Durability and Reliability of SOFCs

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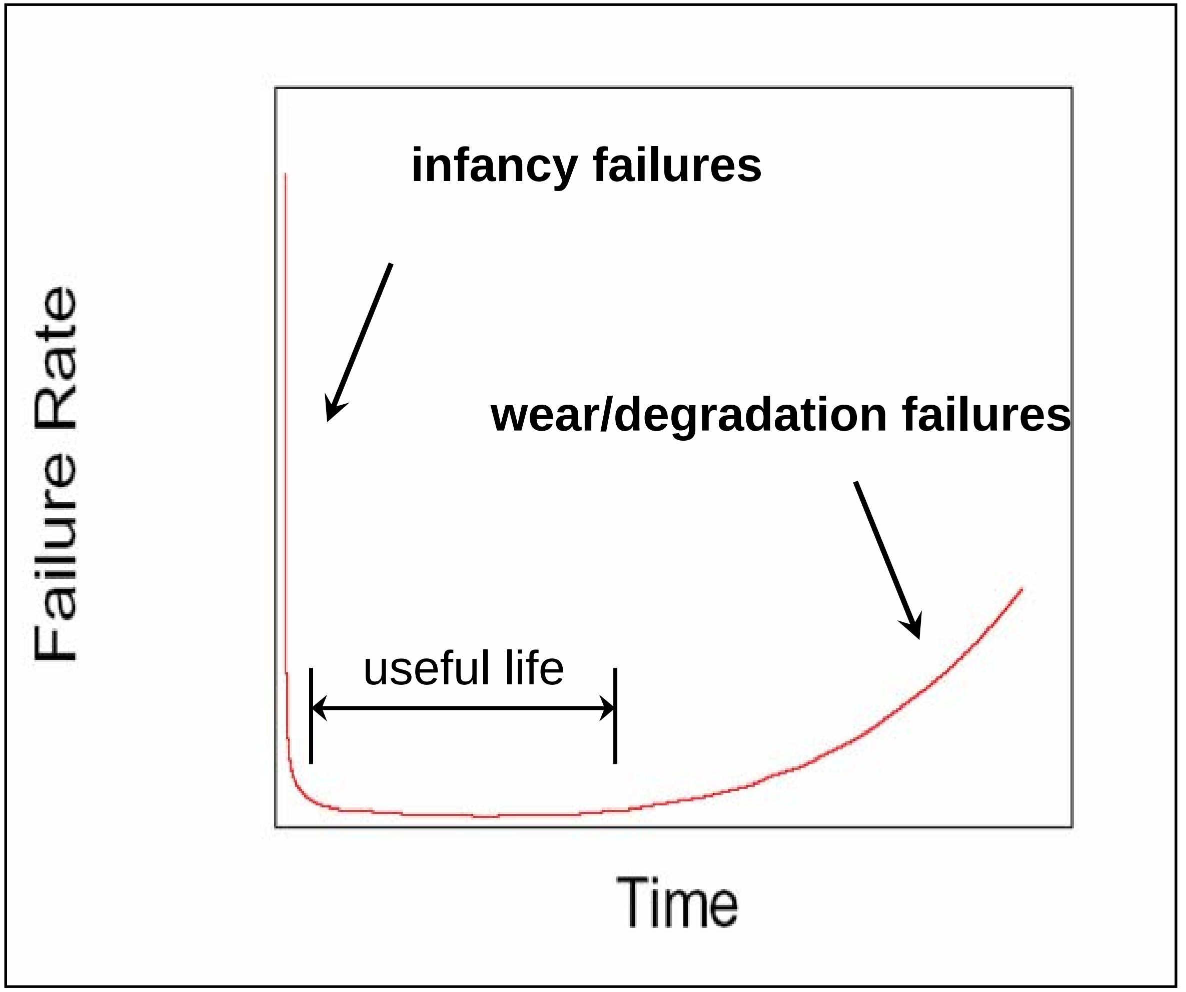
Outline

