Characterization of SOFC Electrolytes for Improved Mechanical Robustness

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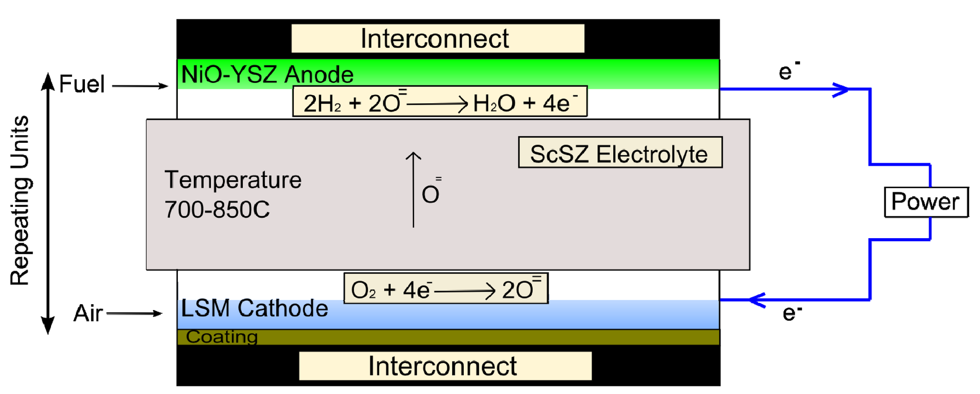
GOAL

Optimize FlexCell™ geometry to improve mechanical robustness without sacrificing electrochemical efficiency.

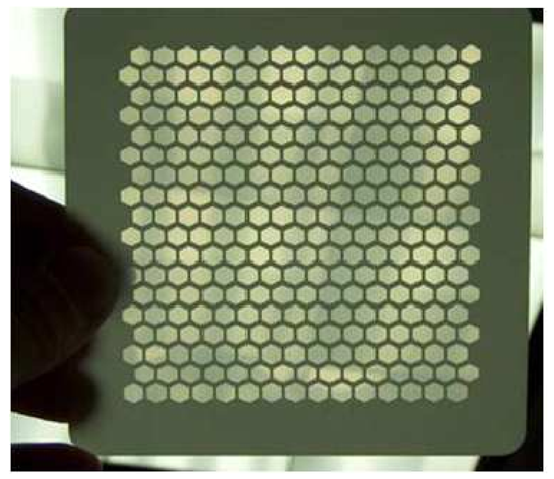
INTRODUCTION

The FlexCell™ is the latest generation electrolyte-supported planar SOFC from NexTech Materials Ltd.



SOFC Construction and Operation

FlexCell™ Innovation: A honeycomb-type structure provides a thicker support mesh with thin active area.



Honeycomb structure in a FlexCell™

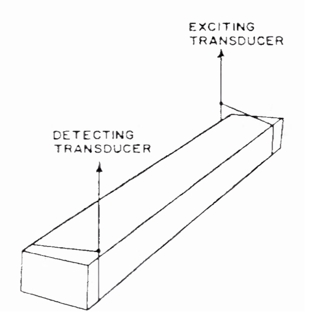
Thin regions are more electro-chemically efficient for improved performance.

Brittle electrolytes can withstand considerable bending

Thick regions support against mechanical damage during manufacturing, assembly, and operation.

Electrolyte Material

Elastic properties are obtained using ASTM 1875-08, a sonic resonance technique.



Configuration of bar specimens used in the experiments.

$$E = 0.9465\frac{mf_E^2}{b}\left(\frac{L}{t}\right)^3\left[1+6.585\left(\frac{t}{L}\right)^2\right]$$

Where
E = Young's Modulus (GPa)
m = Mass of specimen (g)
L, b, t = Geometry of specimen (mm)
f_E = Fundamental frequency in flexure (Hz)

Rectangular bar specimens are suspended in a furnace, and excited over a range of frequencies.

