# SiC/SiC joining for cladding applications


**Monica Ferraris**

**monica.ferraris@polito.it**

Politecnico di Torino – Italy

https://www.polito.it/
https://www.disat.polito.it/it/

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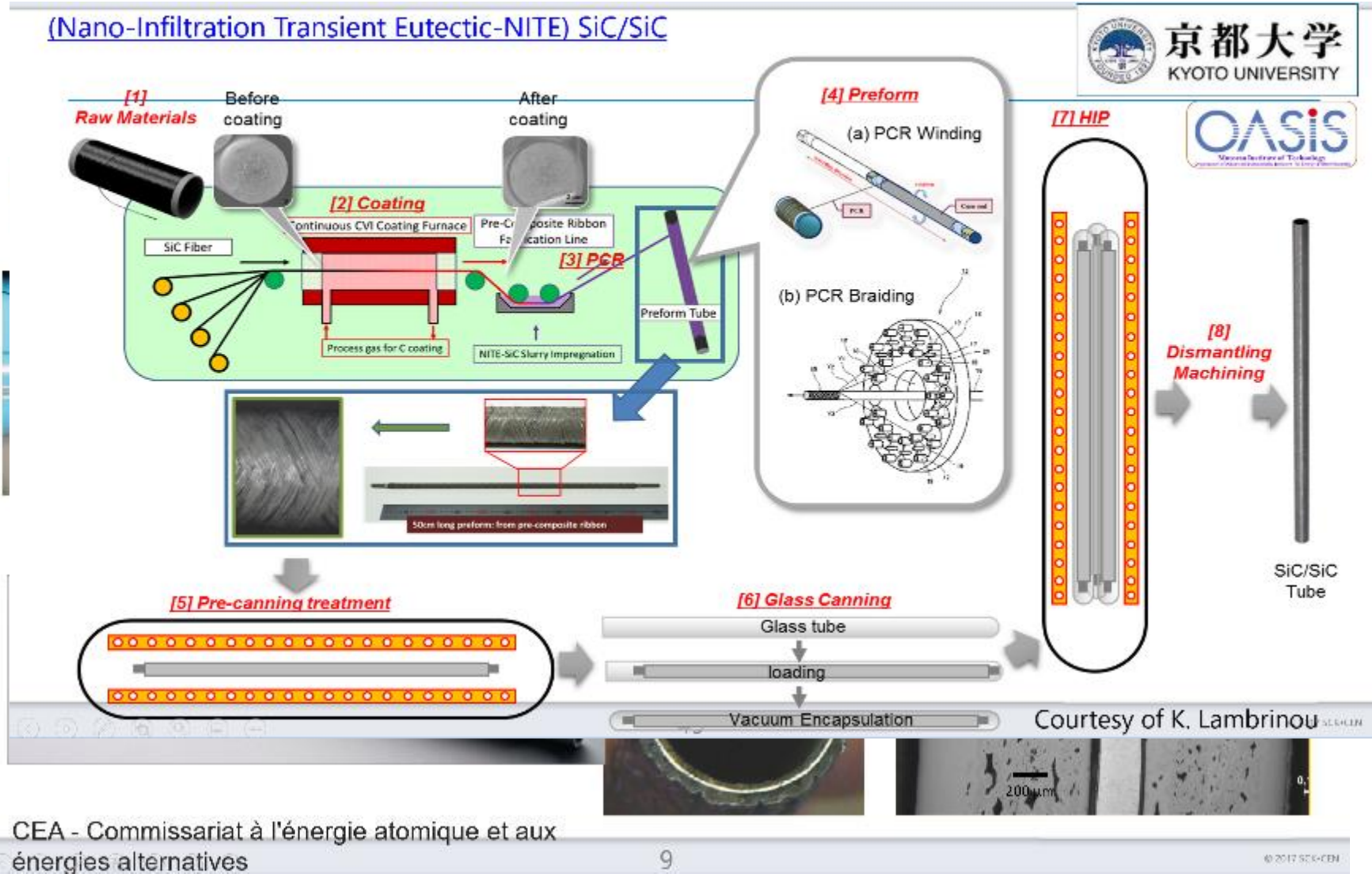
# Available “nuclear grade” SiC/SiC