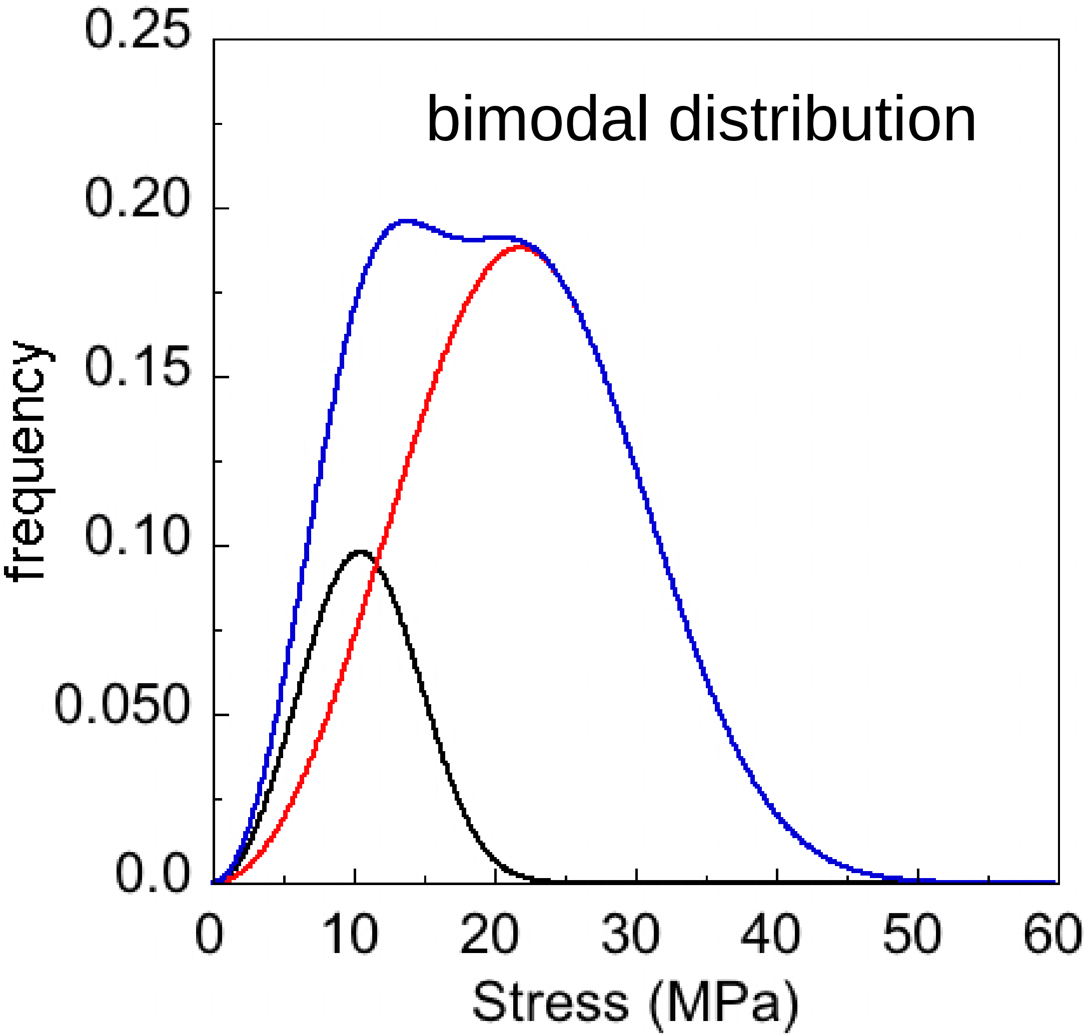
- Durability and Probabilistic Analysis of SOFCs
- Degradation and Wear
  - Creep Deformation
  - Thermal Cycling
  - Slow-crack growth
- Future work

