Testing Systems and Results for Advanced Nuclear Fuel Materials

I.J. van Rooyen, G.W. Griffith, J.E. Garnier

Idaho National Laboratory, P.O. Box 1625, Idaho Falls, USA

isabella.vanrooyen@inl.org

Poster Ref. Number: 1P33

1. Introduction

- Light Water Reactor Sustainability (LWRS) Program Advanced LWR Nuclear Fuel Development (ALFD) Pathway
- Development and testing of high performance fuel cladding identified as high priority to support :
  - ➢enhancement of fuel performance,
  - ➢reliability, and
  - ➢reactor safety.
- One of the technologies being examined is an advanced fuel cladding made from ceramic matrix composites (CMC) utilizing silicon carbide (SiC) as a structural material supplementing a commercial Zircaloy-4 (Zr-4) tube.

2. Out-of pile characterization techniques

•A series of out-of-pile tests to fully characterize the SiC CMC hybrid design to produce baseline data. The planned tests are intended to either produce quantitative data or to demonstrate the properties required to achieve two initial performance conditions relative to standard zircaloy-based cladding [1,2]:

➢decreased hydrogen uptake (corrosion) and

➢decreased fretting of the cladding tube under normal operating and postulated accident conditions.

•These two failure mechanisms account for approximately 70% of all in-pile failures of LWR commercial fuel assemblies.

3. Preliminary Results

3.1. Three Dimensional X-ray Tomography

•Initial non destructive testing using 2D X-ray examinations as well as 3D tomography were conducted on a mock-up assembly of the fabricated SiC CMC hybrid tube. The advantages using 3D tomography are shown in Figure 1 where additional information on the integrity of the hybrid cladding design can be provided namely:

➢Detail on gap between SiC CMC clad and Zr4 tube (at any cross section position over the length of the tube)

➢Information regarding surface finish on the inside of the SiC CMC sleeve

➢Visual and digital demonstration of open pores to the surface

➢Visual and digital demonstration of fibre integrity and weave pattern

➢Examine presence of damage due to fretting and corrosion locations.

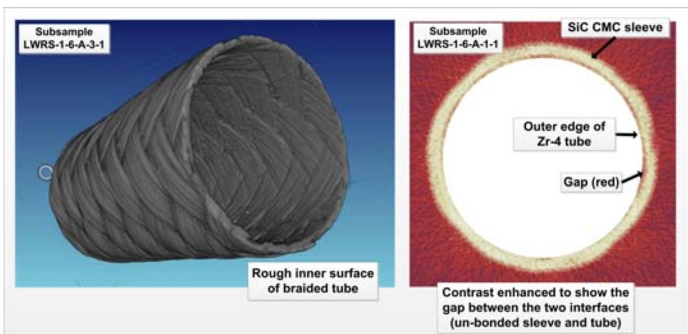

Figure 1: Three dimensional reconstruction of SiC CMC sleeve and fabricated hybrid tube geometry using 3D X-ray tomography techniques.

3.2. Burst Test

•Preliminary burst tests were performed on prototype SiC CMC hybrid samples in cooperation with EPRI at the Halden Reactor using a drop-weight apparatus with results (Figure 2):

➢The SiC CMC hybrid samples outperforming the zirconium samples.

➢The SiC CMC Zr4 hybrid design resisted expansion up to the test limit conditions of the apparatus, ~67 ksi (460 MPa) internal pressure.

➢Standard Zr-4 tubes exhibited about 9.5% strain at 63.5 ksi (437 MPa).

➢Further quasi-static testing will be used to verify the sample performance.

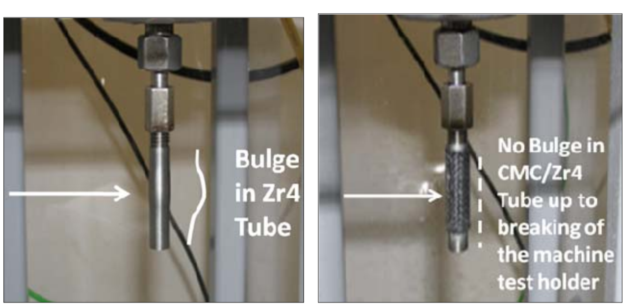

Figure 2: Halden Burst Testing of Zr4 Tube to Failure. Zr4 metal tube failed at 437 MPa (left). The INL hybrid cladding design shows no bulge at failure limit of sample holder at 460 MPa (right).

3.3 Hot Water Corrosion Flow Test (HWCF)

•The hot water corrosion flow test (Figures 3) is uniquely designed for this project to measure the deterioration of SiC CMC tube due to water flow and measure the corrosion properties of the hybrid SiC CMC Zr-4 tube under accelerated conditions :

➢Water temperature ranging from 278 to 355 K at pressures less than 0.17 MPa

➢Water flow rates ranging from 0.003 to 12 m/s.

➢pH of 5 to 8, depending on the specific test requirements.

•The HWCF system is designed for two modes of operation:

➢Corrosion-only: Heated water without internal rodlet heating; and

➢Thermal stress: Heated water with internal rodlet heating.

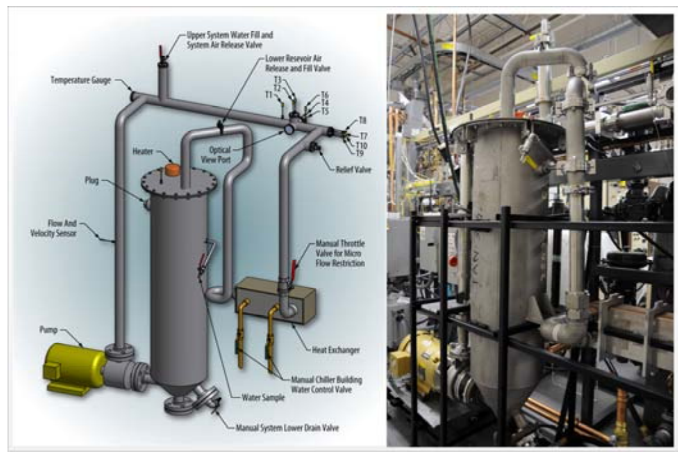

Figure 3: Diagram of the hot water corrosion flow test system and the assembled test equipment at INL; test samples are installed in the top leg of the flow loop at the optical view port position.

Figure 4: Photos showing the position of the sample during testing and the sample holder, which can hold up to four samples during testing

4. Conclusions

•The hot water corrosion flow test system will be fully demonstrated using pre-prototype SiC/CMC clad designs in advance of introducing alternate design candidates into the test section. Pre-prototype testing is planned for May/June 2012.

•A steam test loop intended to assess advanced clad design performance under postulated accident conditions is currently being designed and is planned for construction and operation by the end of FY12.

•Other tests for tubular clad samples, including bend and burst tests, are also under development in FY12

Acknowledgements

- The authors gratefully acknowledge the work of internal experts who contributed to the presented results, specifically Kevin McHugh and Karen Wendt.
- The authors gratefully acknowledge the review of this poster by Shannon Bragg-Sitton (INL) and Doug Porter (INL).

References

[1] DC Crawford *et al*., An approach to fuel development and qualification, J. Nucl. Mater. 371 (2007) 232-242

[2] K. Edsinger, *EPRI and the zero fuel failures program*, Nuclear News, p. 40, Dec 2010.