High Performance SiC/SiC Pipes/Tubes by New Prototype Continuous NITE Process

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SiC/SiC cladding for BWR

SiC/SiC cladding for PWR

Fuel, Claddings, Control Rod...
Fabrication Process for Original NITE-SiC/SiC

1. SiC Fiber
2. SiC Fiber/Fabric
3. SiC Nano Powder
4. SiC Slurry
5. SiC Fiber/Fabric Coating
6. Prepeg Sheet
7. Fiber Coating
8. Green Sheet
9. Prefrom
10. HP, HIP, P-HIP
11. SiC/SiC Block
12. SiC/SiC Tube
13. SiC/SiC Plate
14. SiC/SiC Cylinder
15. Long SiC/SiC Tube
Remained Technical Issues in Original NITE Process

Batch Type F/M Coating ⇒ Residual Deformation on coated fiber

Aqua-Base Slurry ⇒ Poor Workability and Storability
Background

- OASIS, Muroran Institute of Technology, is developing high performance SiC/SiC fuel cladding for light water reactor safety. Basically, the production of SiC/SiC fuel cladding in OASIS is based on the advanced NITE process (DEMO-NITE) which provides well crystallized and densified SiC matrix. Advanced NITE process is designed with the aim of the industrialization of SiC/SiC Pipes/Tubes. Thus, several challenging processes suitable for this purpose are under development, as follows:

- **Advanced NITE Process (Demo NITE)**
  - **New Prototype Continuous NITE Process** ⇒ (P1.060 Dr. Nakazato)
    - Fiber coating (Open-End Type CVD Continuous Furnace)
  - **New intermediate Products**: Pre Composites Ribbon (PCR)
  - **New Preform Fabrication Method** (Filament Winding using PCR)
  - Near Net Shaping Technology (HP, P-HIP, HIP) ⇒ (P1.062 Mr. Nishimura)
  - Characteristics of DEMO-NITE SiC/SiC ⇒ (P1.008 Prof. Kohyama and P1.032 Mr. Hayasaka)
Advanced Fabrication Process (DEMO-NITE)

Raw Materials
- SiC Fiber
- Powder (+Aids)

Intermediate Materials
- Batch CVD coat SiC Fiber
- Continuous CVD coat SiC Fiber
- Prepreg Sheet
- PCR
- Sheet Stacking/Winding
- Ribbon (Filament) Winding

Finished Product
- Machining
- Joining
- QC, etc.
- Sintered Body
- HP, P-HIP, HIP
DEMO-NITE Process GEN. I

**Polymer base SiC Slurry**
- SiC nano powder
- Sintering additive
- Binder
- Solvent

**SiC fiber**
- Cef-NITE
- 800 lines / bundles
- Carbon coating

**Green sheet**
Ceramic film made of SiC powder and binder

**Prepreg sheet**
Fibers are arrayed in the green sheet

**Preform**
Near-net-shaped

**Transient Eutectic Process**

**Product (DEMO-NITE method)**
DEMO-NITE Process GEN.II

PCR Winding
Continuous CVD Coating Furnace

New Intermediate materials
Pre-Composite Ribbon Fabrication Line
NITE-SiC Slurry Impregnation

SiC Fiber
Process gas for C coating

PCR Winding
Preform Tube

New Intermediate materials
50cm long preform: from pre-composite ribbon
New open-end type CVD continuous furnace has been designed and installed at OASIS in this year.
Macroscopic Comparison between Cont. CVD/ Batch CVD

There are no residual deformations, like twist and curve, on SiC fiber coated by Continuous CVD process.

(P1.060 Dr. Nakazato)
PyC Coated SiC Fiber using Cont. CVD

PyC Coat successfully formed on the surface of SiC fiber. PyC Thickness can be controlled freely from 100 to 1,000 nm.
DEMO-NITE Process GEN.III (PCR)

A. Kohyama: Organization of Advanced Sustainability Initiative for Energy System/ Material, Muroran Institute of Technology
Pre Composites Ribbon and Filament Winding

Prepreg sheet

Fiber
Make space
Infiltration

Shaping

PCR

PyC SiC fiber  SiC matrix

travelling direction
rotation
Core rod

PCR
Shaping of the SiC/SiC PCR is rather difficult due to the stiffness of the C coated SiC fibers and the local bend and twist of the fiber bundles.

The surface irregularity caused by interconnecting PCR can be controlled about 100μm. The smaller irregularity for the case of SiC/SiC Preform is mainly due to the difference in fiber numbers per bundle. 800 fibers/bundle for SiC/SiC.
Near Net Shaping (HP, HIP, P-HIP)
Fracture Surface of DEMO-NITE SiC/SiC Cladding
He Leak Tight SiC/SiC Claddings by DEMO-NITE Process

SiC/SiC segments with Zircaloy End-caps
HBWR
Neutron Irradiation Test

FINAL DRAWING OF SiC SEGMENT FOR IRRADIATION

“SCARLET” SiC segment (before assembling; three elements)

“SCARLET” SiC segment (after assembling)

SiC and Zircaloy elements
A: SiC/SiC (Muran L.T.)
B: Zircaloy (Muran L.T.)
C: Zircaloy (IFE, Halden)
Additional Option: DEMO-NITE SiC/SiC Tube with CVD SiC Coat

- **Inner layer**
  - CVD-SiC (340 μm)

- **GS-SiC layer**
  - (60 μm)

- **SiC/SiC layer**
  - (1000 μm)

- **Outer layer**
  - CVD-SiC (30 μm)
Microstructure of CVD SiC Coated SiC/SiC Tubes

- Inner CVD-SiC
- Inner GS-SiC
- SiC/SiC
- Outer CVD-SiC
Summary

• For the industrialization of SiC/SiC Pipes/Tubes, challenging processes based on DEMO-NITE are under development in OASIS, Muroran IT, as follows.
  - New Continuous Fiber coating (using Open-End Type CVD Continuous Furnace)
  - New Intermediate Products: Pre Composites Ribbon (PCR)
  - New Fabrication Method for Preform (Filament Winding using PCR)
  - Near Net Shaping Technology (HP, P-HIP, HIP)

• SiC/SiC Cladding fabricated by DEMO-NITE process shows well densified/crystalized microstructure and excellent gas tightness.
Thank you for your attention.