JAPAN

FRANCE

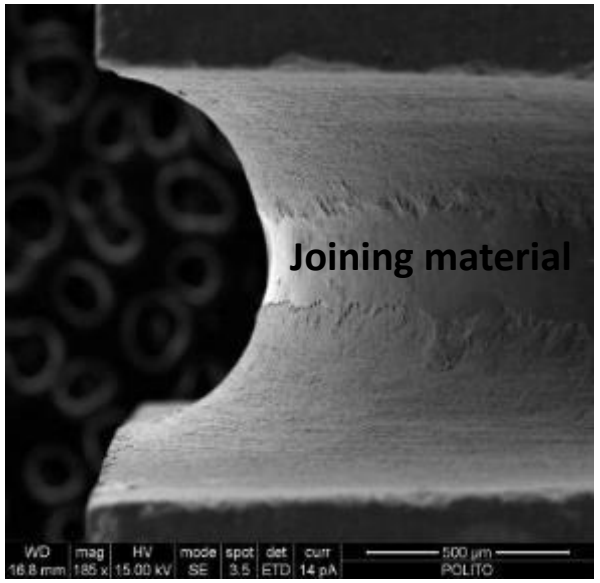
ORNL
General Atomics
Westinghause - USA

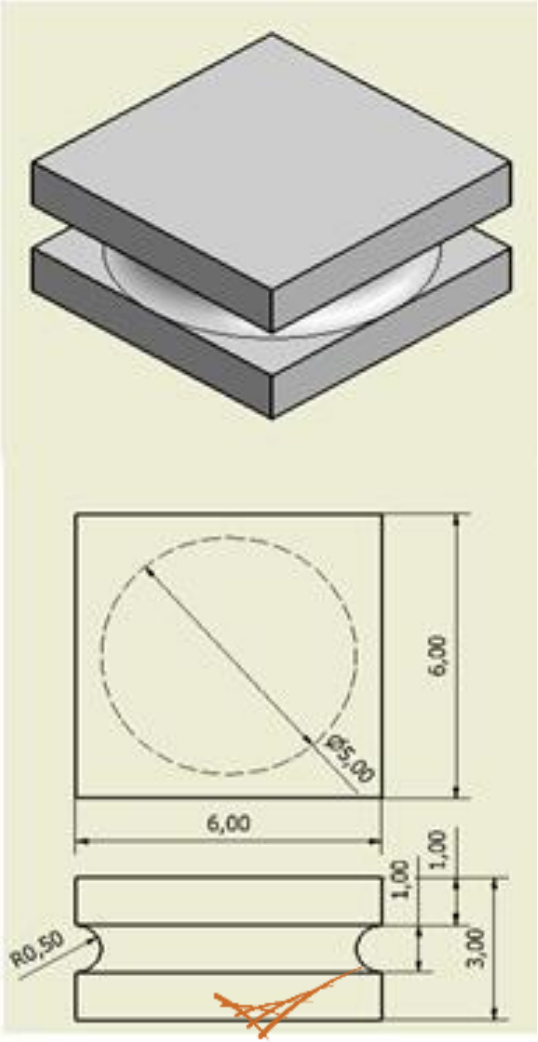



monica.ferraris@polito.it

# SiC/SiC *JOINING* for NUCLEAR APPLICATIONS

1. Develop *joining methods* for silicon carbide-based ceramics and composites
2. Establish *standard test* methods for determination of joint strength under shear loading
3. Determine *effect of neutron* irradiation on integrity of silicon carbide joints



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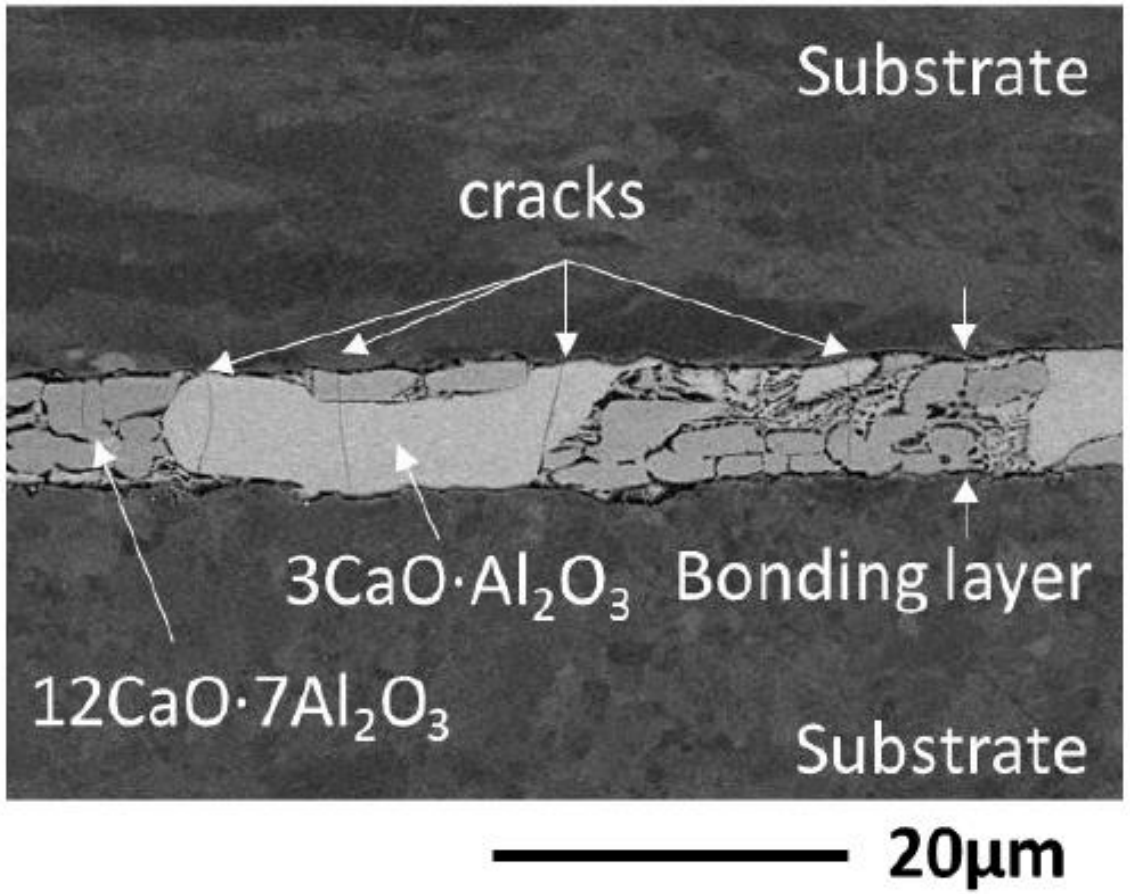
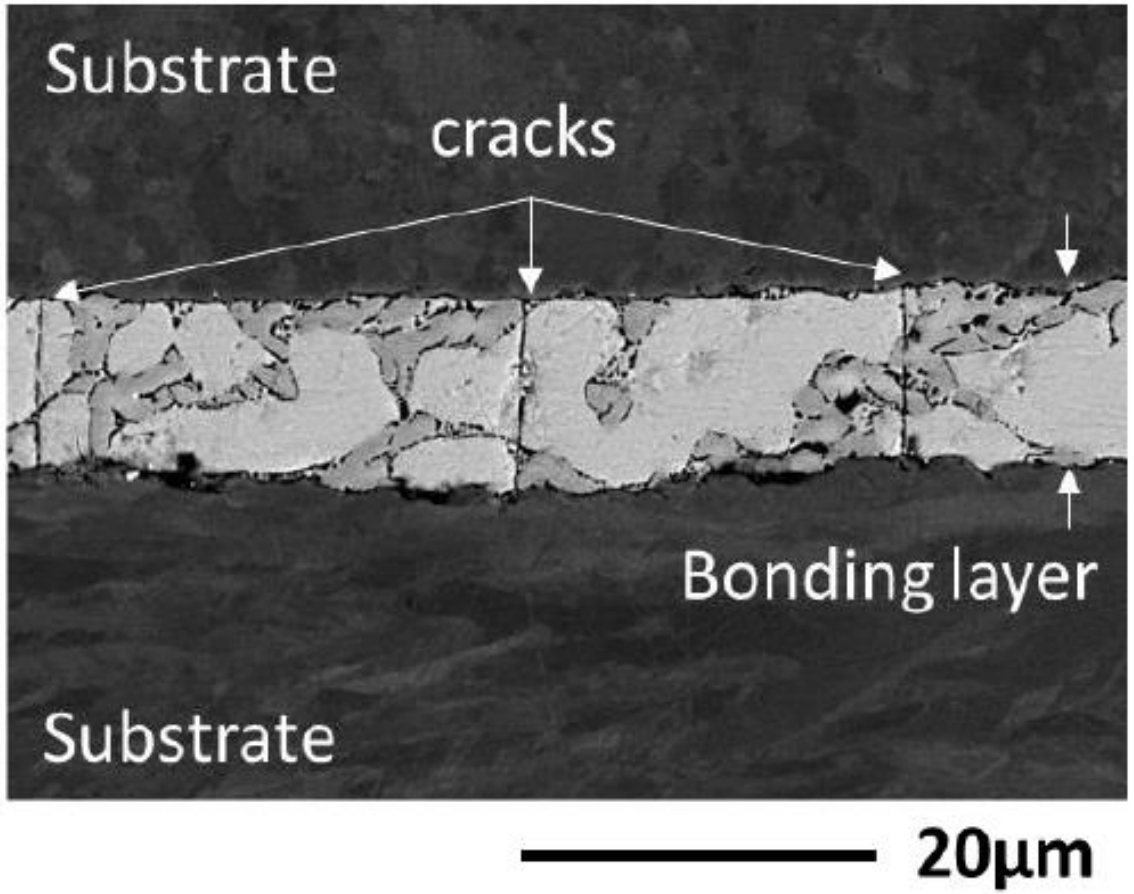
# SiC/SiC JOINING for NUCLEAR APPLICATIONS

