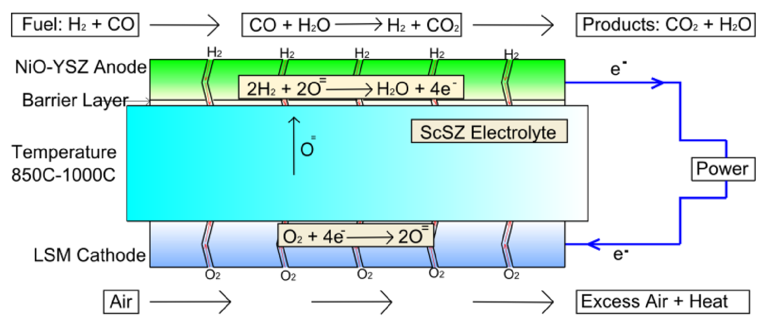
Mechanical Characterization and Modeling of Electrolyte Membranes in Electrolyte-Supported SOFCs

Mark E. Walter, Angel Suresh, Ryan Berke, The Ohio State University

Paul Matter, Mick Day, Robin Kimbrell, Kellie Chenault, Scott Swartz, NexTech Materials Ltd

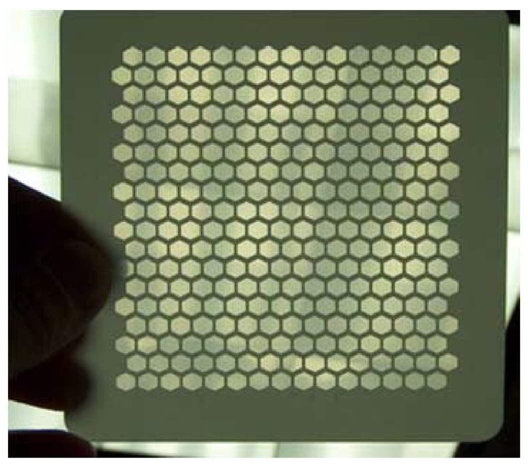
Introduction and Goal

- The FlexCell™: is the latest generation electrolyte membrane for electrolyte supported planar SOFC from NexTech
- FlexCell Innovation: A honeycomb-type structure provides thin active area with a thicker support mesh
- The thin electrolyte may be susceptible to mechanical damage during manufacturing, assembly, and operation
- Goal: To optimize the FlexCell geometry for mechanical robustness while maintaining high active area
- Approach
  - Small Scale: developing material models and modeling the repeating unit cell
  - Large Scale: modeling whole electrolyte membranes and identifying key geometric design parameters



