INL/CON-24-81330-Revision-1

Micro-Tensile Properties of Irradiated AGR-2 TRISO Fuel Pyrolytic Carbon (PyC) and Silicon Carbide (SiC) Coatings

December 2024

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Idaho National Laboratory

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract n/a

2024 Workshop on Storage and Transportation of TRISO and Metal Spent Nuclear Fuels, December 3-5

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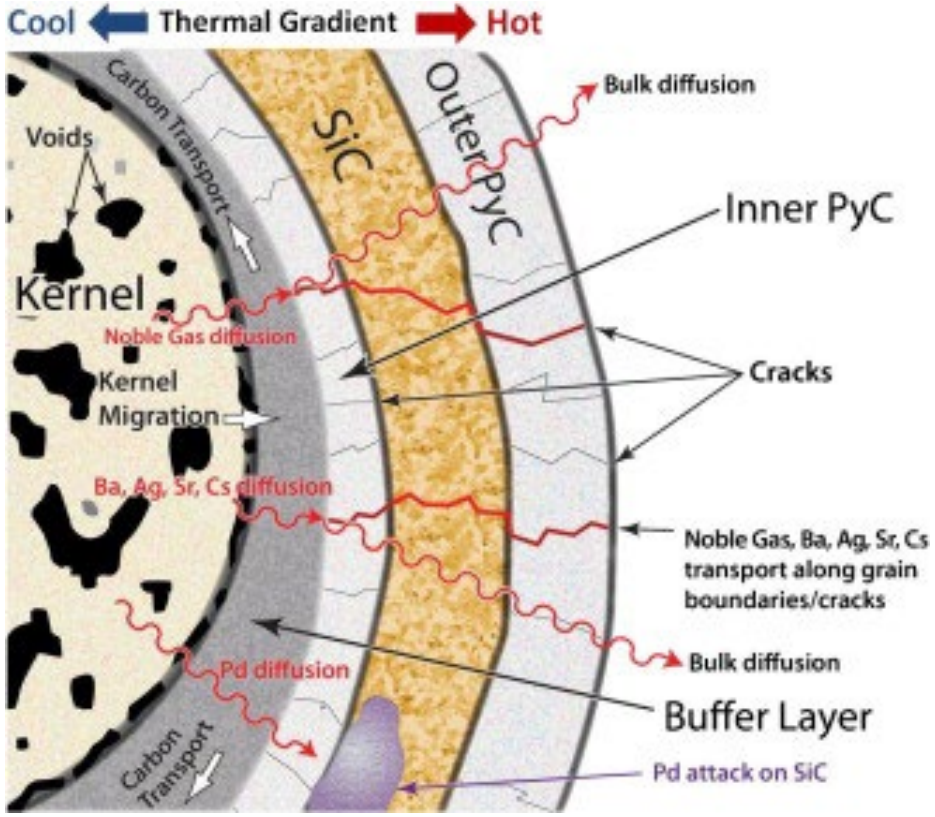
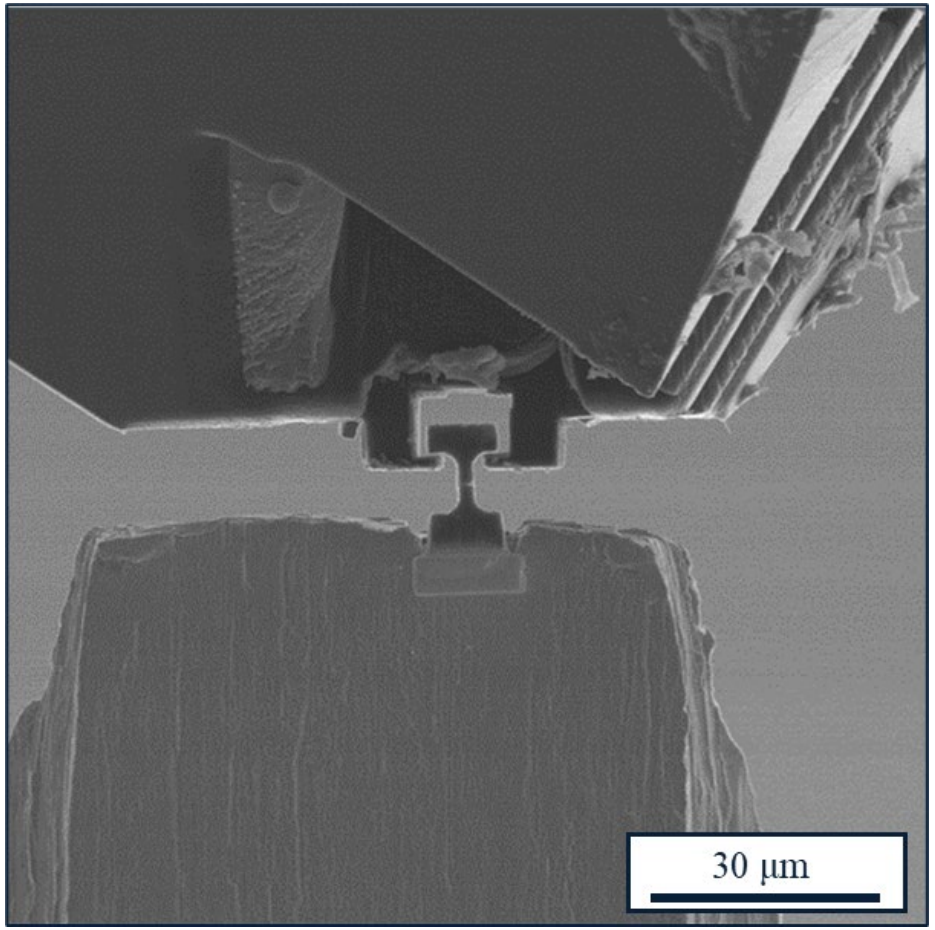
Introduction and PyC Creep Overview