Failure of systems

The failure rate of complex systems can be described by the bathtub curve



Failure of systems



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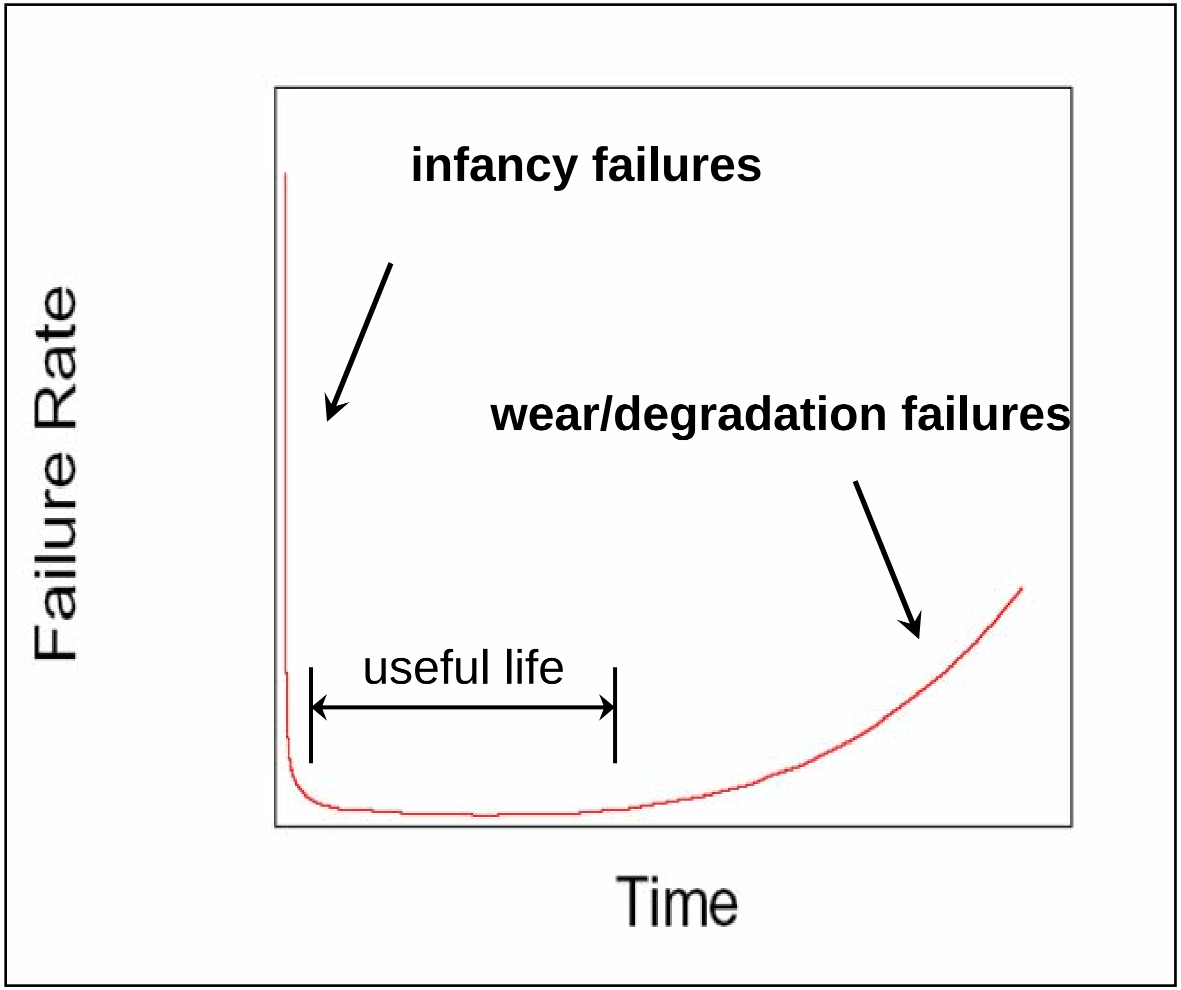
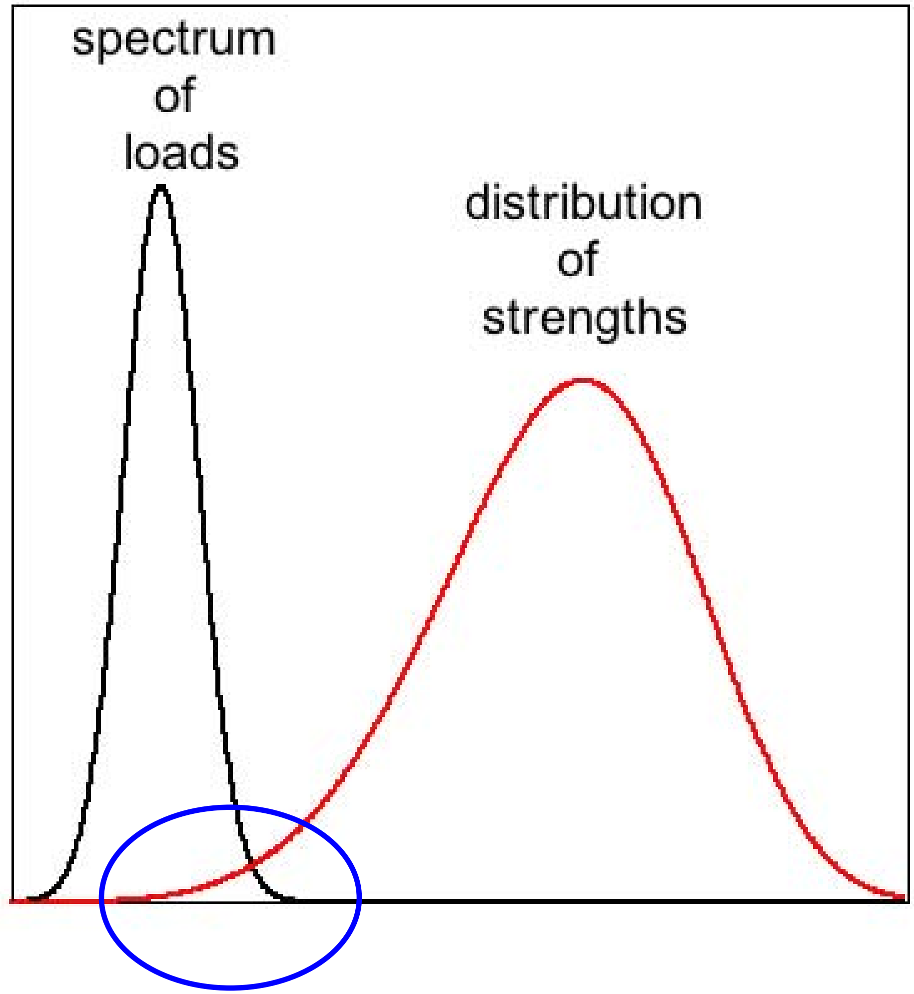


Failure of systems

- Failure is determined by the intersection of the distributions of loads and strengths.
- Failure can be avoided by designing components so that these distributions don't intersect
- The weakest elements of the population determine the reliability of the system.