SOFC Construction and Operation

FlexCell™

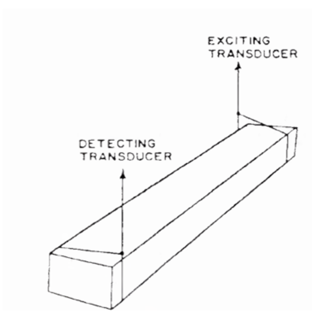


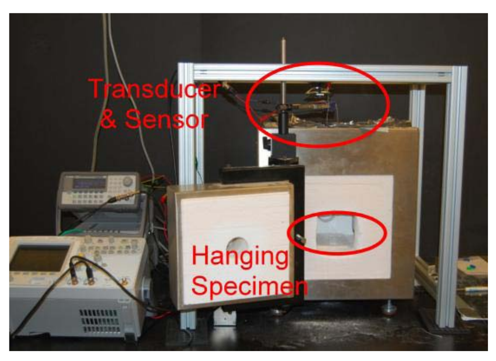
Honeycomb structure in a FlexCell™

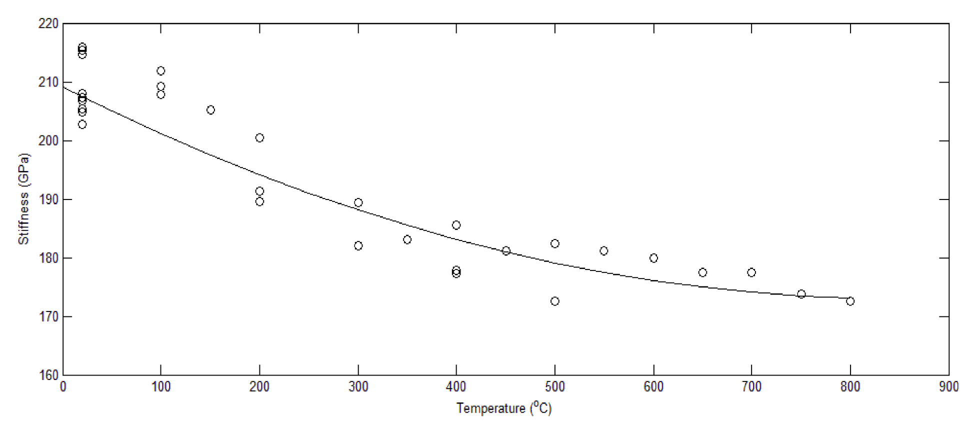
Material Properties and Models

Sonic Resonance Technique (ASTM E 1875-08)

- Modulus calculated from resonant frequency of a vibrating specimen, geometry, and mass of specimen
- Modulus determined up to 800 ºC

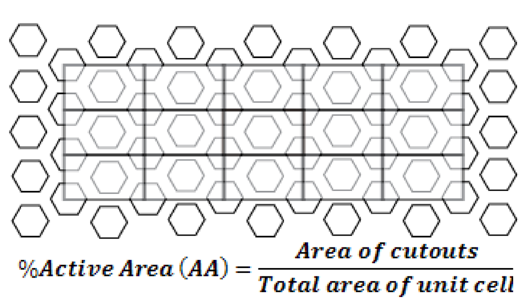


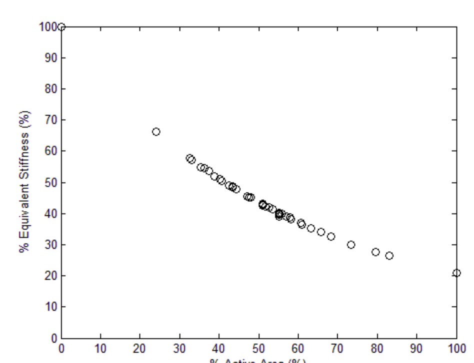




Equivalent Stiffness by FEM

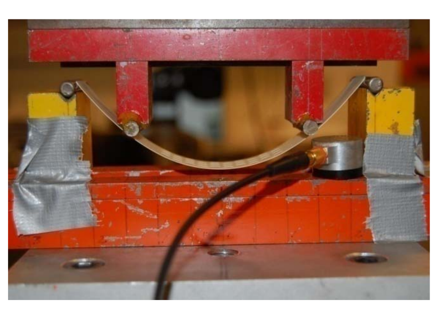
- Periodic boundary conditions applied to repeating unit cell
- Stiffness found to be the same in both in-plane directions
- Cutout shape has no effect on stiffness
- % Active Area found to be more important

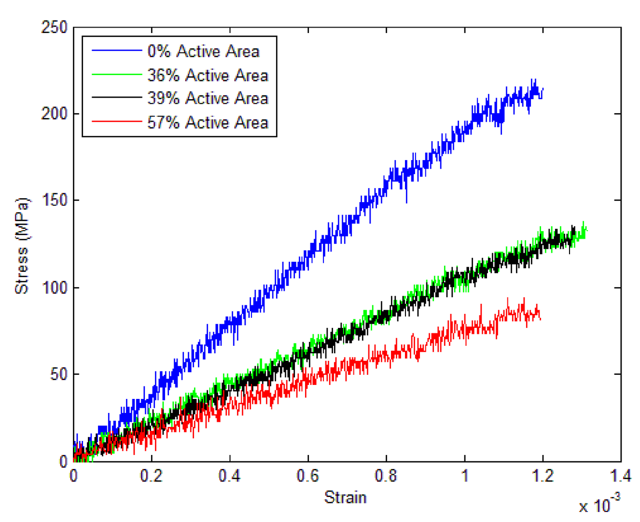




Validation by Four-Point Bend Experiments

- Specimen's gage section contains thick and thin regions corresponding to a given *%AA*
- Specimen is highly elastic/flexible





