Carbon Composite Bipolar Plate for PEM Fuel Cells

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Objective

To develop a slurry-molded, carbon fiber material with a carbon chemical vapor infiltrated (CVI) sealed surface as a bipolar plate that would meet cost and property goals.

Property	***Specification***
Bulk Conductivity	**> 100 S/cm**
H_2 permeability	**$<2 \times 10^{-6}$ cm^3/cm^2-sec**
Corrosion rate	**$<16\ \mu A/cm^2$**
Cost	**<$10/kW**

Approach

- Bipolar plate utilize carbon/carbon concept
- Preform is slurry-molded carbon fibers
  - similar to paper or felt production
  - fibers ~100 μm plus filler particles
  - features stamped/embossed into preform
- CVI with carbon
  - seals and makes hermetic high-density surfaces
  - provides continuous, high-conductivity material

Advantages of Approach

- Preforms prepared from slurry-molded carbon fibers
  - net shape process/press-in features
  - process can be continuous (i.e., papermaking)
  - low-cost materials
- Appropriate surfaces sealed via deposition of carbon
  - high-conductivity (graphitic) carbon coating all surfaces
  - infiltration makes component fully integral
  - potential for continuous or semi-batch processing
- Negligible impurities/poisons with minimal corrosion
- Strength and toughness of carbon/carbon
- Very light weight (about half that of other approaches)
- Potential for integral diffuser/catalyst support, therefore, lower ohmic losses

Timeline of Project Accomplishments

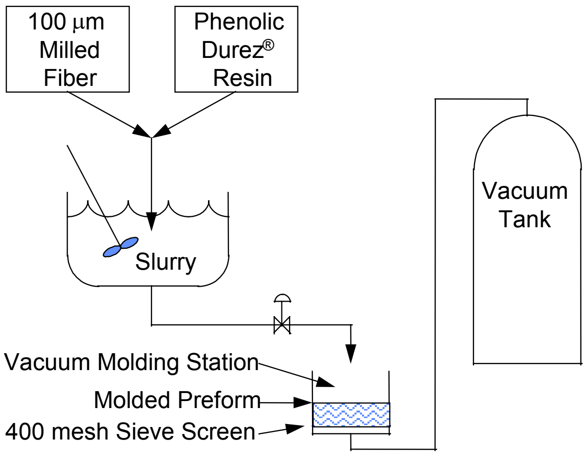
- **March 1998**
  - Project Initiated
- **July 1998**
  - 3-cm disks with machined flowfield
  - High conductivity meas.
  - Promising cell perf.
- **June 1999**
  - 100-cm^2 plates with machined flowfield
  - Good cell performance
  - High conductivity meas.
  - Light weight demonstrated
  - High strength/toughness
  - Initial samples to industry
- **June 2000**
  - Pressed preforms
  - Freeze/thaw testing
  - Low corrosion meas.
  - Multiple samples to industry
- **April 2001**
  - License signed with Porvair Fuel Cell Technologies
- **June 2001**
  - Two-sided 100-cm^2 plates with pressed flowfield evaluated
  - Thermal conductivity meas.
  - Resistivity/polarization meas.
- **June 2002**
  - Developed carbon composite with graphite particulate filler
  - Measured mechanical properties of plate material
  - Significantly improved wetting of bipolar plate surface
  - Determined surface roughness of finished plate
- **Sept. 2002**
  - Developed a series of bipolar plate materials/specimens that meet specific fuel cell manufacturer's design needs
- **Sept. 2003**
  - With licensee, developed manufacturing capability for specific bipolar plate designs through sample preparation, process modeling, and consultation

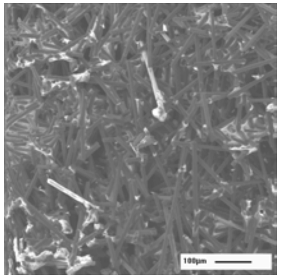
Current Accomplishments

- With licensee, have reduced thickness of plates from 2.5 mm to 1.5 mm
- Determined influence of CVI temperature on depth of infiltration
- Further characterized and measured mechanical properties of carbon composite plate material
- Determined electronic properties, including effect of surface roughness on resistance
- Developed initial model of chemical vapor infiltration process that is scalable to production – model demonstrated value through guidance on flow control improving uniformity