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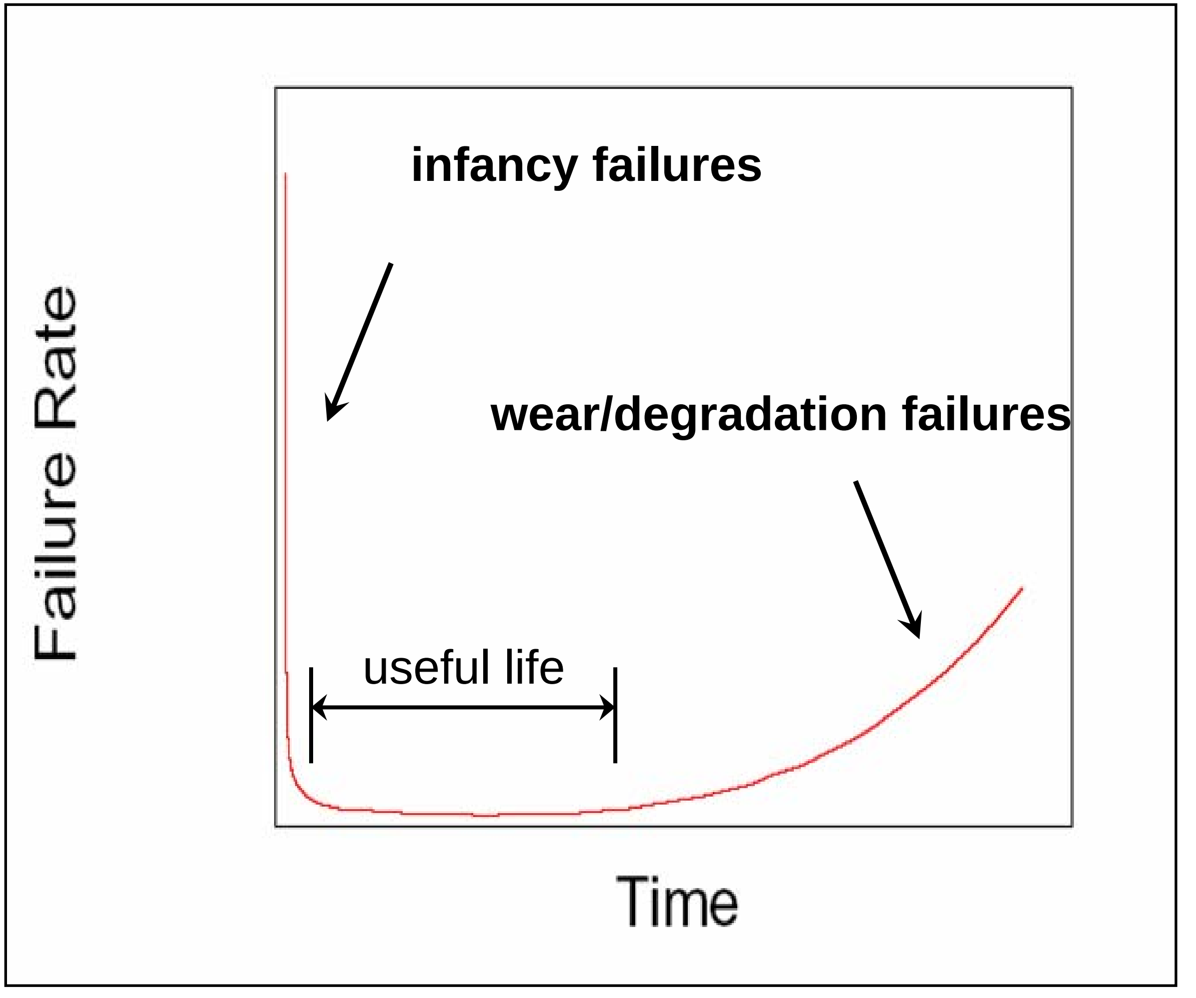

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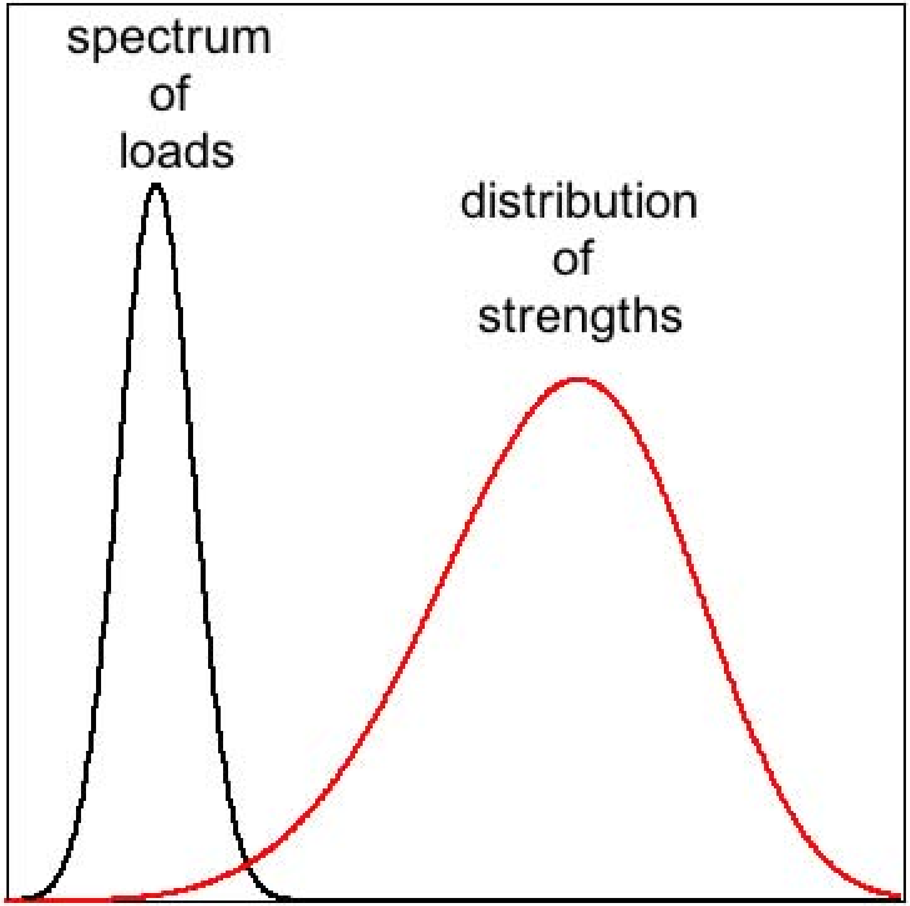

