# Mechanical Reliability Predictions for Compliant Engineering Seal Designs

W. Xu, E.V. Stephens, and B.J. Koeppel

Pacific Northwest NATIONAL LABORATORY

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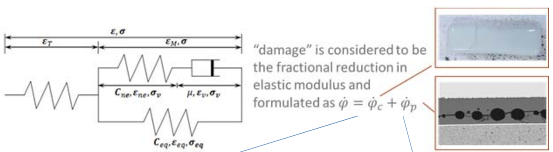
## OVERVIEW

Further development and optimization of compliant engineering seal designs within SOFC stacks requires a fundamental and thorough understanding of their essential nonlinear thermo-mechanical behaviors. In the present study, a continuum 3D thermo-visco-elastic-damage-healing model has been developed to capture the unique stress-strain characteristics of compliant seal glass. The effects of their designs and operation on the mechanical performance of single- and multi-cell SOFC stacks were then also evaluated.

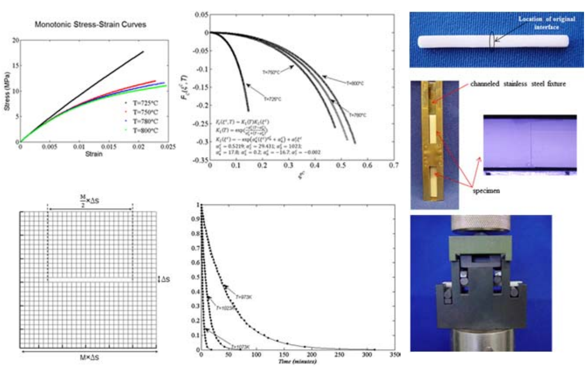
## TECHNICAL APPROACH

Different physically-driven evolution kinetics have been unified to describe the distinct major mechanical degradation phenomena in terms of the evolution of structural damages, i.e. the CTE mismatch induced mechanical cracks and the internal pores, so that the strong coupling and interactions between the high-temperature operation conditions and the seal response can be explicitly resolved. The proposed constitutive model was then implemented into the finite element (FE) analyses for SOFC stack simulation.



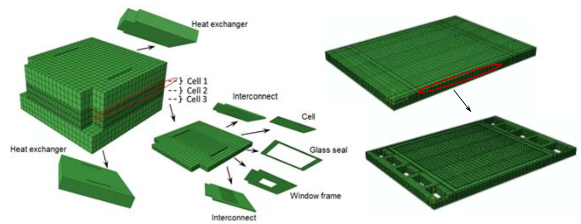

- Pressure driven crack nucleation
- Elastic energy driven crack growth
- Thermal diffusional crack healing
- Sub-microscopic imperfection induced homogeneous pore nucleus formation
- Inelastic flow induced internal pore growth

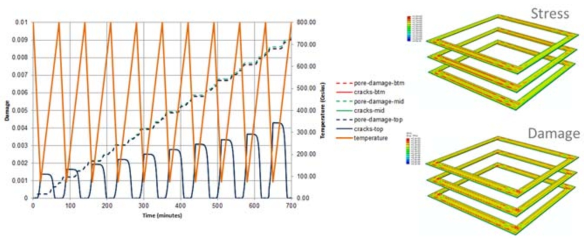
The physically-driven damage and healing kinetics were determined through experimental measurements and lower-length scale simulations.




## STACK FINITE ELEMENT ANALYSIS

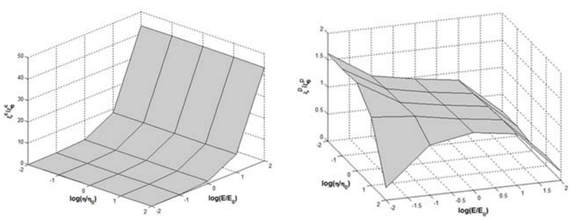
Two types of SOFCs were modelled. One corresponded to PNNL's SECA Core Technology Program stack test fixture, while the other corresponded to a larger planar design that more closely resembled full-sized SECA cells and stacks. In both cases, glass seals joined the electrolyte layer to the metallic cell frame. Multi-cell stack models were generated by sequentially repeating the single-cell units.



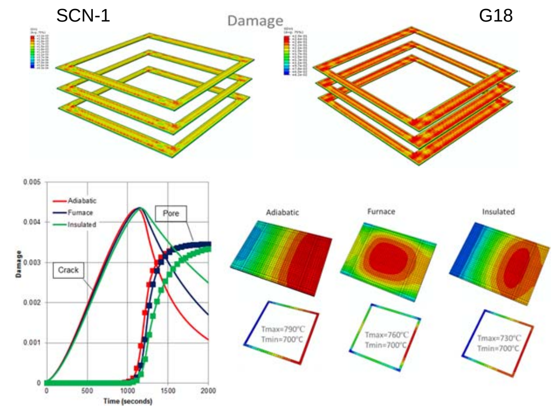




## EFFECTS OF MATERIAL PROPERTIES AND ELECTROCHEMICAL OPERATING CONDITIONS

The mechanical response of SCN-1 glass in terms of characteristic material properties, i.e. elastic modulus and viscosity was obtained. Note: since viscosity typically has opposing effects on micro-cracking and micro-voiding, its net influence for other compliant glass materials can be different.



resistance to cracking    resistance to voids




## CONCLUSIONS

- CTE mismatch induced cracks can be completely repaired at high temperatures by the prevailing inter-diffusion while pore coarsening induced material degradation tends to accumulate over the time/operational cycles. Addition of reinforcement phases to prevent the viscous pore growth has been experimentally observed and can be better understood through high-fidelity modeling.
- Internal damages can be also reduced through temperature control and adjustment of electrochemical operating conditions.
- Compared to the devitrifying glass G18, the SCN-1 compliant glass is found to have clear advantages in terms of the ability to minimize and mitigate damage by effectively relaxing the stress concentrations.

## PUBLICATIONS

Xu W, X Sun, BJ Koppel, H Zbib, 2014. A continuum thermo-inelastic model for damage and healing in self-healing glass materials. *International Journal of Plasticity* doi: 10.1016/j.ijplas.2014.06.011

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For more information on the science you see here, please contact:

**Wei (Wesley) Xu**
Pacific Northwest National Laboratory
P.O. Box 999, MS-IN: K7-90
Richland, WA 99354
(509) 375-7214
Wei.Xu@pnnl.gov

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