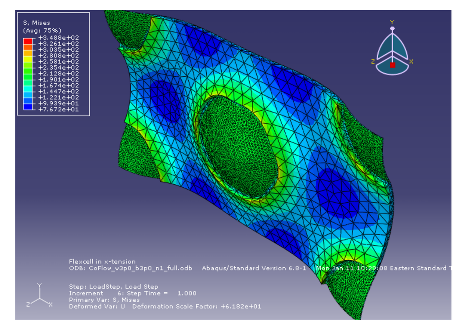
- E calculated at 0.02% strain
- Predicted and Experimental agree well

Specimen Geometry	*%AA*	*%E_{eq}*	Predicted Stiffness (GPa)	Experimental Stiffness (GPa)
Large Hexes	57	39	79.6	73.3
Small Hexes	39	52	106.4	108.6
Small Circles	36	55	111.7	112.1
No Hexes	0	100	204.6	202.2

Small-Scale Stress Simulations

Factors

- Size and shape of the active area cutouts
- Spacing allowed between cutouts
- Thickness of active and support layers

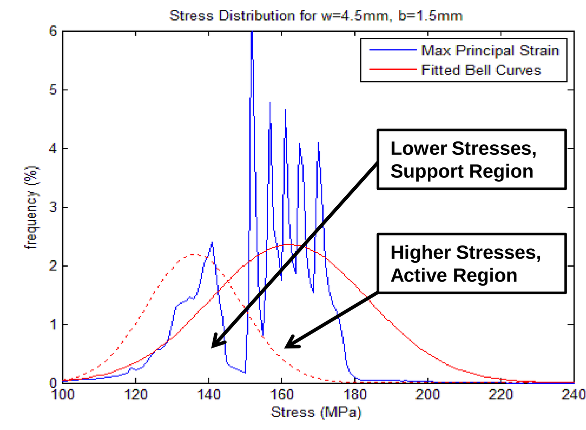


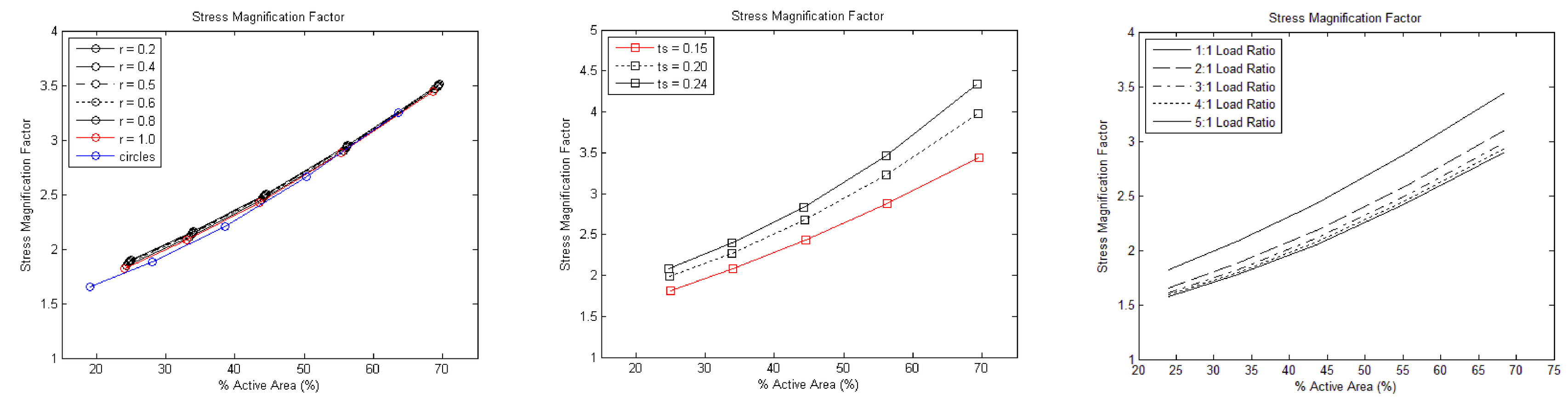
Stress contours of unit cell in tension

Model and Analysis

- Modeled using 3D solid elements
- Approximately 1.5million elements in Abaqus running on the Ohio State Super Computer