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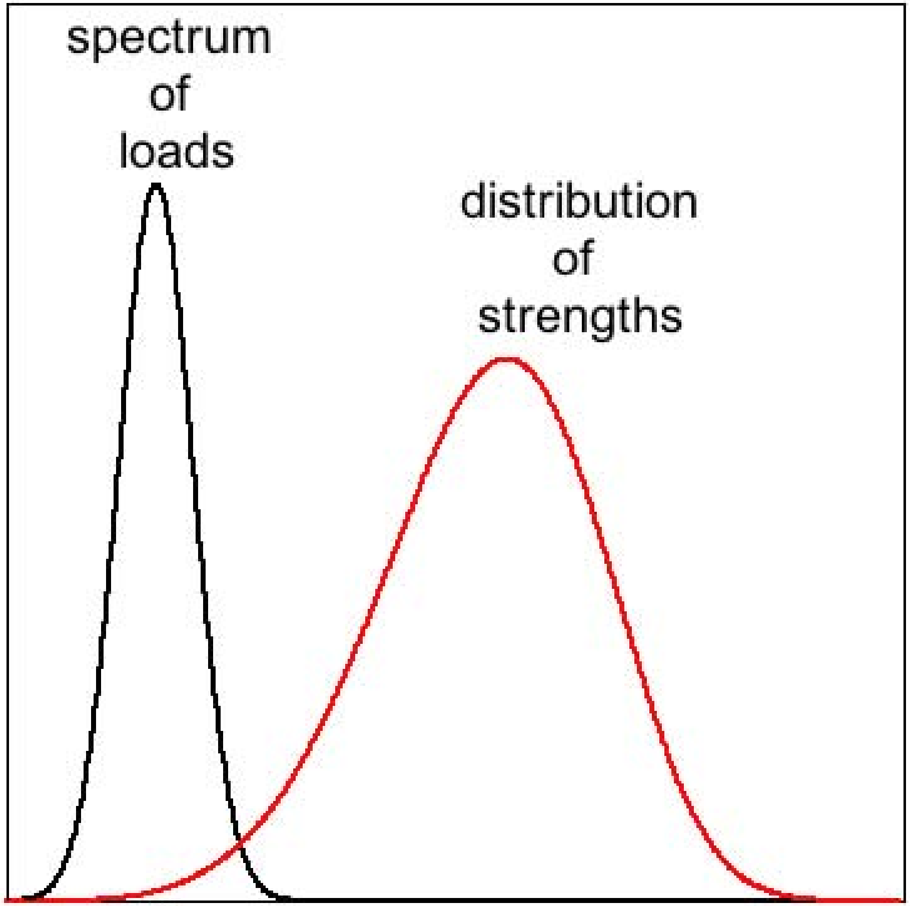

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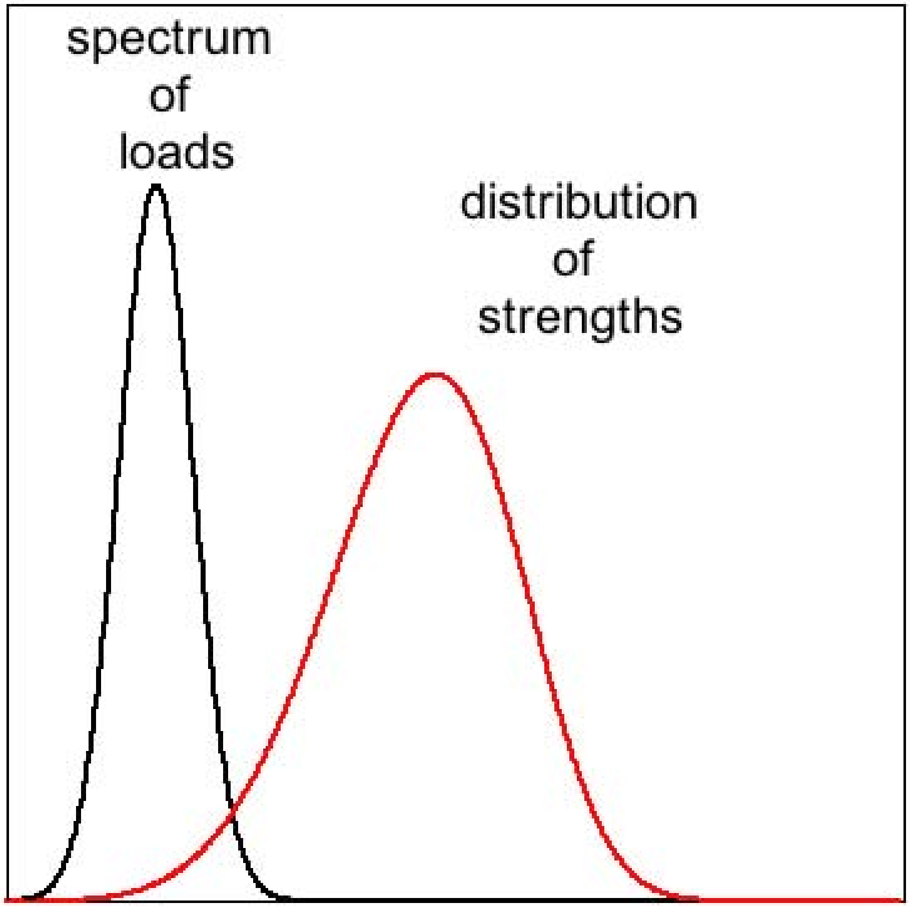