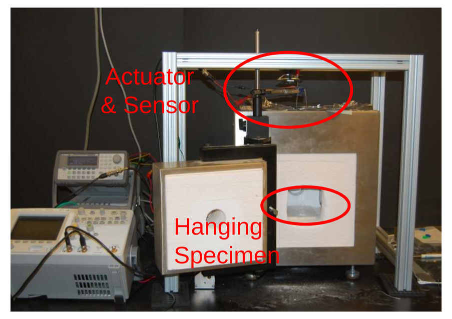
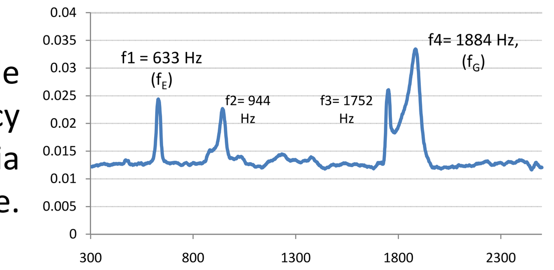
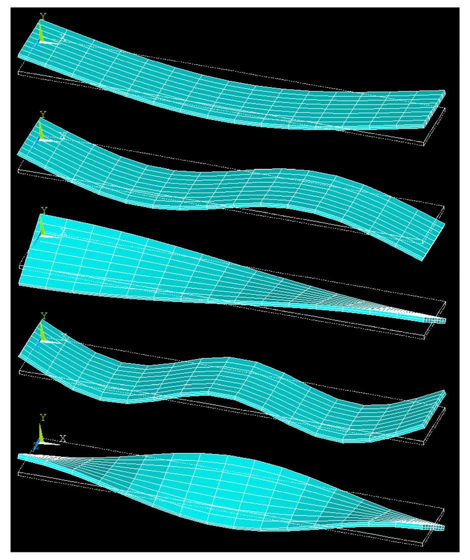


Photo of resonance apparatus.

Typical amplitude versus frequency data obtained via resonance.



Certain frequencies exhibit resonance. The resonant modes are reproduced via FEA.

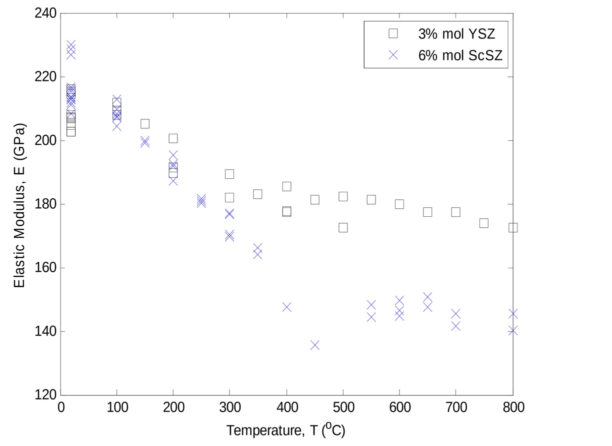


First flexural mode (F_E)

First torsional mode (F_G)

First 5 resonant modes obtained using ANSYS.

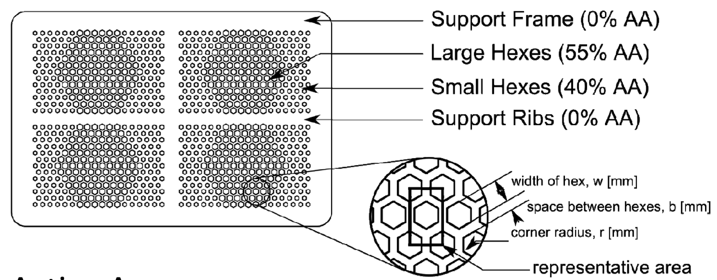
The frequencies are used to calculate Temperature-dependent elastic properties for 3-YSZ and 6-ScSZ.



The elastic properties are used as inputs for the structural and thermal models below.

Support Structure

A small-scale repeating geometry models the support structure.



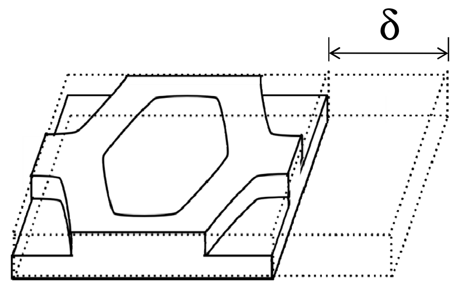
% Active Area:

$$\%AA = \frac{\text{Area of Hexes}}{\text{Total Area}} \times 100\% = \frac{2\left[\frac{1.5\,w^2}{\sqrt{3}} - 6\,r^2\left(\frac{1}{\sqrt{3}} - \frac{\pi}{6}\right)\right]}{\sqrt{3}(w+b)^2} \times 100\%$$

78 small-scale geometries were selected by varying:

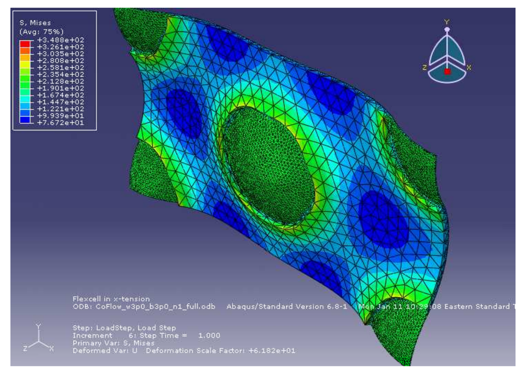
1. Width of each hex, w (mm)
2. Space between hexes, b (mm)
3. Radius of corner fillets, r (mm)
4. Thickness of membrane, tm (mm)
5. Thickness of support mesh, ts (mm)

Each small-scale geometry is modeled under uniaxial tension using FEA.