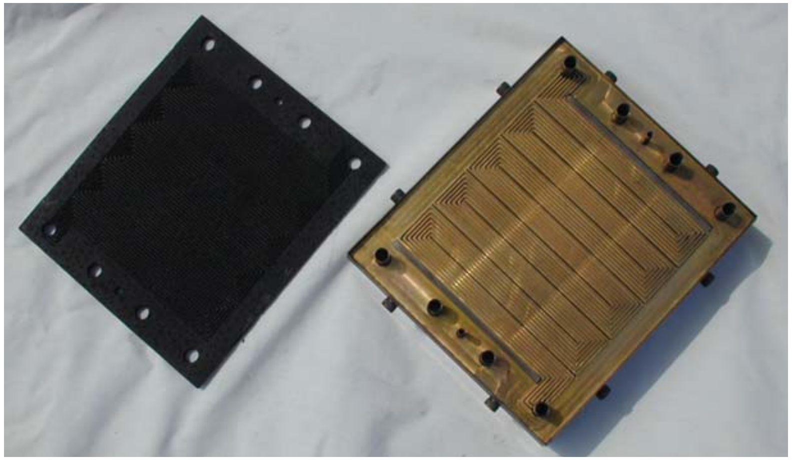
Carbon Composite Plate Fabrication

Slurry Molding of Preforms

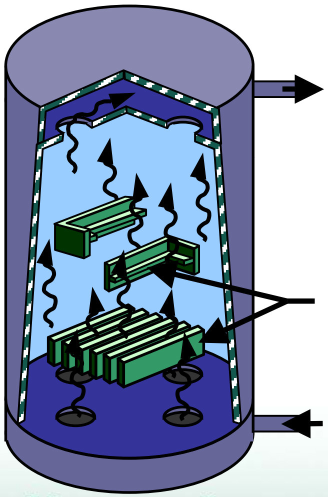


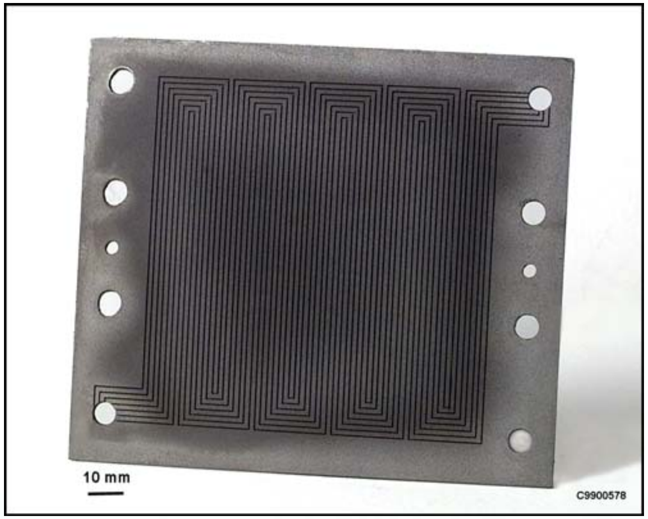


Press or Stamp Features



CVI Carbon





Porvair Preform Material Used in Study of Infiltration Depth as a Function of Reactor Conditions and Position

CVI Conditions:

Temperature

High Rate - 1500°C

Low Rate - 1350°C

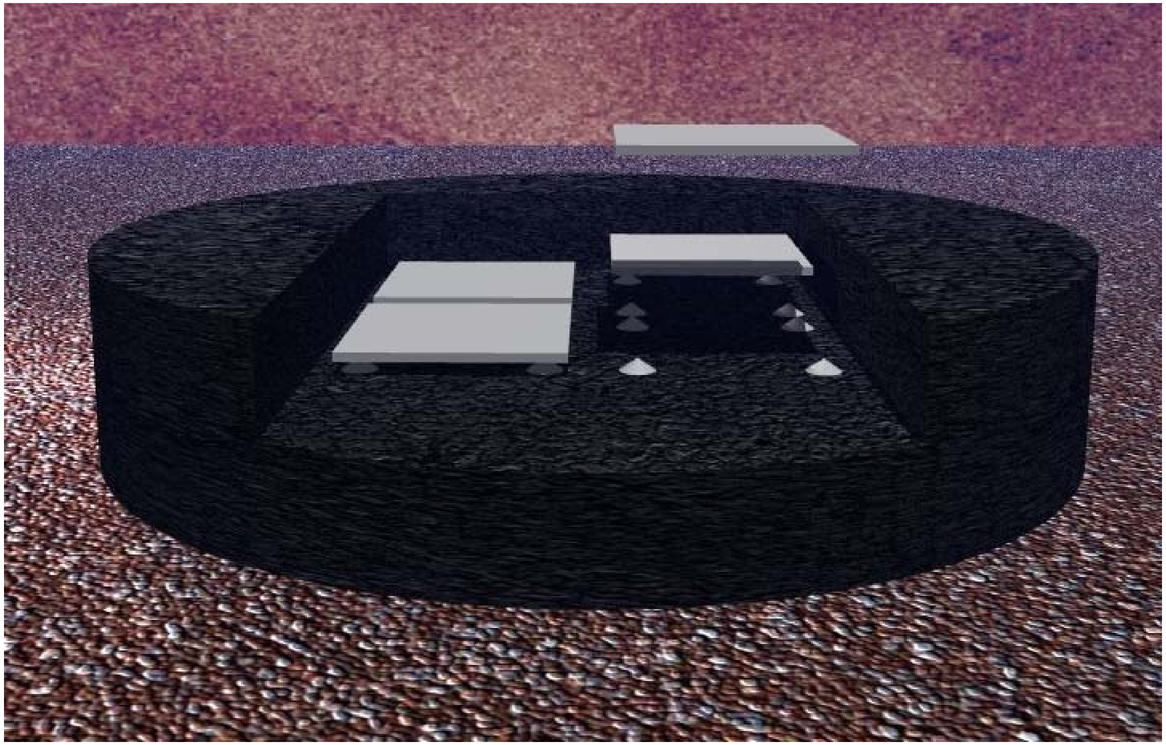
Flow

1 sccm methane

2.5 sccm argon

Pressure

4 kPa

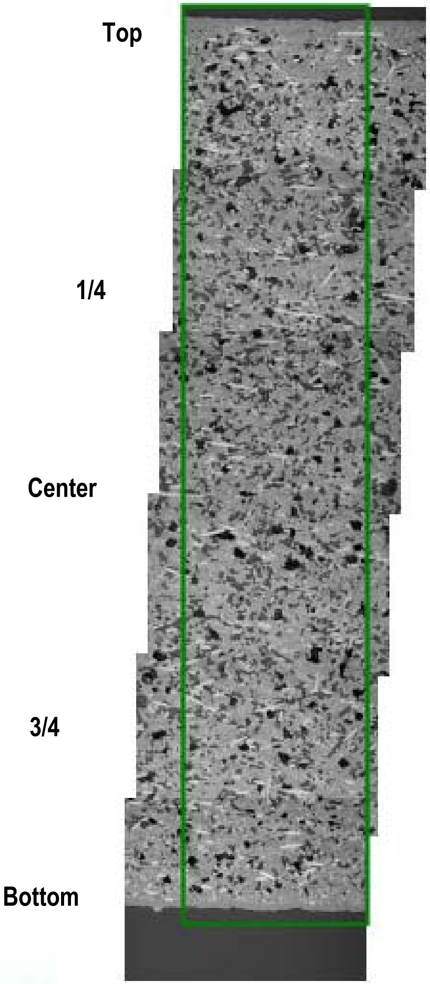


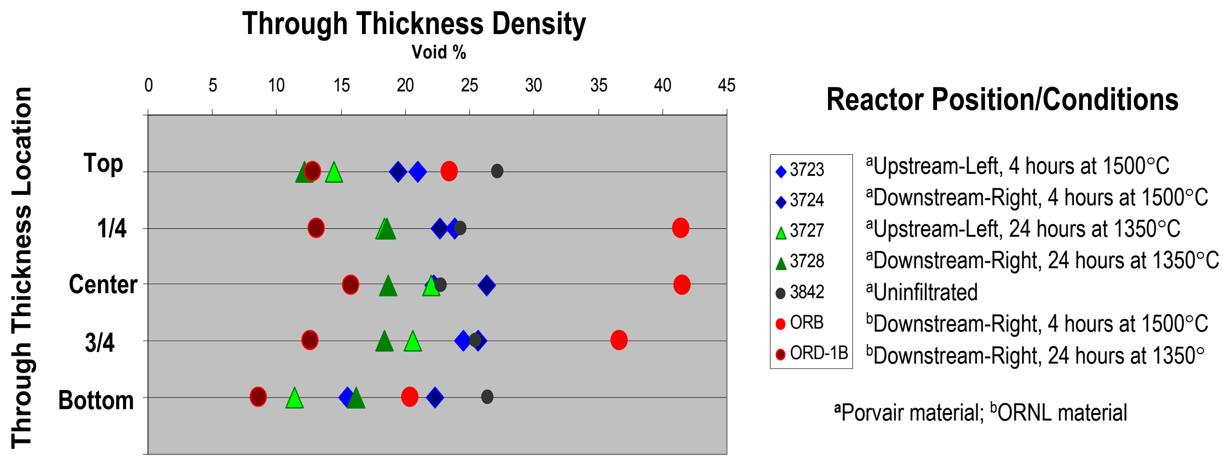
CVI Reactor Chamber Showing Position of Samples