| | Joining material | Starting products | Joining T [°C] | Joining Pressure [MPa] | Time [min] | Atmosphere | Joining material |
|---|---|---|---|---|---|---|---|
| Glass ceramics | • CA | CaO, $Al_2O_3$ | 1480 | 0 | 10 | Ar | 12CaO.7Al2O3; 3CaO.Al2O3 |

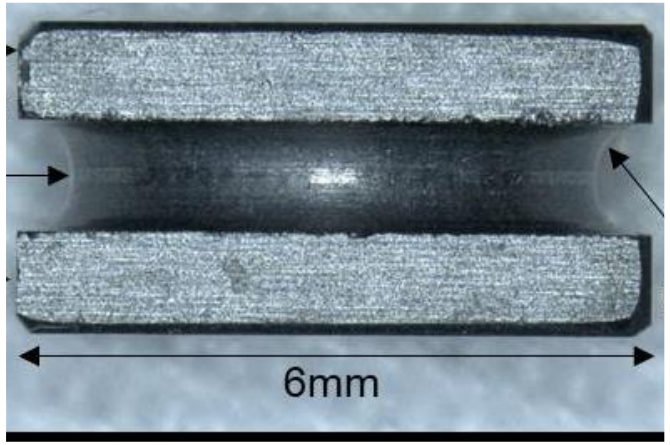
(a) Unirradiated



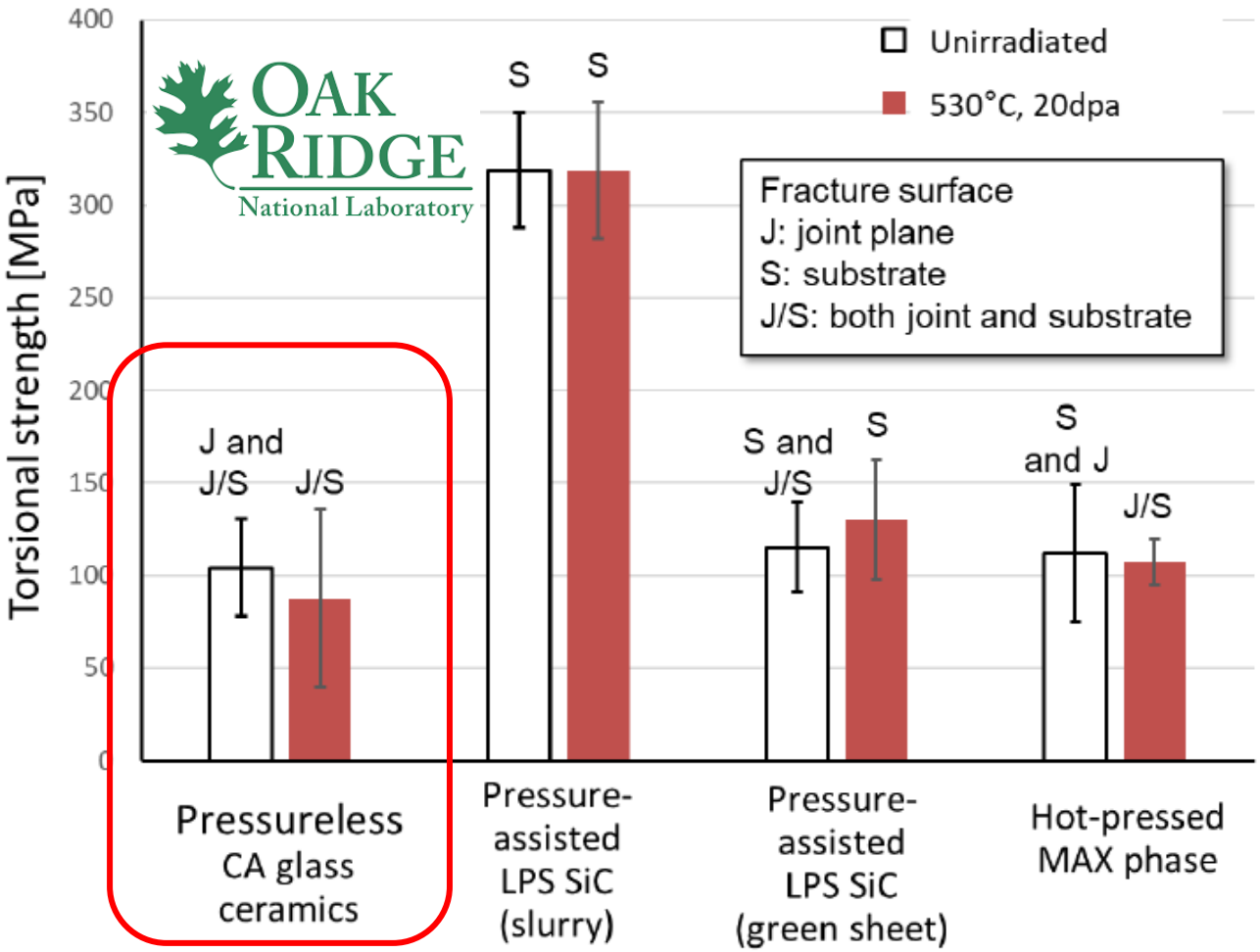

(b) Irradiated at 530°C to 20dpa



| | Joining material | Starting products | Joining T [°C] | Joining Pressure [MPa] | Time [min] | Atmosphere | Joining material | 530 °C, 20 dpa 350 days |
|---|---|---|---|---|---|---|---|---|
| Glass ceramics | • CA | CaO, $Al_2O_3$ | 1480 | 0 | 10 | Ar | 12CaO.7Al2O3; 3CaO.Al2O3 | |