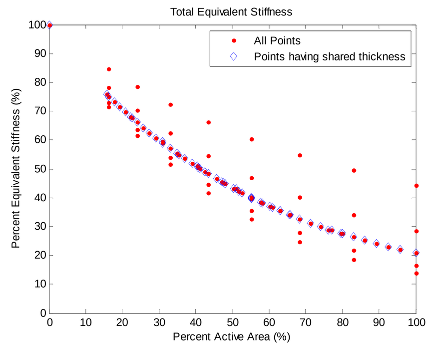


Tensile displacement applied to the model.

Principal stress distribution resulting from edge displacement.

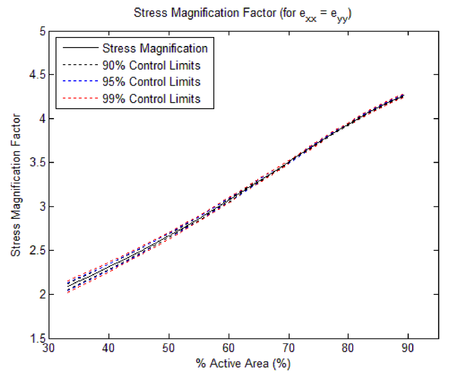


"Effective" properties are computed relative to those of a uniformly thick solid:

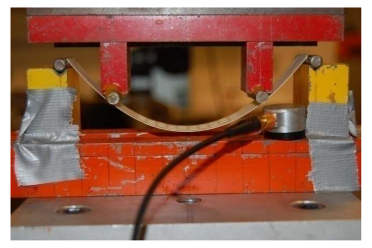


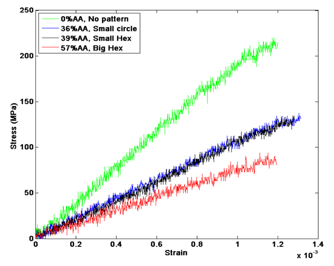
Reduction in stiffness with increased active area.

Magnification of membrane stress with increased active area.



"Effective" properties are validated with 4-point bending of representative samples.



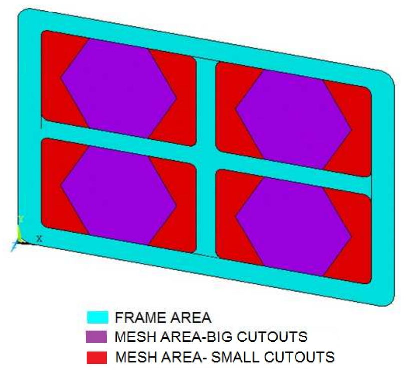


Specimen Geometry	%AA	$\%E_{eq}$	Predicted Modulus (GPa)	Experimental Modulus (GPa)
Large Hexes	57	39	79.6	73.3
Small Hexes	39	52	106.4	108.6
Small Circles	36	55	111.7	112.1
No Hexes	0	100	204.6	202.2

The "effective" properties can be used for larger scale modeling.

Whole Electrolyte

Large-scale geometries are modeled using "effective" mechanical properties in active regions.

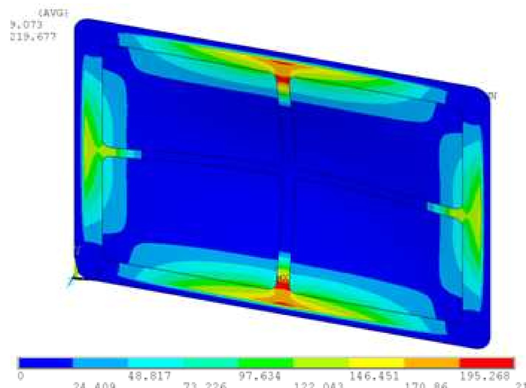


Electrolyte color-coded to show "effective" material types.