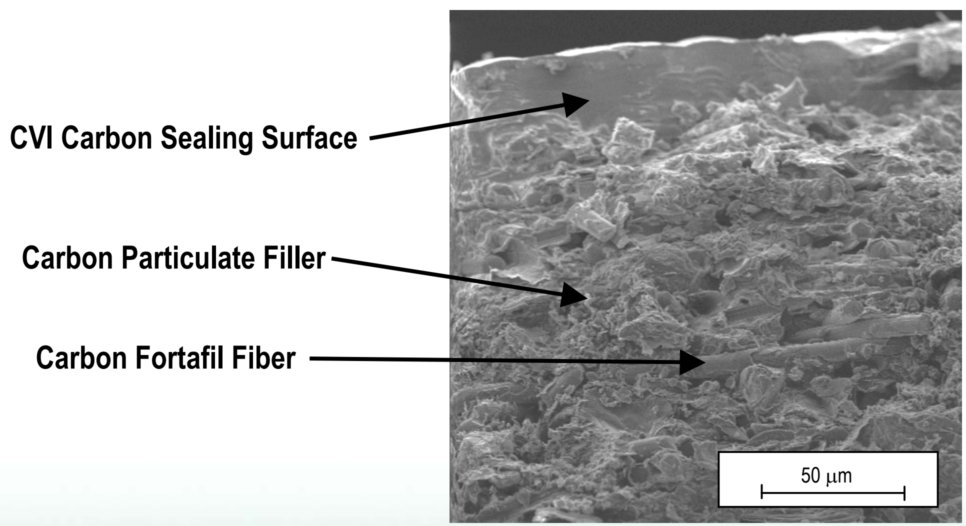
Effect of CVI Conditions/Material on Density Profile

Image analysis reveals density gradients through plate thickness more pronounced for:
- *ORNL material, which has no filler particles and thus higher green state porosity*
- *More rapid infiltration (higher infiltration temperature) in ORNL material*

Mosaic of Optical Images of Plate Cross-Section (Porvair Material)