**CA glass ceramic is at present, *one of the very few pressure-less* and *neutron resistant* joining material tested up to *530°C, 20 dpa*, with *unchanged mechanical and structural properties***




monica.ferraris@polito.it

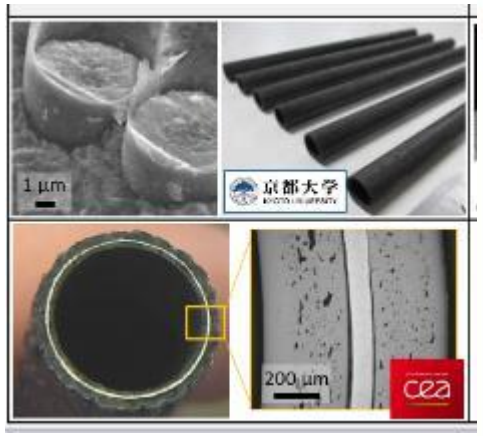
# SiC/SiC joining for cladding applications

## – surge of interest for LWR applications

IL TROVATORE

**INNOVATIVE CLADDING MATERIALS FOR ADVANCED ACCIDENT-TOLERANT ENERGY SYSTEMS**

Coordinated by Konstantza Lambrinou SCK-CEN, Belgium
now Huddersfield Univ., UK



# WP3. Joining of ATF clads & testing of joints/welds

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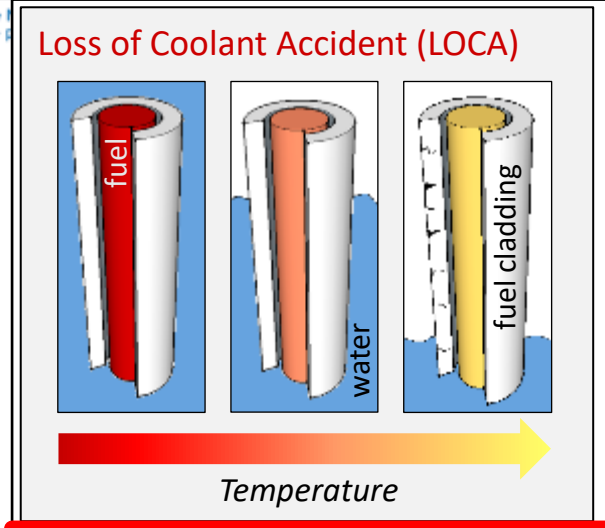
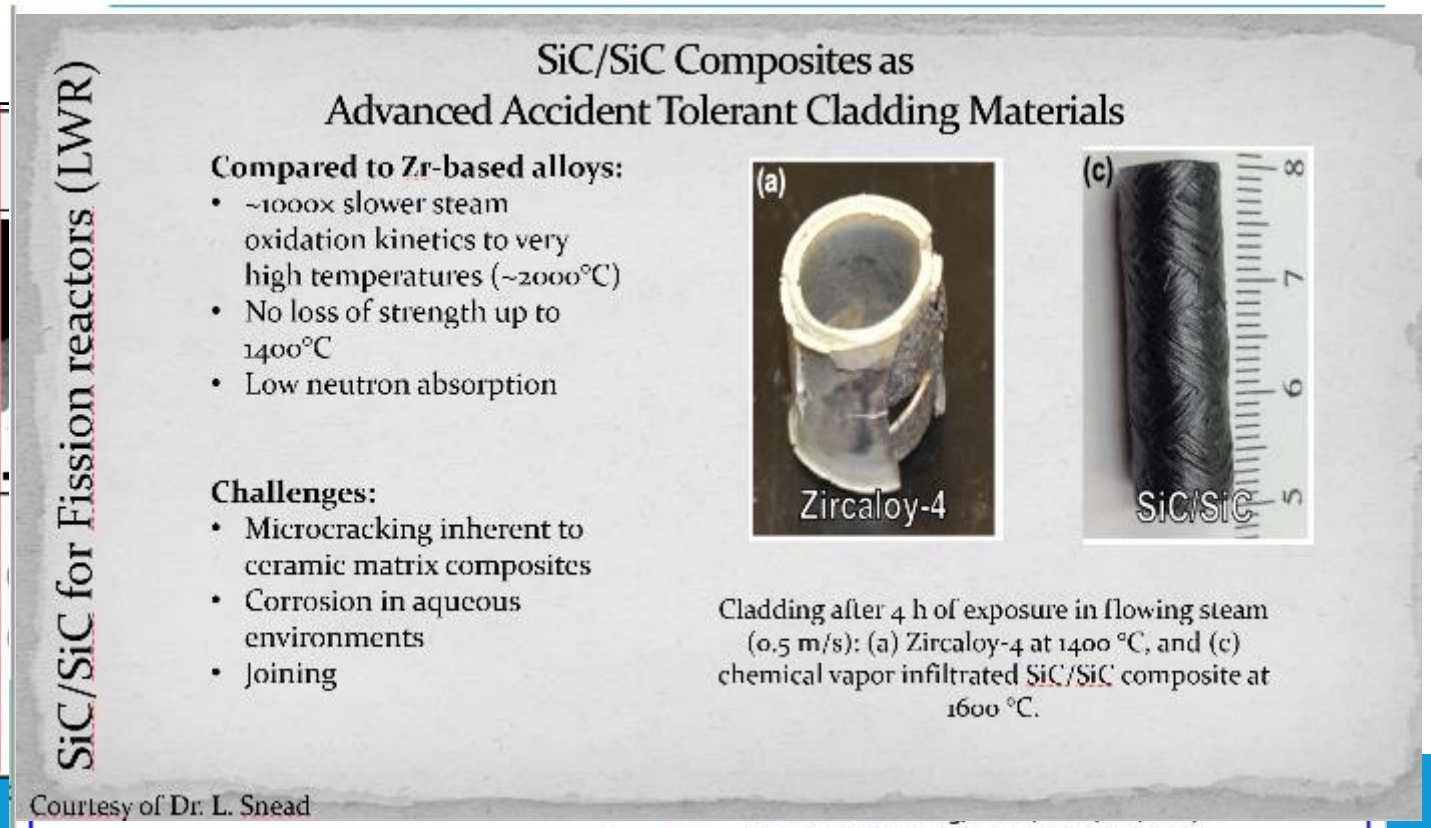



