in the longitudinal direction.

Principal results

The burst test consists in increasing the internal pressure inside a cladding tube up to rupture and burst of the cladding. This test allows performing mechanical testing of cladding under biaxial loading condition that is more relevant for fuel cladding than uniaxial test.

The fluid used in the burst test equipment developed at SCK•CEN is a high temperature oil generally used in heat exchangers. Low compressibility liquids have several advantages over the use of a gas: it allows monitoring cladding tube deformation that is correlated to the injected oil volume and reduces the energy stored in the system that could lead to a violent burst. However, the maximum operating temperature of the oil remains a limitation. The oil pressure is developed using a high pressure screw spindle pump that can deliver a pressure of 2100 bar and displace a volume of 12 cm^3. All accessories such a capillary tubes, valve and pressure transmitter are dedicated to be used under very high pressure.

To date the equipment has been qualified at 25 °C and 200 °C. During a burst test, pressure is measured as a function of time up to rupture. A typical result is given in Figure 1. This figure is very similar to a tensile test record, it contains a linear elastic, a hardening and localization region.

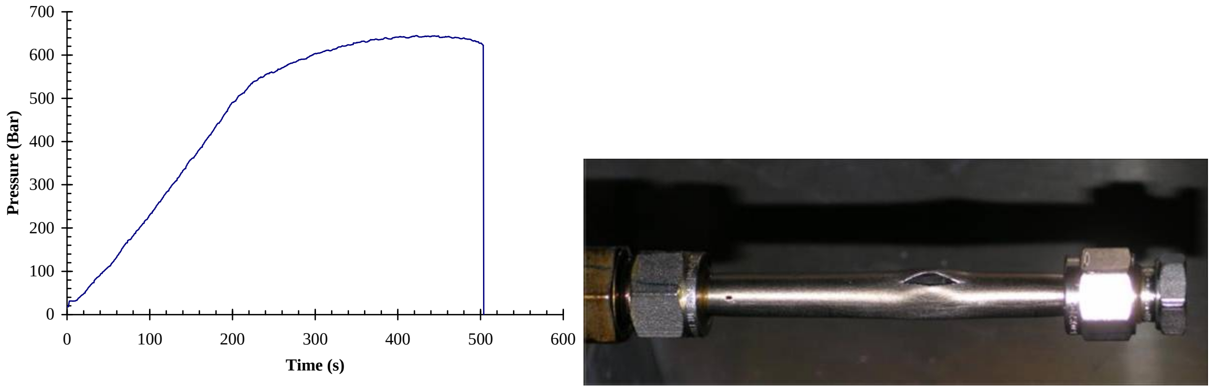

Figure 1: Pressure monitored during a constant speed burst test.

In order to analyse the data in the more conventional tensile test framework, pressure test using a cap instead of a tube is performed to take the compliance of the system into account, the pressure and the resulting biaxial stress state is analytically converted into an equivalent uniaxial stress and the time scale is analytically converted into an circumferential strain using the information of the pump volume. The resulting analysis is compared to a conventional tensile test in Figure 2. Results demonstrate that material properties such as the yield strength are equivalent from both test method. However the hardening and uniform elongation are larger for the tenile test. This might be a consequence of the biaxial loading of the burst test leading to reduced deformation to rupture. The behaviour after maximum is not expected to be the same in a tensile test and a burst test as localization of strain occurs resulting in non uniform deformation. Such behaviour can only be further investigated using more advance techniques such as the Finite Element Method.

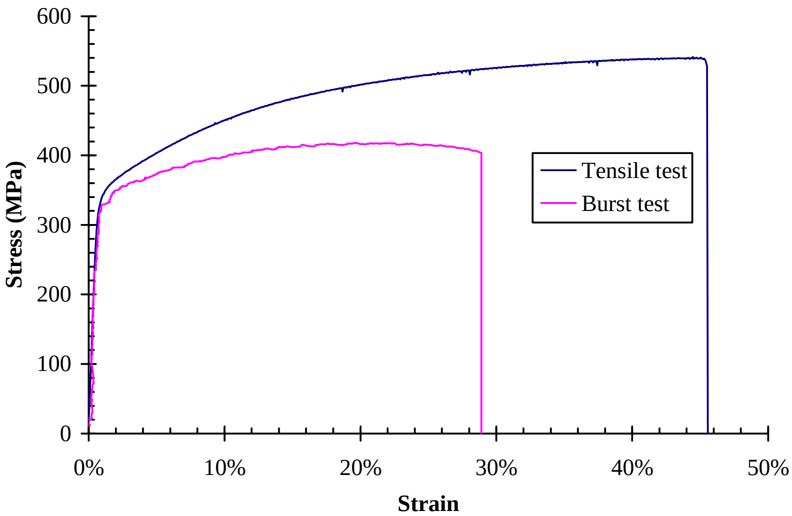

Figure 2: Comparison of tensile test and burst test results performed in the longitudinal orientation.

Future work

The future work will be intended to extend the methodology to higher temperature and to use the developed method to test the produced materials that have been already received. It is also planned to qualify cladding tubes irradiated within the ASTIR program and FP7-GETMAT-project.

Main contact persons

Al Mazouzi Abderrahim, abderrahim.al.mazouzi@sckcen.be
Scibetta Marc, marc.verwerft@sckcen.be

Main reference

IP_EUROTRANS/ DEMETRA-Domain: http://nuklear-server.ka.fzk.de/eurotrans/