Each large-scale geometry was selected by varying:

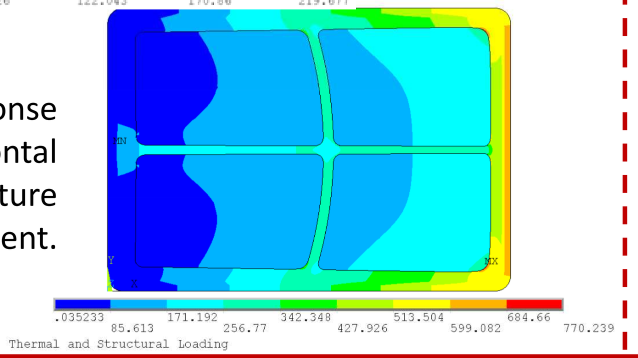
1. Stiffness applied to active regions, Eeq (GPa)
2. Support rib and frame dimensions, (mm)
3. Radius of corner fillets, (mm)

Large-scale geometry is modeled with shell elements under structural and thermal loading using FEA.

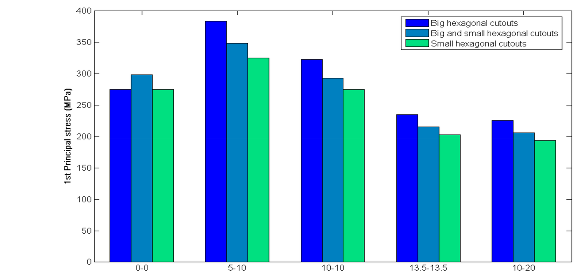


Stress response to out-of-plane pressure loading.

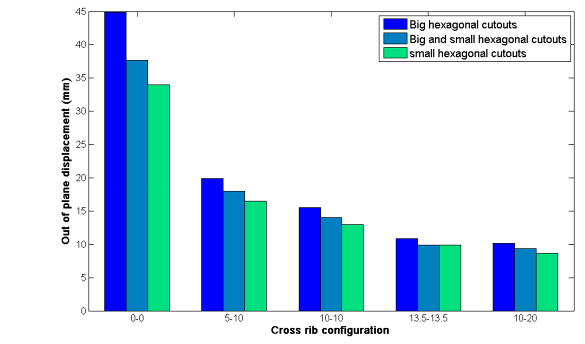
Stress response to horizontal temperature gradient.



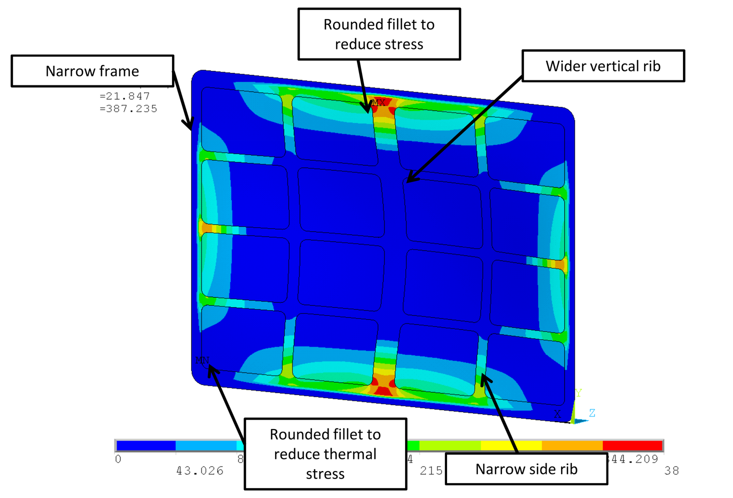
The relatively stiffer ribs appear to carry more stress, but unlike the active area the stresses are unmagnified.



The ribs also reduce out-of-plane displacements.



Based on initial findings, recommendations are made for the development of even larger cells.

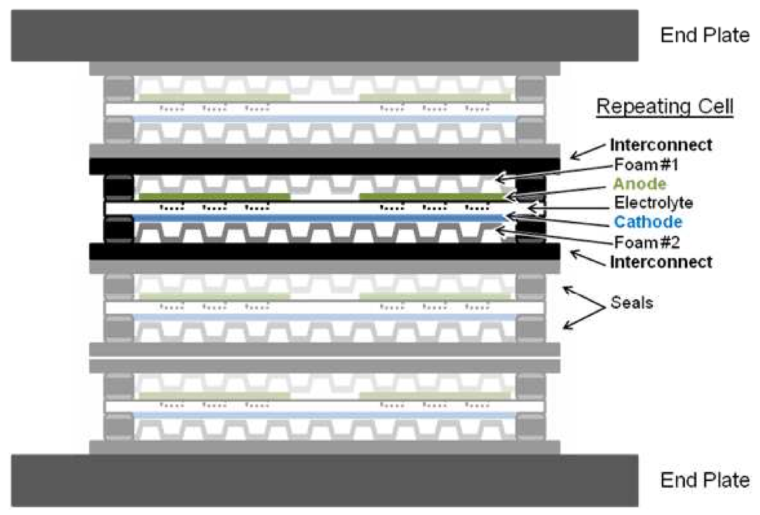


1st principal stress contour plot of ultra large FlexCell with widened rib

Large cells which are mechanically robust have a higher power density..