- IL TROVATORE Objective: Validation of selected ATF cladding material concepts in an industrially relevant environment, i.e., under neutron irradiation in PWR-like water (BR2 research reactor, SCK•CEN)



# Available joining for SiC/SiC in LWR

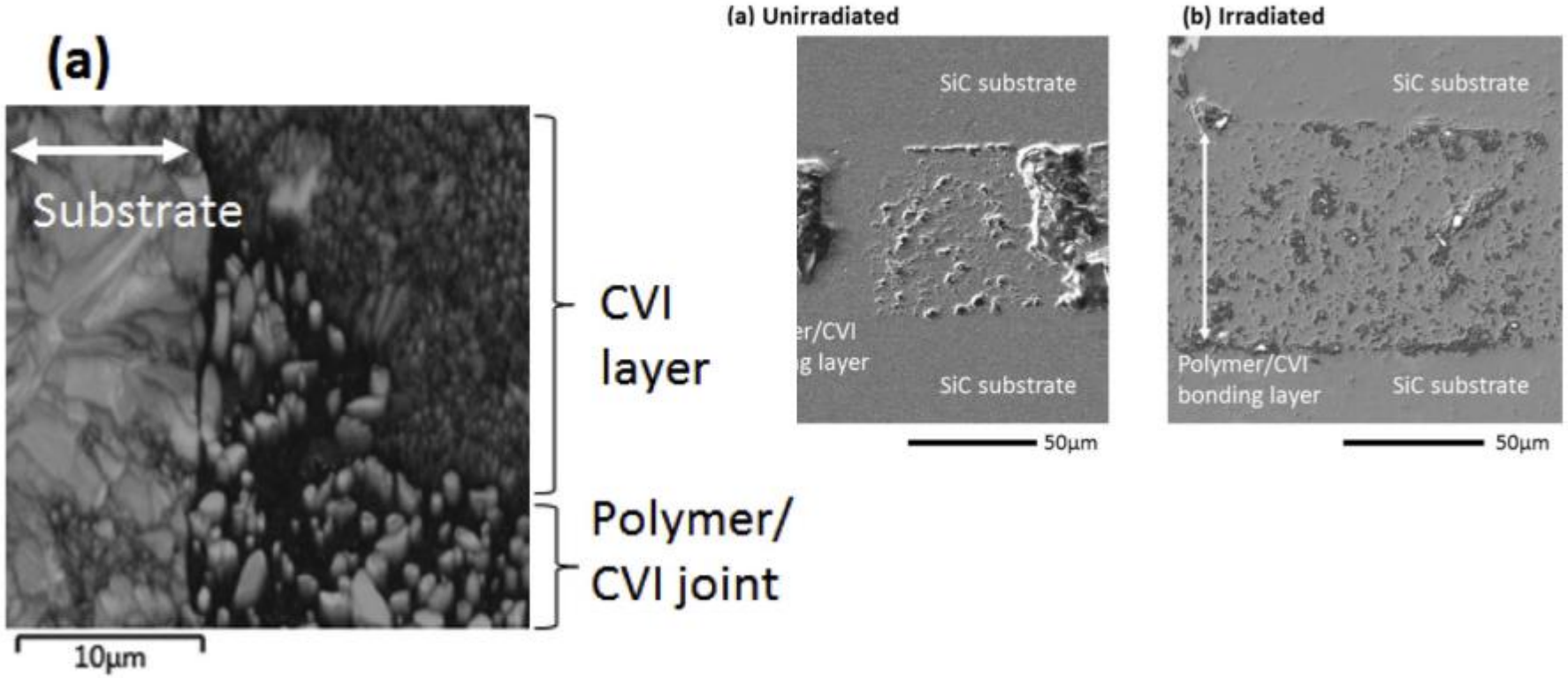
JAPAN

ORNL

General Atomics (GA) - USA

## Joining of SiC/SiC for LWR current approaches: General Atomics-USA

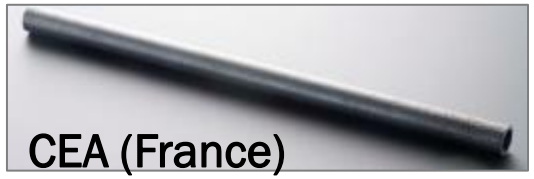
### Hybrid polymer pyrolysis/CVI joint




T. Koyanagi et al. / Journal of Nuclear Materials 488 (2017) 150-159

monica.ferraris@polito.it

# Available joining for SiC/SiC in LWR



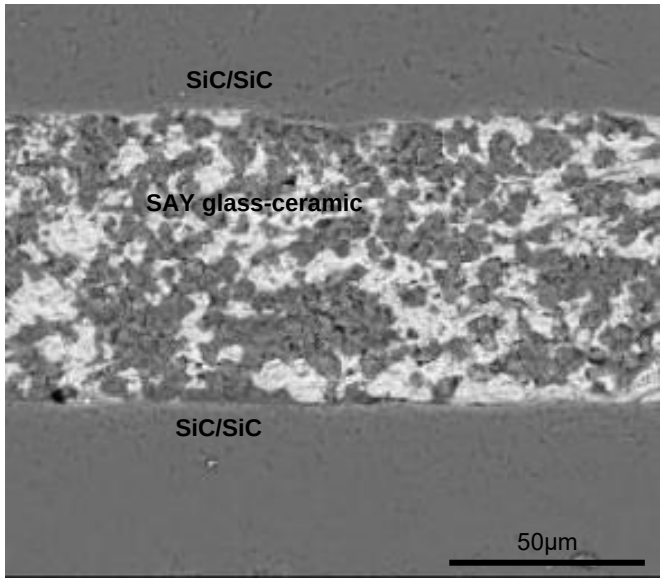
brazing

End plug fabrication

POLITO pressure-less joining by Silica-Alumina-Yttria based glass-ceramics

CTE (400-700°C)= 5.49 $10^{-6}$ °$C^{-1}$

Joining process: 1375°C 20 min, 1235°C for 1 hour



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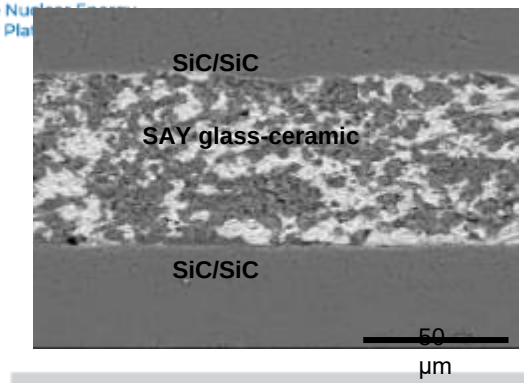
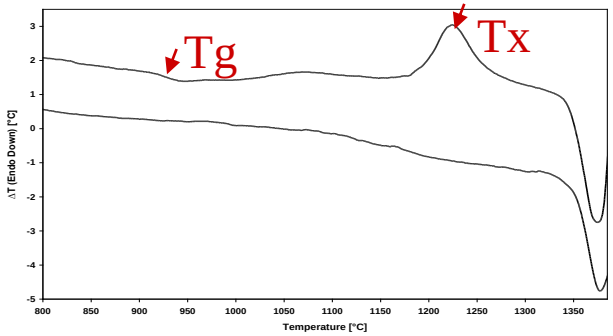
# Pressure-less glass-ceramic joining of SiC/SiC nuclear fuel clads for LWR



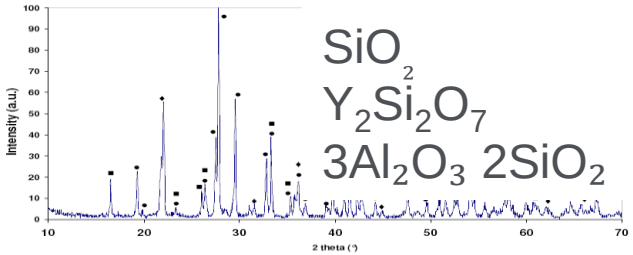