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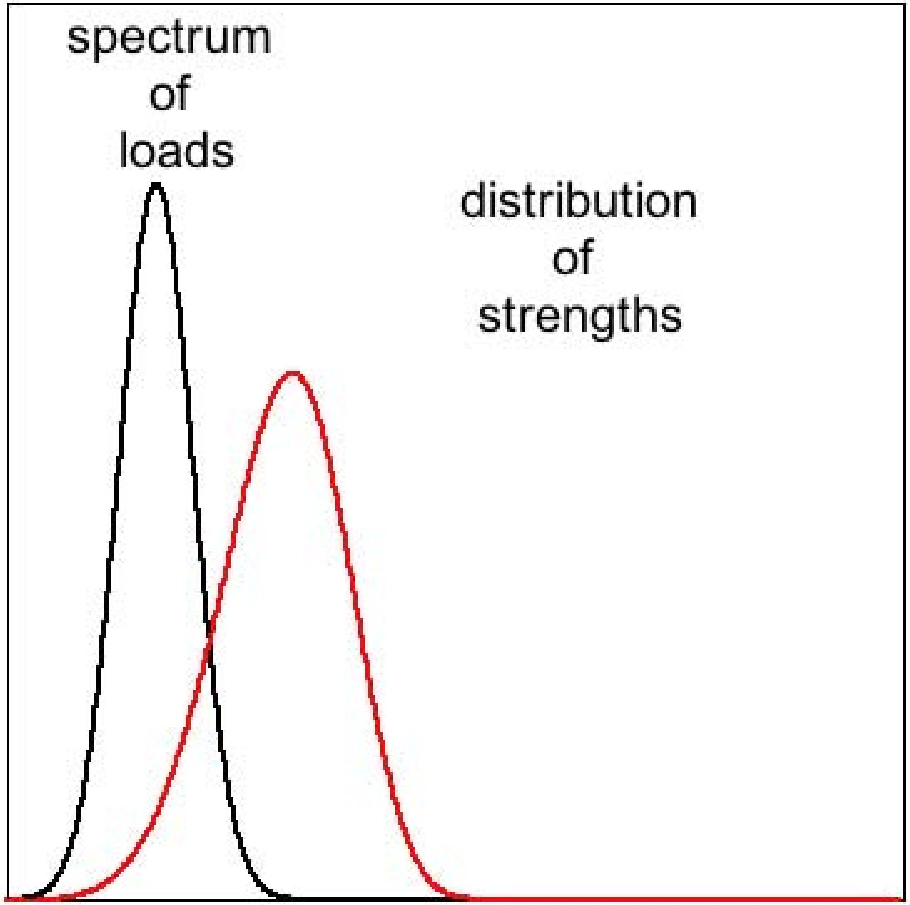

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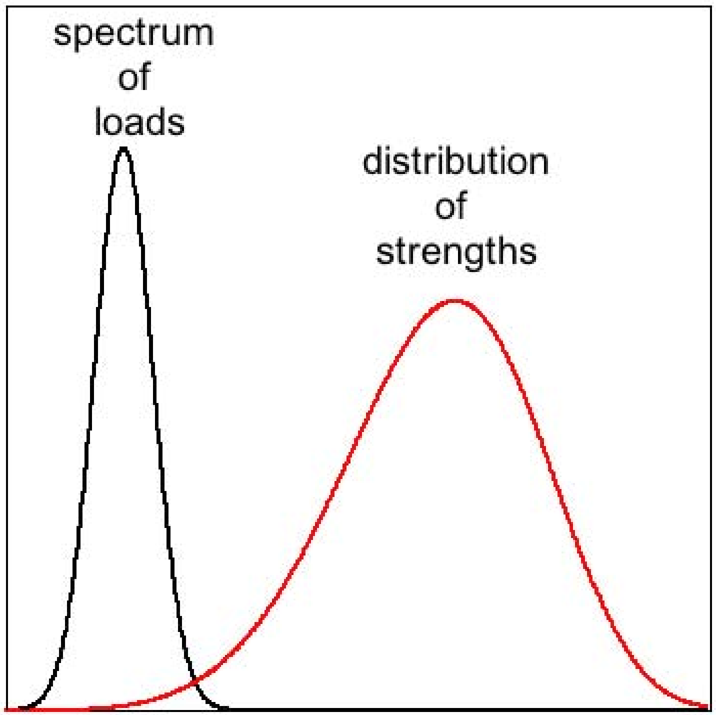
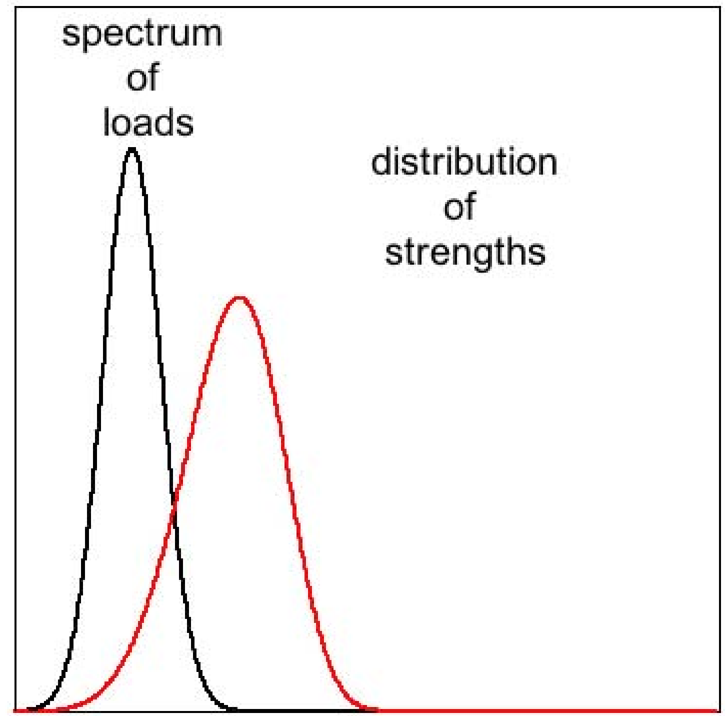