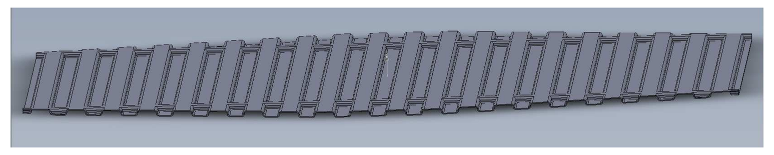
Load Transfer

An individual cell model is used to evaluate the electrolyte within the context of a stack.

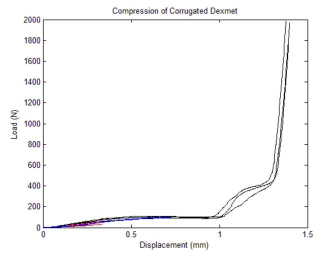


Schematic of a planar SOFC stack assembly.

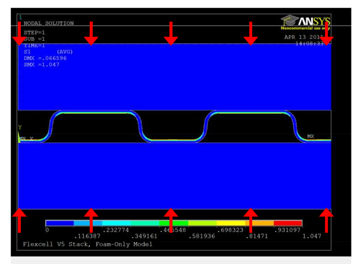
Current-collecting, corrugated foams in the cell transfer loads onto the electrolyte.



The load-displacement behavior of foam compressed in a load frame is reproduced in a contact model.

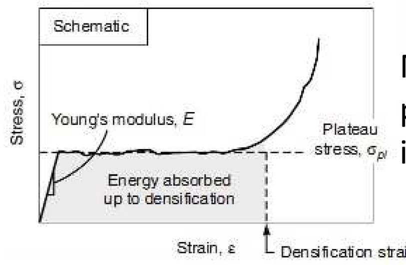


Load frame data.

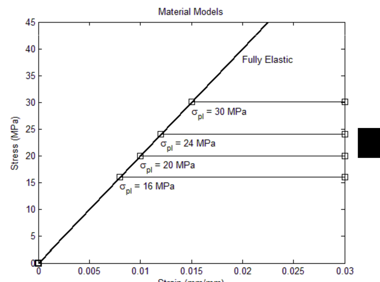


Contact simulation.

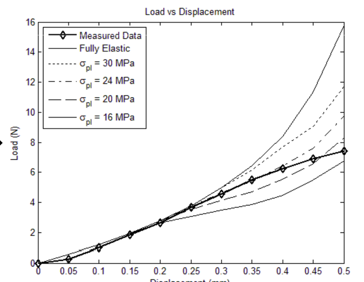
Foam properties in the model are changed over several iterations until the load-displacement behavior matches the experimental data.



Mechanical properties of an ideal foam.

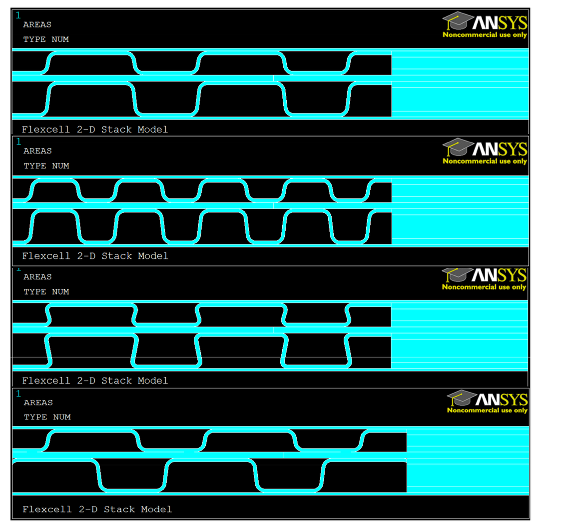


Material property inputs.



Load-displacement results.

Cell models consider variations in foam geometry to characterize stress distributions in electrolytes.



Changes in foam geometry may reduce loads (and therefore stresses) imposed on electrolyte.