Figure 3. XRD measurement conducted on the SAY glass-ceramic after heat treatment at at 1375°C for 20 min and at 1235°C for 1 hour, heating rate of 1000°C/h, in Ar flow.

| Parent glass | | | | | | | Glass-ceramic | | | CMC Joining | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| acronym | Composition (wt%) | Prepar. T (°C) | CTE ($10^{-6}$°$C^{-1}$) | $T_g$ (°C) ±5 | $T_{soft}$ (°C) ±10 | Cryst. T (°C) ±5 | CTE ($10^{-6}$°$C^{-1}$) | Crystalline phases | Melting onset T (°C) ±10 | Joining T (°C) ±10 | Joined CMC |
| SAY | 54 $SiO_2$ 18.07$Al_2O_3$ 27.93 $Y_2O_3$ | 1750 | 3.8 (400-700°C) | 910 | | 1220 | 5.5 (400°C-700°C) | cristobalite, $Y_2Si_2O_7$ mullite | 1377 | 1375 (20 min) 1235 (60 min) | SiC/SiC |

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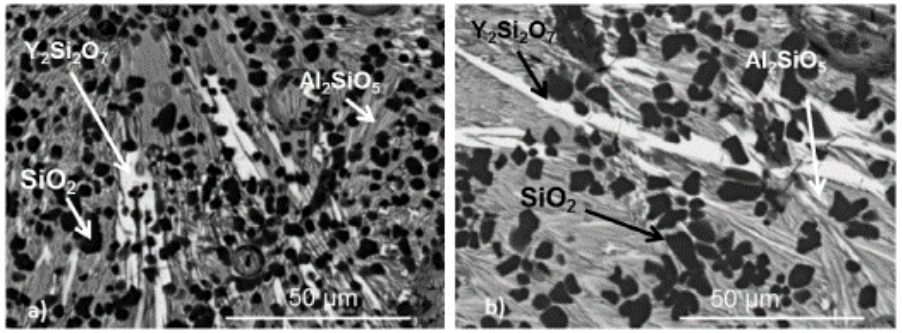
SPECIAL ISSUE ARTICLE
International Journal of Applied Glass Science

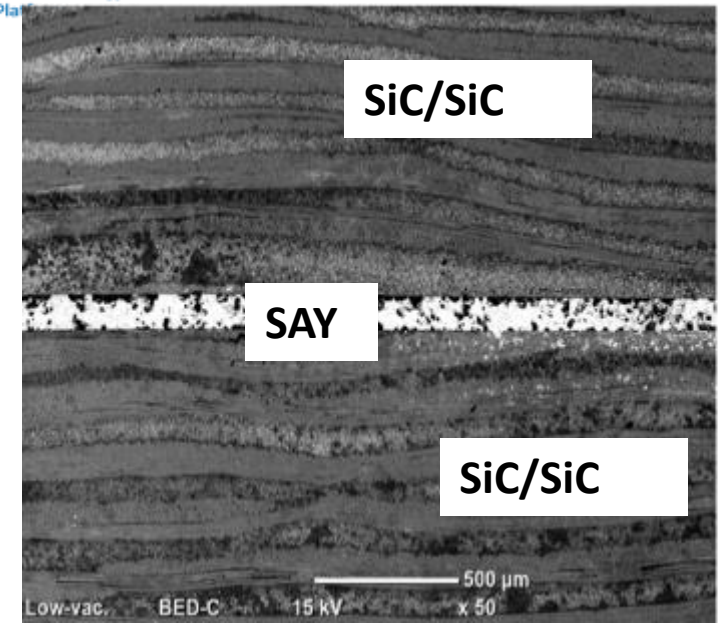
**Glass as a joining material for ceramic matrix composites: 25 years of research at Politecnico di Torino**