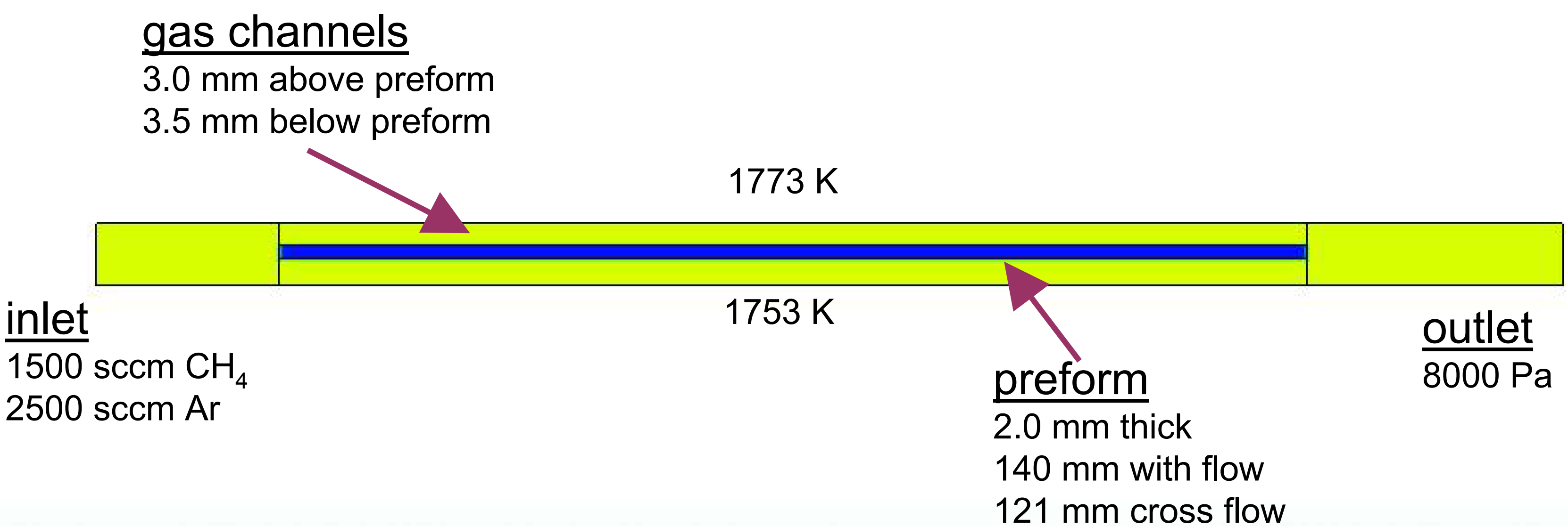




SEM Image of a Fracture Surface of an Infiltrated Bipolar Plate Produced From Porvair Preform Material Indicating That Carbon Deposition Is Limited Largely to the Exposed Surfaces

2-D Computer Model for CVI Reactor

- Commercial fluid dynamics code (CFD-ACE from CFD Research, Huntsville, AL) Cross-section reactor/preform geometry
- Kinetics and transport parameters from literature and from experiments at ORNL
- Finite-volume method with 136,000 element structured grid
- Boundary conditions match experiment
- Steady-state solution for gas flow



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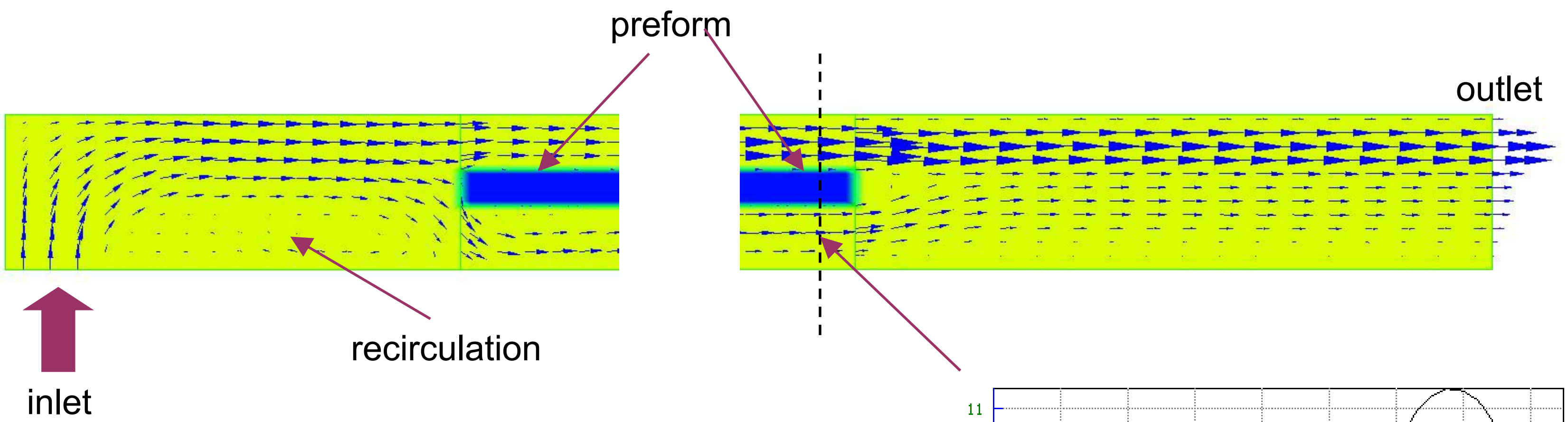
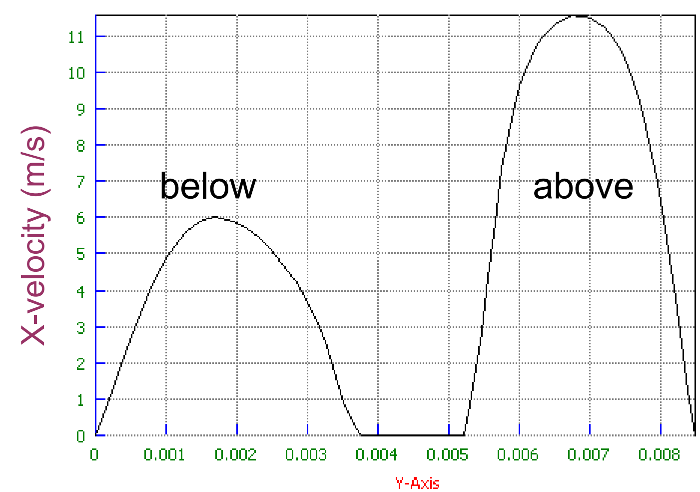
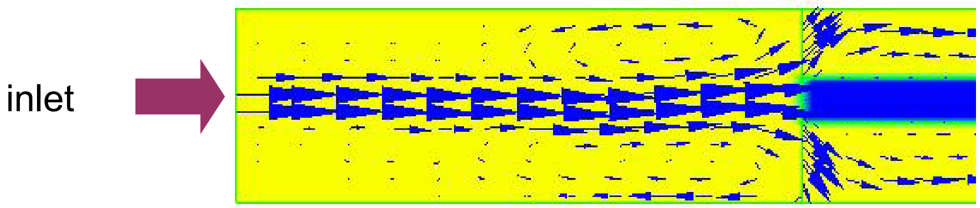
Original Inlet Design Yielded Non-Uniform Flow



