# MULTISCALED AND MULTILAYERED STRUCTURES OF THE $SiC_f$/SIC COMPOSITE NUCLEAR FUEL CLADDING TUBES

Chen Bo[1]; Liu Chuanxin[1]; Li Xiaoqiang[1]; Cheng Laifei[1]; Zhang Litong[1];
[1] Science and Technology on Thermostructural Composite Materials Laboratory, Northwestern Polytechnical University, West Youyi Rd., No. 127, Xi'an, Shaanxi 710072, PR China,
vincent@nwpu.edu.cn

**Keywords:** $SiC_f$/SiC Composite, Nuclear Fuel Cladding, Multilayer Structure, Multiscale Structure

## ABSTRACT

The aim of the study is to examine the complicated multiscaled and multilayered microstructures of the $SiC_f$/SiC composite fuel cladding tube for PWR. Firstly, the two dimensional braided $SiC_f$/SiC composite tube is prepared using the isothermal isobaric CVI process. Secondly, the X-ray computed tomography imaging analysis is used to characterize the tube internal structure non-destructively. And then, the tube is cut into several pieces and section analysis is also conducted using the scanning electric microscopy (SEM) assisted with the energy-dispersive X-ray spectroscopy (EDS) to further investigate the internal microstructures and determine the different substructures of the $SiC_f$/SiC composite.

## 1 INTRODUCTION

Continuous Fiber Reinforced Ceramic Matrix Composite is an attractive candidate as a structural material for future fusion power plants and advanced nuclear applications because of their light weight, high temperature capability, high strength and toughness, one of which is the silicon carbide reinforced silicon carbide matrix composite ($SiC_f$/SiC) is promising for nuclear and fusion technology due to its excellent radiation resistance, especially exposure to high-energy particles such as neutron, proton, and alpha [1]. After decades of development in applications of aerospace thermostructures components [2], $SiC_f$/SiC composite is on the way to be mature for potential structural components such as the channel box of boiling water reactor (BWR), fuel cladding tube of light water reactors (LWRs), the control rod in gas cooled fast reactor (GFR), and other nuclear applications. Following the event at Fukushima in 2011, enhancing the accident tolerance of LWRs became a topic of serious discussion all over the world. Nuclear-grade $SiC_f$/SiC composite is the most promising alternative to the conventional commercial zirconium alloy in pressed water reactor (PWR) fuel cladding. Several prototypes of the $SiC_f$/SiC composite fuel claddings are proposed and accomplished, details in [3-7].
However, porosity, which is mainly due to manufacturing process of the $SiC_f$/SiC composites, is a critical issue in nuclear applications. Internal pores mitigate most of the outstanding properties of the $SiC_f$/SiC composites such as thermal conductivity, high strength, gas-tightness and radiation stability. Especially in the composites acquired via the Chemical Vapor Infiltration (CVI) process, those pores are unavoidable and significantly reduce the life time and performance of the composites under harsh environments.

The aim of the study is to examine the complicated multiscaled and multilayered microstructures of the $SiC_f$/SiC composite fuel cladding tube for PWR. Firstly, the two dimensional braided $SiC_f$/SiC composite tube is prepared using the isothermal isobaric CVI process. Secondly, the X-ray computed tomography imaging analysis is used to characterize the tube internal structure non-destructively. And then, the tube is cut into several pieces and section analysis is also conducted using the scanning electric microscopy (SEM) assisted with the energy-dispersive X-ray spectroscopy (EDS) to further investigate the internal microstructures and determine the different substructures of the $SiC_f$/SiC composite.

## 2 MATERIALS AND METHODS

Firstly, SiC fibers with 0.5 K tows was tubular braided with a braided angle of +/-45°to prepare the fiber preforms. Secondly, pyrolytic carbon (PyC) interface with a thickness around 100 nm was coated on the fibers using $C_3H_6$ precursor at 900◦C under a reduced pressure of 5 kPa via an isothermo chemical vapor deposition/infiltration (CVD/CVI). And then the SiC matrix was prepared by low pressure chemical vapor infiltration (LPCVI) with reduced pressure of 2 kPa around 1100◦C and the ratio of $H_2$/MTS was about 10. Afterward, the composite tube were machined and polished into samples with outer diameter of 12mm, internal diameter of 8.5 mm, and length of 10 mm.

X-ray computed tomography (XCT, YXLON Y.Cheetah, Germany) imaging analysis is used to characterize the tube internal structure non-destructively.