before



after

Failure of systems

Mechanisms that contribute to wear and degradation

- Creep deformation
- Thermal cycling and thermal aging
- Slow-crack growth

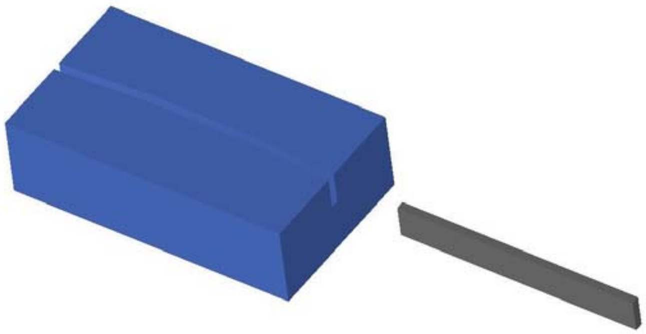
Creep Deformation

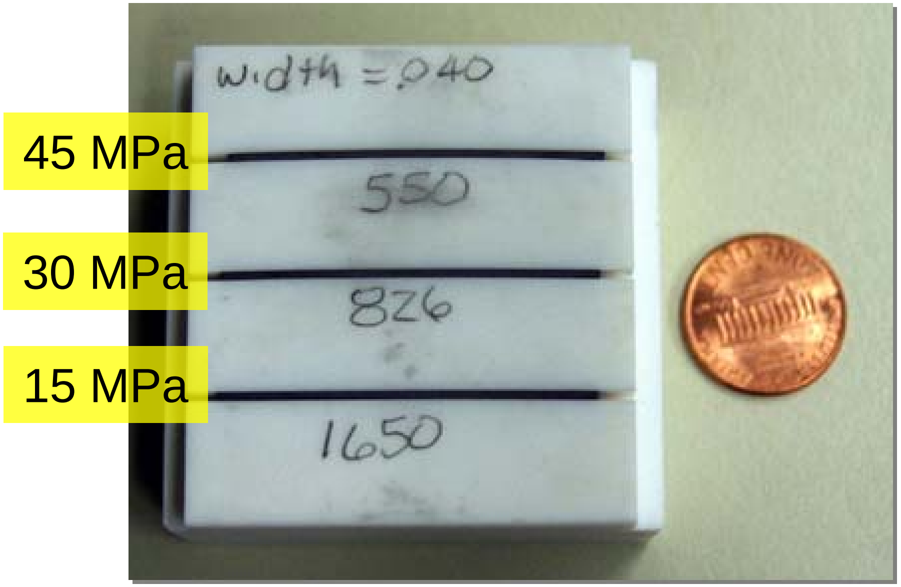
Creep Deformation

- Is creep deformation really an issue for SOFCs?
- Stress relaxation testing provides a rapid means to answer that question.
- Beam-shaped test specimens are subjected to constant bending strain at high temperature