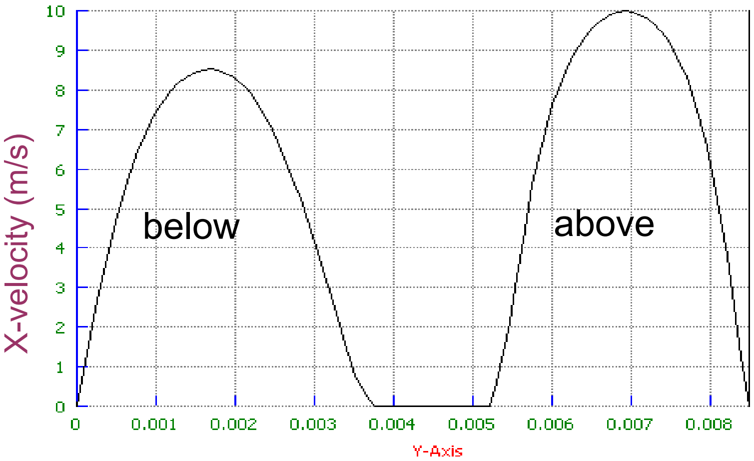


- **Single recirculation cell near inlet**
- **Parabolic, laminar flow above/below preform**
- **Higher velocity above preform**

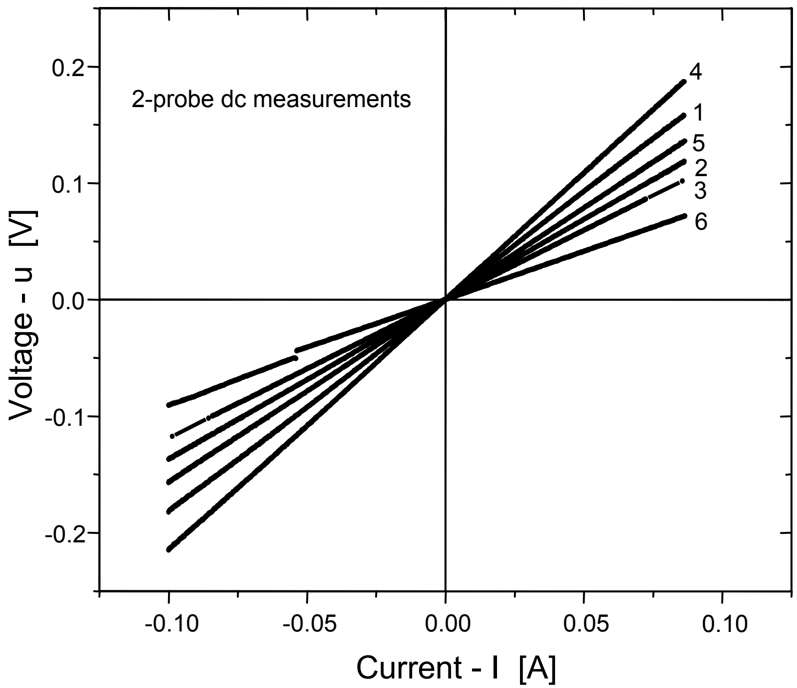
Installation of a Nozzle Yielded Uniform Flow



- **Nozzle turns and centers inlet flow**
- **Top/bottom recirculation cells**
- **Uniform velocity above/below preform**