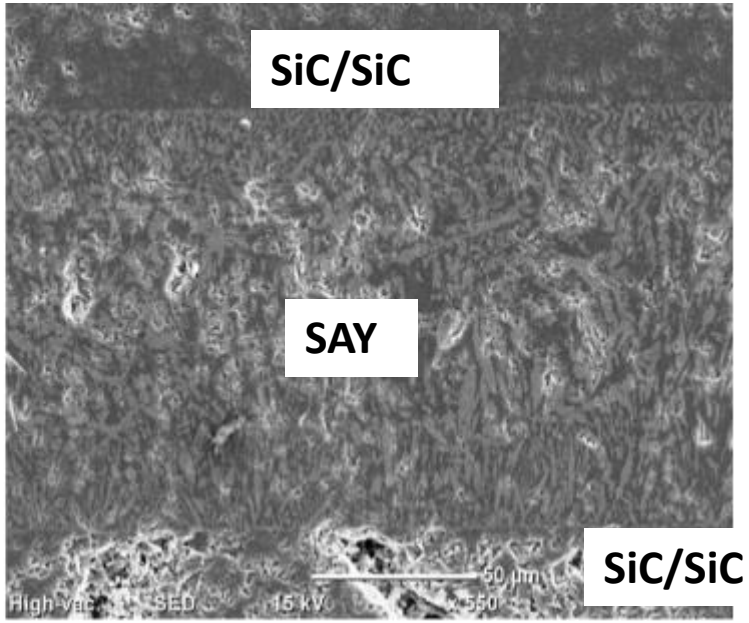
Monica Ferraris | Valentina Casalegno | Federico Smeacetto | Milena Salvo




**500° C, 6.92 * $10^{24}$ n/m²(E > 1 MeV, about 1 dpa in steel)**

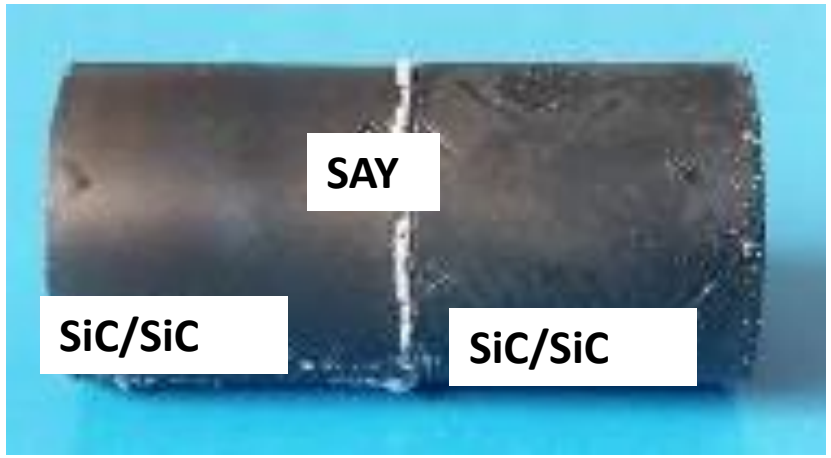
# Pressure-less glass-ceramic joining of SiC/SiC nuclear fuel clads for LWR



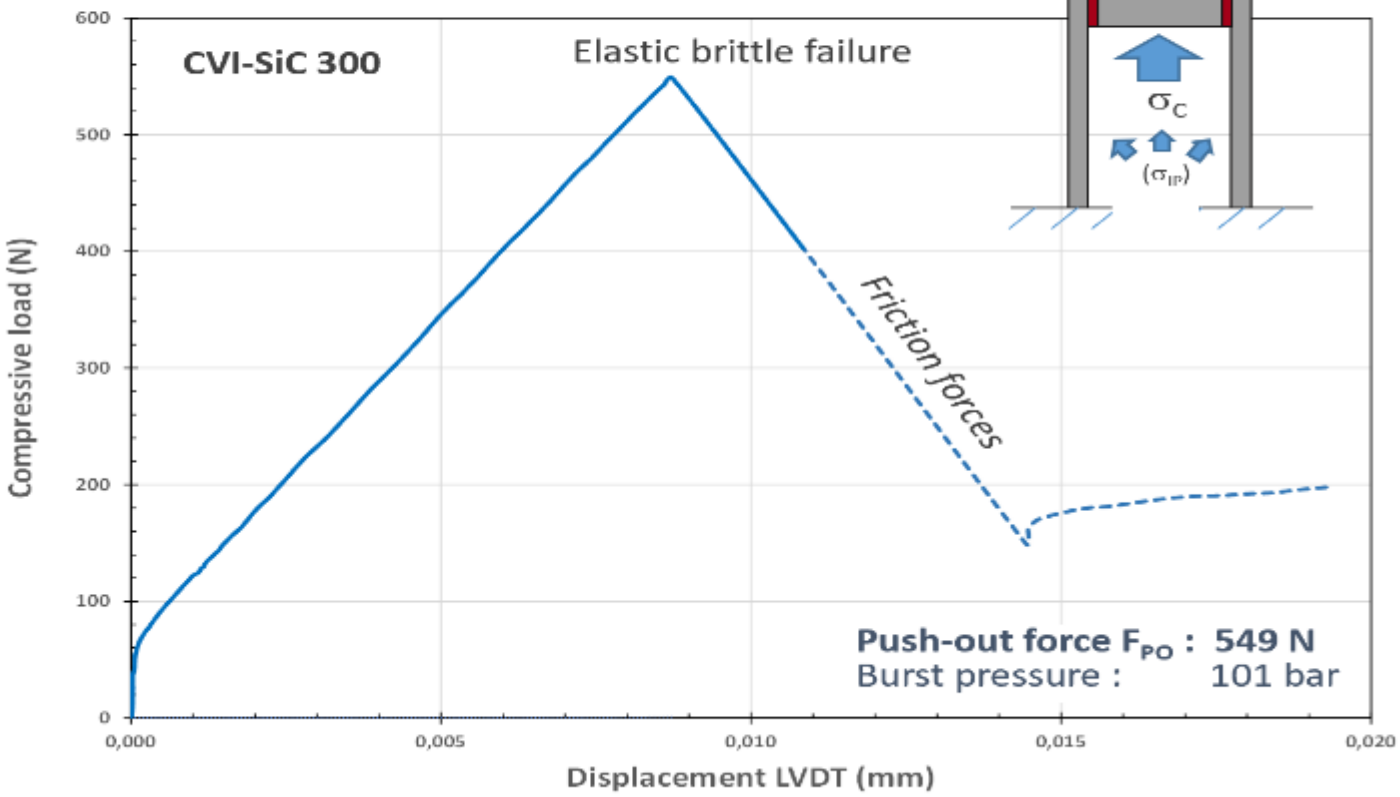

Successful pressure-less SAY joining of SiC/SiC from:

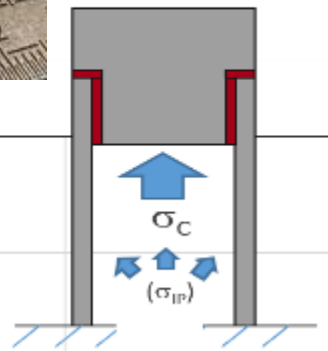
- IAE-Kyoto Univ.(Japan)
- NITE Corporation (Japan)
- CEA (France)



# SAY joined CEA SiC/SiC tubes to end plugs

## MECHANICAL TESTING



# SiC/SiC joining for cladding applications: PROGRESS AND CHALLENGES

POLITECNICO DI TORINO
J-TECH @PoliTO
SNETP Sustainable Nuclear Energy Technology Platform

-Static autoclave test at 330°C in PWR water chemistry + $N_2$ – 14 or 30 days

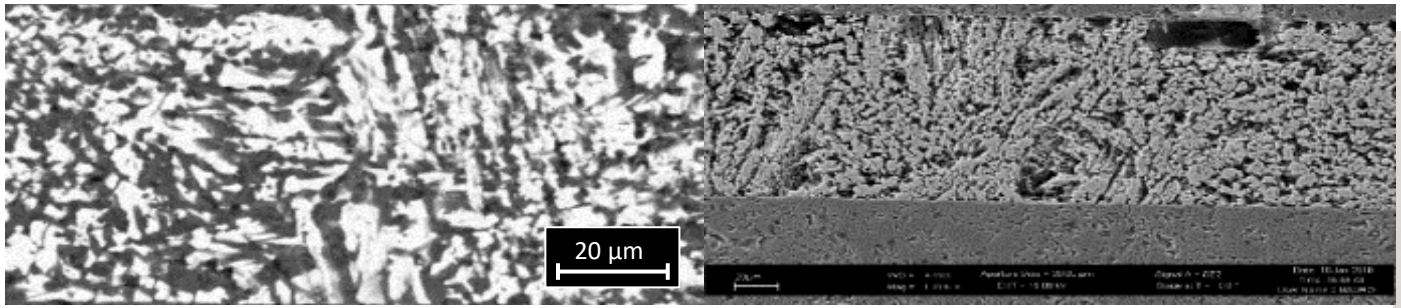
-Loop test at 330°C in PWR water chemistry + $H_2$ – 30 days

→ 45 cc/kg $H_2$ for SiC materials

- LWR resistant joints
- Pressure-less&Localized heating/coating

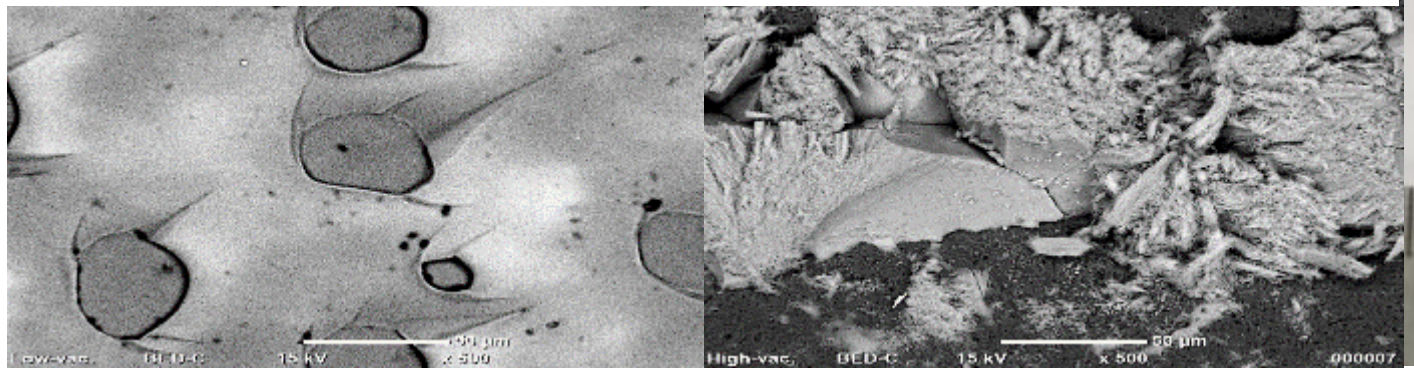
SAY JOINED SiC: conventional heating

Before autoclave After autoclave




SAY JOINED SiC: laser joining

Before autoclave After autoclave

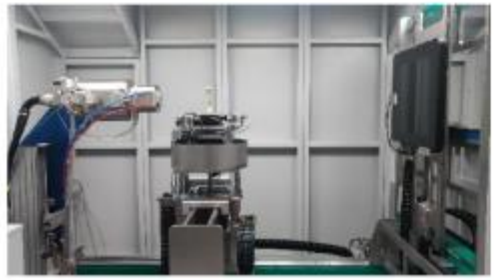


marion.herrmann@tu-dresden.de

# SiC/SiC joining for cladding applications at:

http://www.j-tech.polito.it/

X-Ray Computer Tomography



Laser And Arc Welding, Laser Heat Treatments on Surfaces, Resistance Spot Welding, FEM Welding Simulation; Friction Stir Welding

Split Hopkinson Bars

Torsion Test System

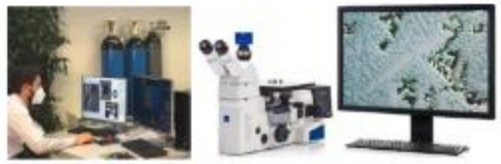
Axial-Torsional Fatigue Tests, Very-High-Cycle Fatigue

Impulse Excitation Technique and Infrared Thermography

Air and Vacuum Furnaces

Universal Tensile/Compression Machine

Field Emission Scanning Electron Microscopy with EDS and EBSD/optical microscopy



**Virtual Tour: https://youtu.be/bS_f5g82hDY**

Web page:
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monica.ferraris@polito.it

# SiC/SiC joining for cladding applications

http://www.j-tech.polito.it/

Thank you for listening!

Monica

**monica.ferraris@polito.it**

*IL TROVATORE Project ID: 740415 : H2020-Euratom-1.1. - Support safe operation of nuclear systems "Innovative cladding materials for advanced accident-tolerant energy systems" is kindly acknowledged for partially supporting this research*