Silicon Carbide Tritium Permeation Barrier for Steel Structural Components

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Modeling and Testing

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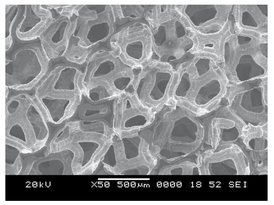
Approach

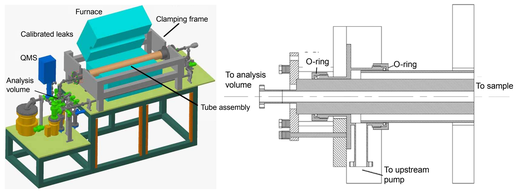
Ultramet foam shows compliance when bonded to substrates with large thermal expansion differences. Silicon carbide (SiC) formed by chemical vapor deposition (CVD) has superior resistance to tritium permeation even after irradiation.

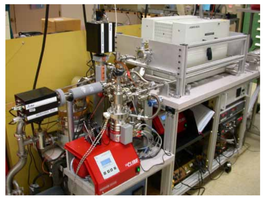


- Evaluate foams of vanadium, niobium, and molybdenum metals and SiC for CTE mitigation between dense SiC barrier and steel structure.
- Perform thermostructural modeling of SiC tritium permeation barrier/Ultramet foam/ferritic steel architecture.
- Evaluate deuterium permeation of CVD SiC.
- Construct higher temperature (>1000 °C) permeation testing system with improved sealing.
- Fabricate 7 × 35 cm prototype tube.
- Perform tritium and hermeticity testing of tube.

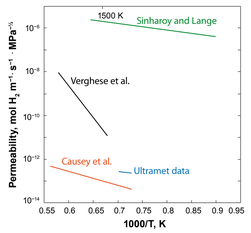
Deuterium Permeation

To address the leak present around the sample in Phase I, inner and outer tubes were sealed by a custom assembly of stock vacuum flanges and large-diameter UltraTorr fittings, which use a fluorocarbon FKM O-ring. Analysis volume (by which QMS is measured) was minimized to improve sensitivity to permeating flux. Calibrated leaks were used for absolute sensitivity and mass tuning calibration of QMS. Three pumping systems isolated the analysis volume during setup and bakeout, thus limiting background deuterium. A PID-based controller allows ramp-to-setpoint operation, which helps avoid thermal shock and allows thermal desorption experiments to be performed in situ.





Clamping force to seal sample in tube assembly (*light brown*) provided by outer frame around furnace (*gray*). Deuterium gas flows right to left; all pumps on left. Furnace has 12" long × 3" diameter uniform heating zone.



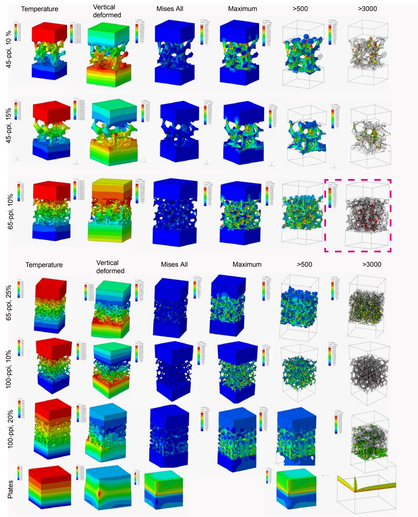
SiC sample ran 3 weeks at 1000 °C (1 mm thick, 0.5 atm upstream side). Temperature increased to 1100 °C on same sample and additional week at temperature. Low permeability correlated with Causey et al.

Modeling

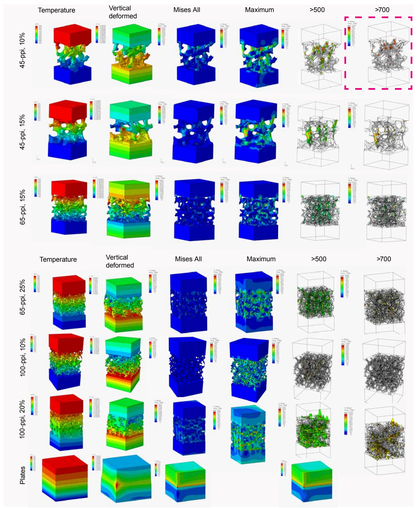
Computerized X-ray microtomography files were generated and translated from stereolithography format to ACIS solid modeling format. Solid models of foam microstructure were meshed and analyzed to determine permeability and ligamental heat conduction. Foam models were closed with facesheets of SiC and steel. Through conjugate heat transfer analyses the temperature distribution for thermal stress analysis was determined. Deflections and inelastic strains and stresses were computed in the ligaments and permeation barrier facesheets.

Niobium foam, 45-ppi/10%, has lowest thermal stress; 65-ppi/10% SiC foam has lowest stress for SiC foams. Stress increased with ppi and density. In all cases foam reduced stress in faceplates, niobium by an order of magnitude. SiC foam was less effective because of higher stress in ligaments, but stress in faceplates was still low.

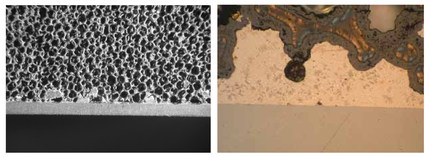
Silicon Carbide



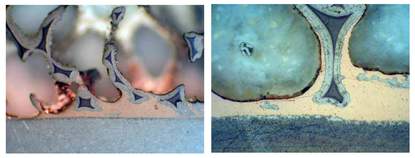
Niobium



Brazing



SiC foam bonded to low-activation steel with Cusil ABA

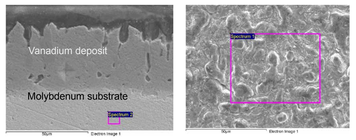


Nicoro braze joint between niobium foam and steel

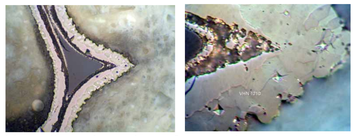
Dense CVD SiC coatings can be deposited directly on foam or separately and then brazed. SiC cannot be deposited on niobium foam because brittle silicides form. Brazing of both SiC and niobium foams to steel was limited to 600 °C.

Vanadium CVD Development

A CVD process has been established for vanadium. Because the deposition rate was impractically slow, only low density foam was fabricated, and cost and schedule requirements prevented further development. Niobium, which has similar physical properties, was substituted to demonstrate prototype fabrication and testing.



Vanadium deposit on molybdenum substrate



Vanadium deposit on foam substrate

Tritium Permeation Testing

The Ultramet SiC tube will undergo hydrogen and tritium testing at the INL STAR facility, which is designed to measure hydrogen isotope permeation in high temperature-resistant commercial alloys. Procedures and instrument calibration have been validated against data published within DOE NE VHTR activities.

- Test conditions will be varied to compare results with previous material characterization data.
- Performance in prototypical fusion blanket conditions will be validated by tritium testing using induction heating in a counter flow arrangement.
- Permeation will be driven by low concentration hydrogen isotopes in a high pressure helium flow.
- Material response to thermal cycles will be characterized.

Tritium permeation experiment at INL STAR facility