Electronic Properties Are Weakly Related to Surface Roughness

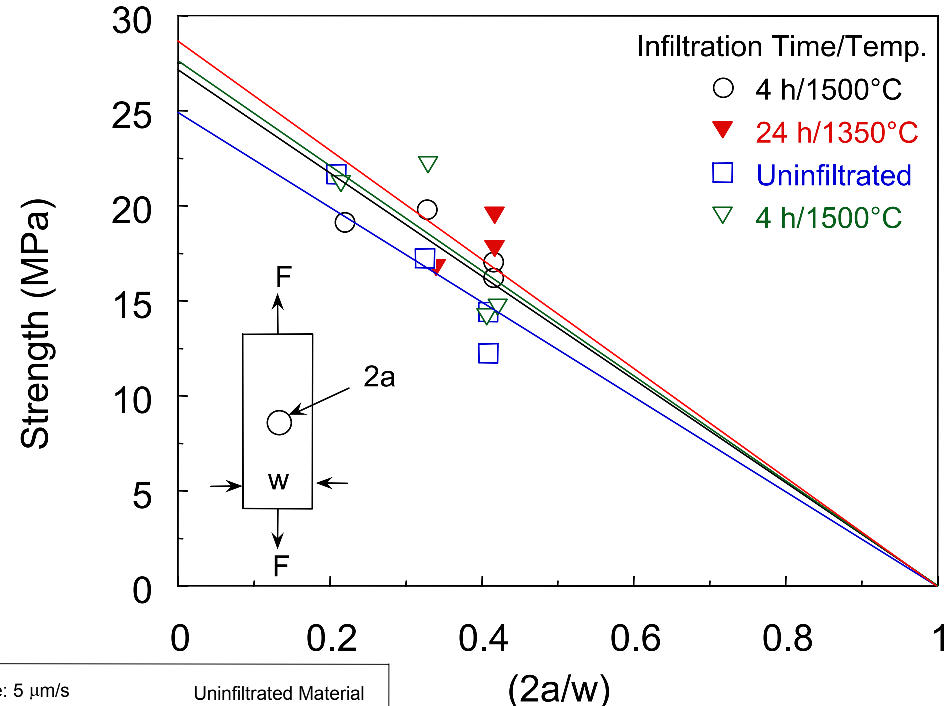


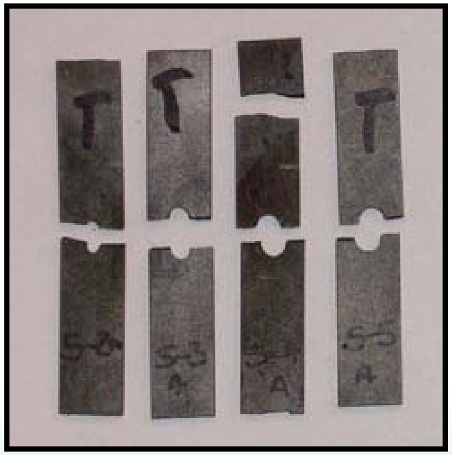
Porvair Material	Infiltration Treatment	Surface Roughness Rz µm	Resistance 2 Probe DC Ω	Conductivity 4 Probe V/I σ S/cm
No. 1 - V162C-L2 A	4hours at 1500°C	8.83	1.86	365
No. 2 - V1631-R1-C	24hours at 1350°C	12.9	1.37	417
No. 3 - V1631-R1-P	Uninfiltrated	13.5	0.86	369
No. 4 - V162C-L2 D-1	4hours at 1500°C	10.2	2.16	386
No. 5 - V163AR1A-1	24hours at 1350°C	14.3	1.57	383
No. 6 - V163A-R1-B	24hours at 1350°C	2.9	0.84	408

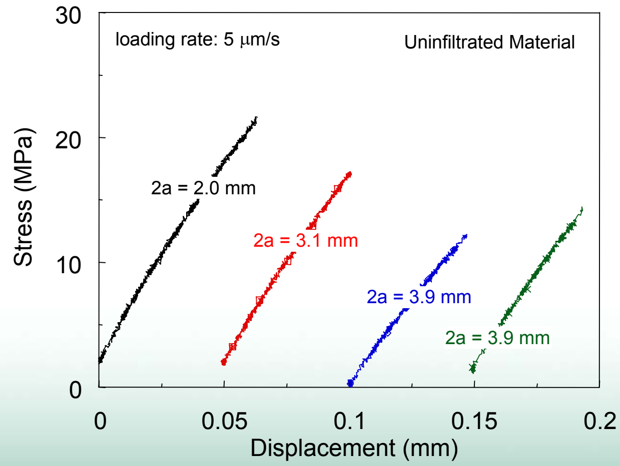
- *2-probe measurements are sums of all contact resistances*
- *Surface roughness does not correlate closely with contact resistance*
- *Sample no. 4 was not infiltrated and thus has fewer "interfaces" to offer resistance*
- *Sample no. 6 was polished and indicates a significantly lower contact resistance than that of unpolished samples (all others)*
- *Bulk conductivity as measured by a 4-probe technique varies little with sample preparation*