- **Role of PyC and SiC Layers:**
  - The inner and outer PyC layers primarily provide structural support to the SiC layer and help contain fission gases.
  - The SiC layer is crucial for retaining fission products, providing mechanical strength, and ensuring chemical stability under high-temperature and irradiation conditions.
- **PyC Creep Phenomenon:**
  - PyC creep, which is the deformation of pyrolytic carbon layers under irradiation due to stress and high temperatures, can exert additional stresses on the SiC layer, potentially causing cracking and structural degradation that compromise the TRISO particle's ability to retain fission products.
  - However, this failure mode has not been observed in the AGR program; SiC failures are more likely due to fission product attacks when IPyC cracking exposes the intact SiC layer.



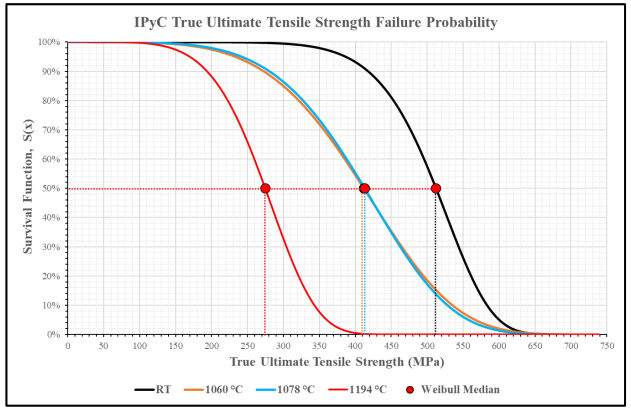
Micro-Tensile Testing Methodology

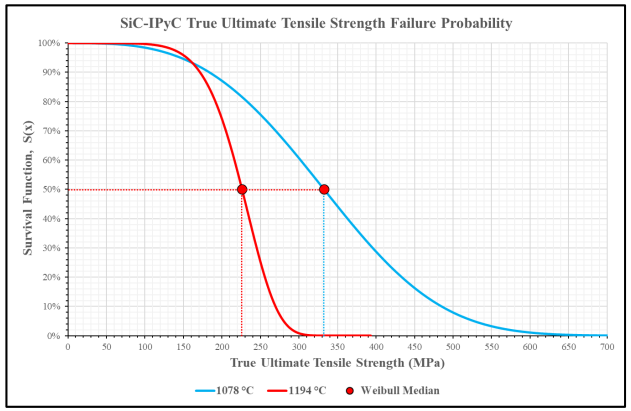
- **Testing Approach:**
  - A Bruker Hysitron PI 88 SEM PicoIndenter, typically used for nanoindentation, was retrofitted with a diamond gripper for in situ micro-tensile testing in conjunction with an SEM.
- **Sample Preparation:**
  - The gallium FEI Quanta 3D Dual Beam and Thermo G3 Plasma Dual Beam FIB SEM systems at IMCL were used to fabricate micro-tensile samples, following the study by Mauseth et al. (2023) with specific modifications for the FIB instruments used.
- **Relevance to SiC Layer Failure:**
  - Micro-tensile testing provides critical insights into the mechanical properties and failure mechanisms of the SiC layer in TRISO fuel particles, including the effects of PyC creep and operational stresses, thereby enhancing our understanding of SiC integrity and performance under realistic conditions.
  - This testing assesses the SiC layer's structural integrity, informs predictive models, enhances safety and performance strategies, and guides improvements in TRISO fuel design, ensuring the reliability and longevity of TRISO fuel particles.

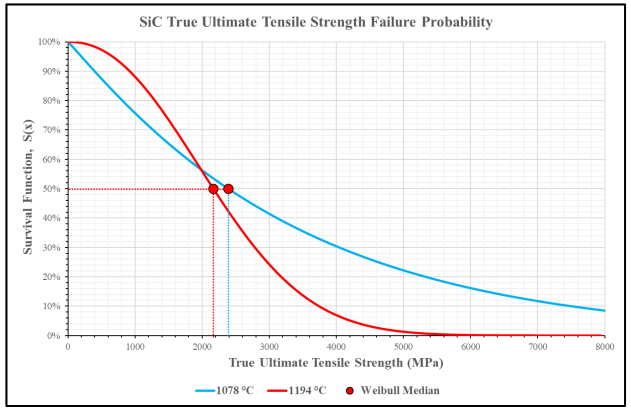


Key Findings from Micro-Tensile Testing

- **Tensile Properties:**
  - After irradiation, both IPyC and SiC show a decrease in tensile strength with increasing Time Average Volume Average (TAVA) temperature.
  - The SiC-IPyC interface exhibits lower tensile strength than the individual layers, indicating the interface as a potential weak point.
- **Implications for TRISO Fuel:**
  - The decrease in tensile strength of IPyC and SiC with increasing TAVA, particularly at the SiC-IPyC interface, suggests potential weak points in TRISO fuel particles that could lead to delamination or cracking under operational stresses, compromising the containment of fission products.
  - Even at low temperatures and with minimal neutron exposure, these weak points could compromise TRISO fuel particle integrity, stability, and fission product containment during storage and transportation due to mechanical stresses and long-term material degradation.







Discussion Points and Questions

- Research Needs:
  - What additional research is needed to better understand PyC creep and SiC layer failure?
- Data Sufficiency :
  - Are current data sufficient to model PyC creep and SiC layer failure during normal and off-normal conditions?
- Design Optimization:
  - How can design features be optimized to prevent SiC layer failure?
- Collaboration:
  - How can industry and regulators collaborate to ensure safety and compliance?