- Statistically Relevant Stress Histograms: Max. Stress vs. # of Elements

$$\sigma_{small} \approx f(E, \varepsilon_{large}, \%AA)$$
$$\approx \sigma_{large} \times [\text{Magnification Factor, M}]$$



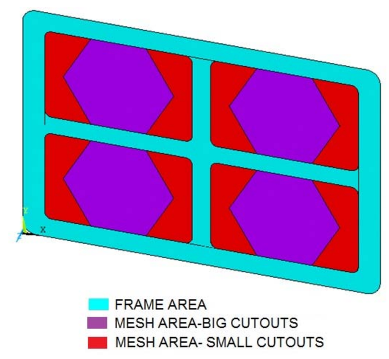


- %AA more significant than geometry
- Current range of radius of curvature has no effect
- For tension loading, results identical in both directions→2:1 same results as 1:2
- 1:1 loading gives the highest stresses of all

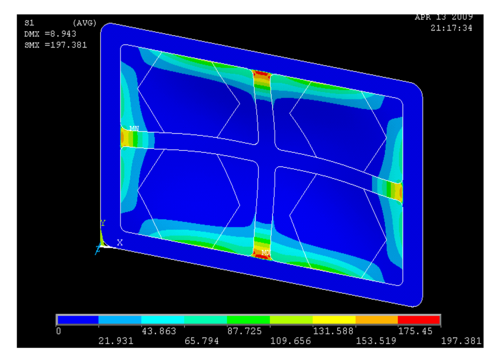
Large-Scale Simulations

Design Factors

- Distribution of cutout geometries
- Addition of support only regions- thickness, width, number, and placement
- Frame width and thickness