Porvair Material Has Reasonable Strength and Apparent Notch Insensitivity

- *The resistance of materials to crack propagation can be evaluated by the notch sensitivity test*
- *Test specimens with holes of various sizes are subjected to monotonic tensile loading*
- *Ultimate strength (un-notched) is at a minimum the zero intercept of the strength vs. 2a/w*



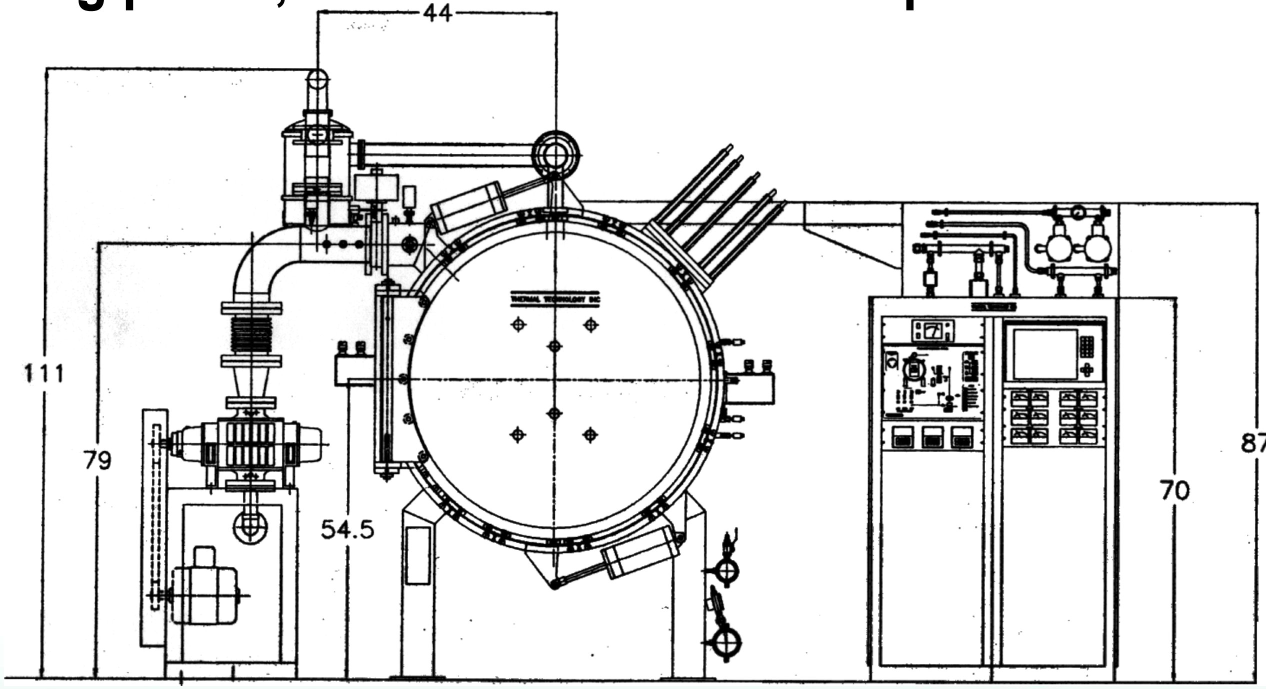




Industrial Interactions

- Supporting licensee Porvair Fuel Cell Technology in scaling up technology
- Porvair has been awarded a $6.1 M DOE program for scaling and applying the carbon composite bipolar plate technology
- Other companies evaluating plates, with some under development

Porvair Scale-Up CVI Furnace



Continuing Development and Technology Transfer of Carbon Composite Bipolar Plates

- Milestone FY 03 - Develop a carbon composite bipolar plate component with reduced thickness and optimized mechanical properties. (Sept. 2003)
- Develop CVI process model that is scalable to pilot and production facilities
- Determine electronic properties as a function of surface roughness
- Milestone FY 04 - Support continued scale-up of the licensee's operation through modeling of fabrication processes. (Sept. 2004)

Some Advisory Panel Comments From Last Year and Responses

- "Demonstrate durability of materials manufactured by industrial partner in larger hardware"
  - Mechanical property measurements were made to better characterize the material which showed notch insensitivity (good toughness)
  - Partner has produced significant numbers of plates that have performed in customer hardware
- "Providing different hydrophobicity could be interesting area to explore"
  - Licensee does not give this a high priority
- "Test method extensively"
  - Developing mechanical and electrical property test results