And then, the tube is cut into several pieces and section analysis is also conducted using the scanning electric microscopy (SEM, JEOL6700F, Tokyo, Japan) assisted with the energy-dispersive X-ray spectroscopy (EDS) to further investigate the internal microstructures and determine the different substructures of the $SiC_f$/SiC composite.

## 3 RESULTS AND DISCUSSION

One of the XCT slice images was shown in Figure 1.

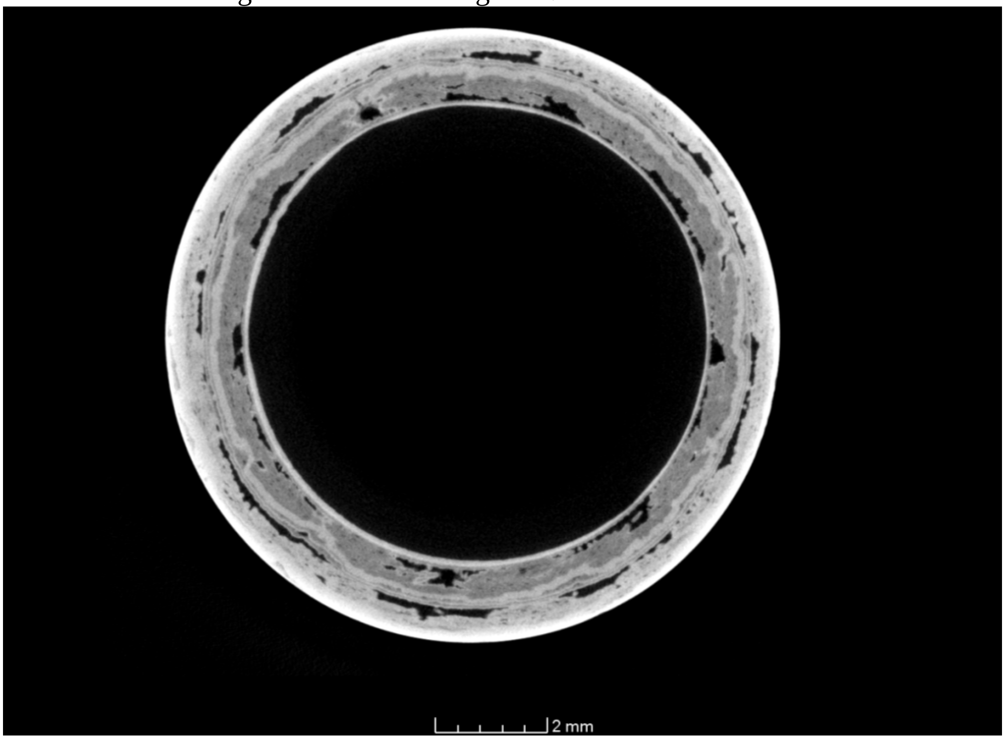


Figure 1 the sectional image by X-ray computed tomography

## REFERENCES

[1] B. Riccardi, L. Giancarli, A. Hasegawa, Y. Katoh, A. Kohyama, R. H. Jones, L. L. Snead. Issues and advances in $SiC_f$/SiC composites development for fusion reactors [J]. *Journal of Nuclear Materials*, 2004, **329**(1):56-65

[2]. D. Glass. Ceramic Matrix Composite (CMC) Thermal Protection Systems (TPS) and Hot Structures for Hypersonic Vehicles. AIAA-2008-2682

[3]. Yueh K, Carpenter D, Feinroth H. Clad in clay. *Nuclear Engineering International*, 2010, **55**(666):14-16.

[4]. DECK CP, JACOBSEN GM, SHEEDER J. Characterization of SiC/SiC composites for accident tolerant fuel Cladding. *Journal of Nuclear Materials*, 2015, **466**: 667-681.

[5]. ROHMER E, MARTIN E, LORRETTE C. Mechanical properties of SiC/SiC braided tubes for fuel cladding. *Journal of Nuclear Materials*, 2014, 453: 16-21.

[6]. BEMACHY-BARBE F, GELEBART L, BOMERT M. Anisotropic damage behavior of SiC/SiC composite tubes: multiaxial testing and damage characterization. *Composites A*, 2015, 76: 281-288.

[7]. KIM D, LEE HG, PARK JY. Fabrication and measurement of hoop strength of SiC triplex tube for nuclear fuel cladding applications. *Journal of Nuclear Materials*, 2015, 458: 29-36.