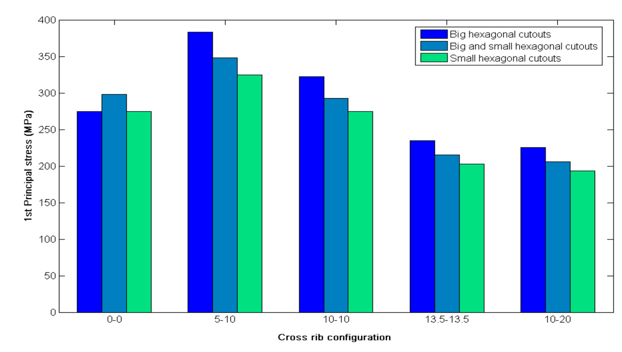


Model of FlexCell in ANSYS



1st principal stress contour plot of FlexCell under normal pressure

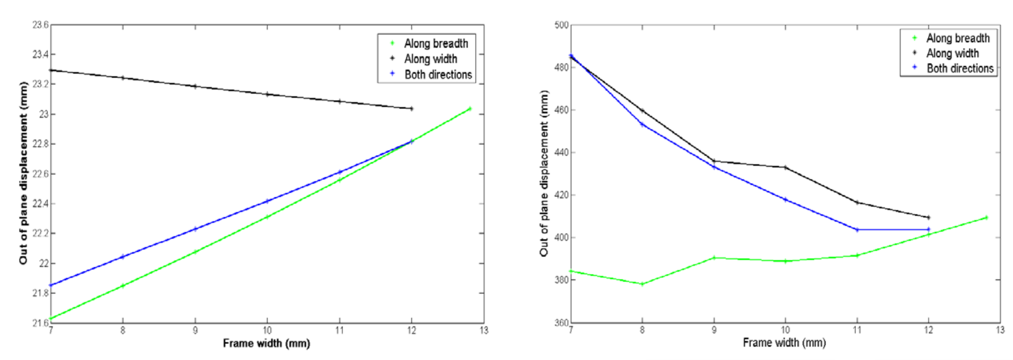
- Displacement scales linearly
- Stress reduced for models with wider vertical ribs



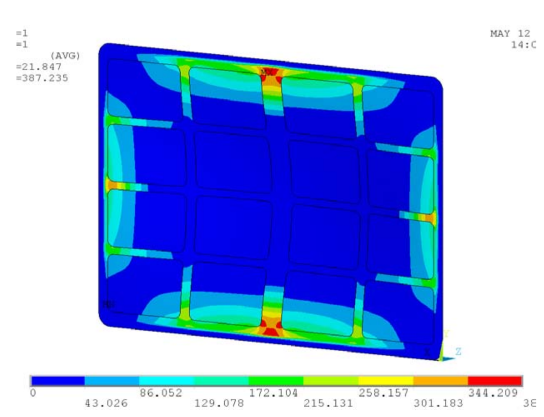
1st principal stresses for different rib sizes and cutout configurations

Scaling Up

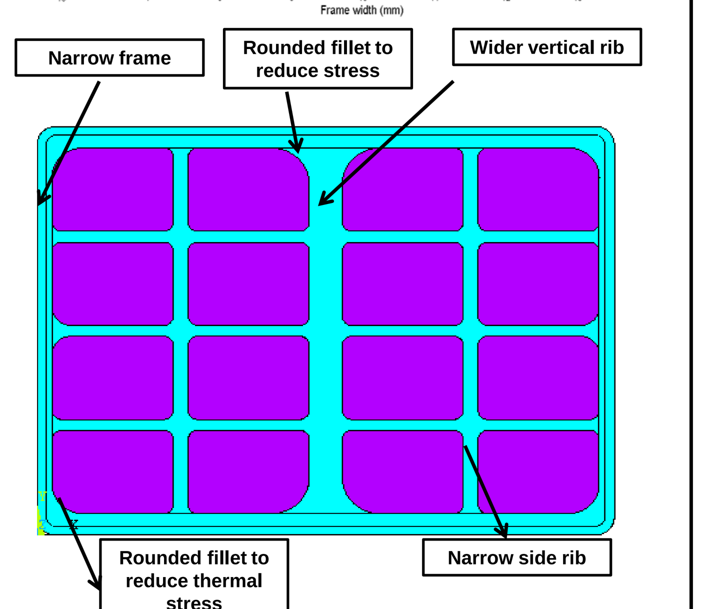
- Design variables are altered and applied to ultra large area FlexCell (31 x 23 cm)
- Need to maintain %AA and overall shape



- Structural analysis and thermal analysis to simulate operating conditions



1st principal stress contour plot of ultra large FlexCell with widened rib



- Width of shorter vertical rib more critical in reducing stresses and deflection
- Strategic arrangement of the cutout patterns is very important for robustness
- Stress concentration reduced by widening fillet radius
- Displacement scales linearly with change in cross rib thickness

Summary and Future Work

- NexTech's FlexCell™ has hexagonal support mesh to enable both mechanical robustness and performance
- Thickness is a trade-off between strength and performance
- Wide thin plates necessitate the use of two-scale modeling
- Magnification curves for loading (bending, compression) are under way
- Geometrical design refined for mechanical strength while maintaining %AA
- Next Step: Modeling of SOFC stacks to improve thermal cycling capability