- The curvature of the beam is monitored before and after the test

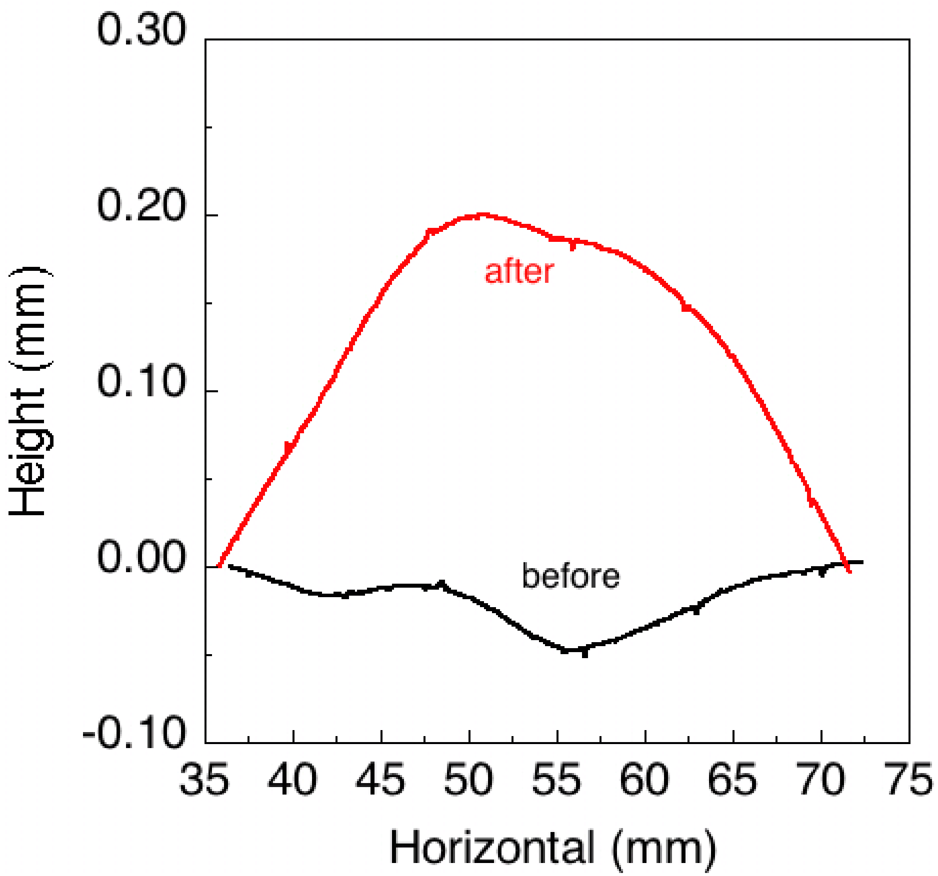
Creep Deformation





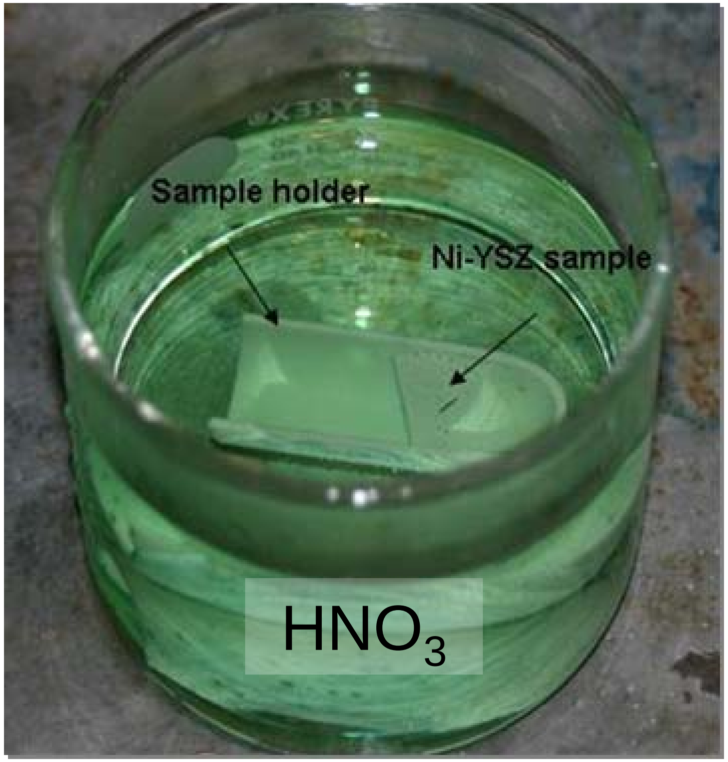
- Ni-YSZ
- 40% final porosity
- 43% Ni (vol. solid phase)
- 1.5" x 0.15" x 0.04"
- curvature determined by laser profilometry
- Macor® fixture with channels of different radii of curvature.
- 50-hr stress relaxation test at 800°C in H_2 (4%)-Ar (96%)

Creep Deformation



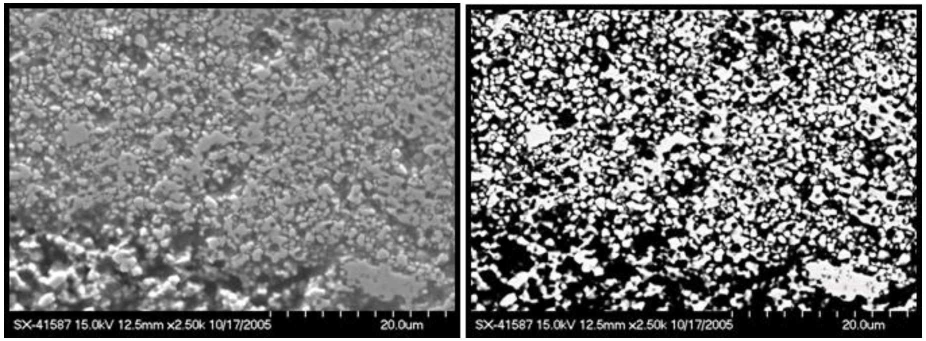
- After stress-relaxation testing test specimens retained the curvature of the fixture channels.
- Therefore, this material is prone to creep deformation.
- What is the mechanism?

Nickel dissolution



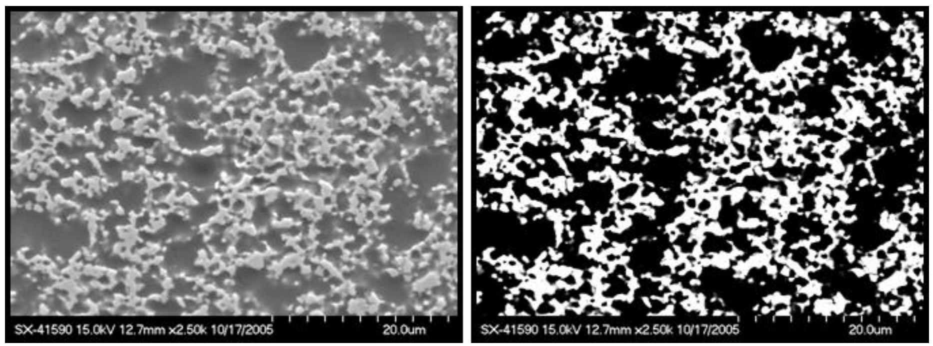
- 14 hrs in 75% HNO_3 solution
- weight after reduction: 2.279 g
- weight after Ni removal: 1.0823 g
- removed Ni (from weight loss): 99.4%

Nickel dissolution

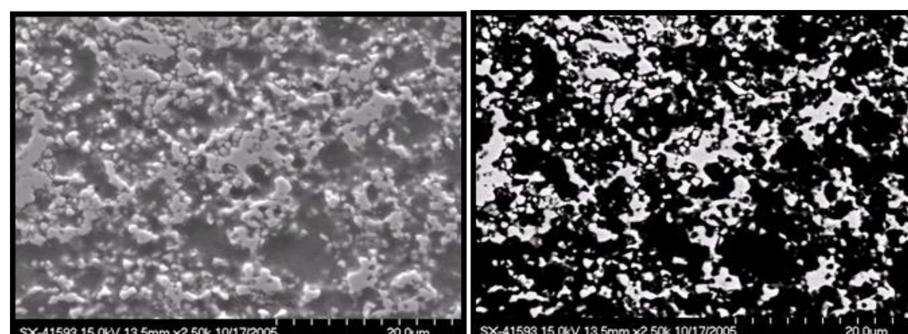


27/**% porosity

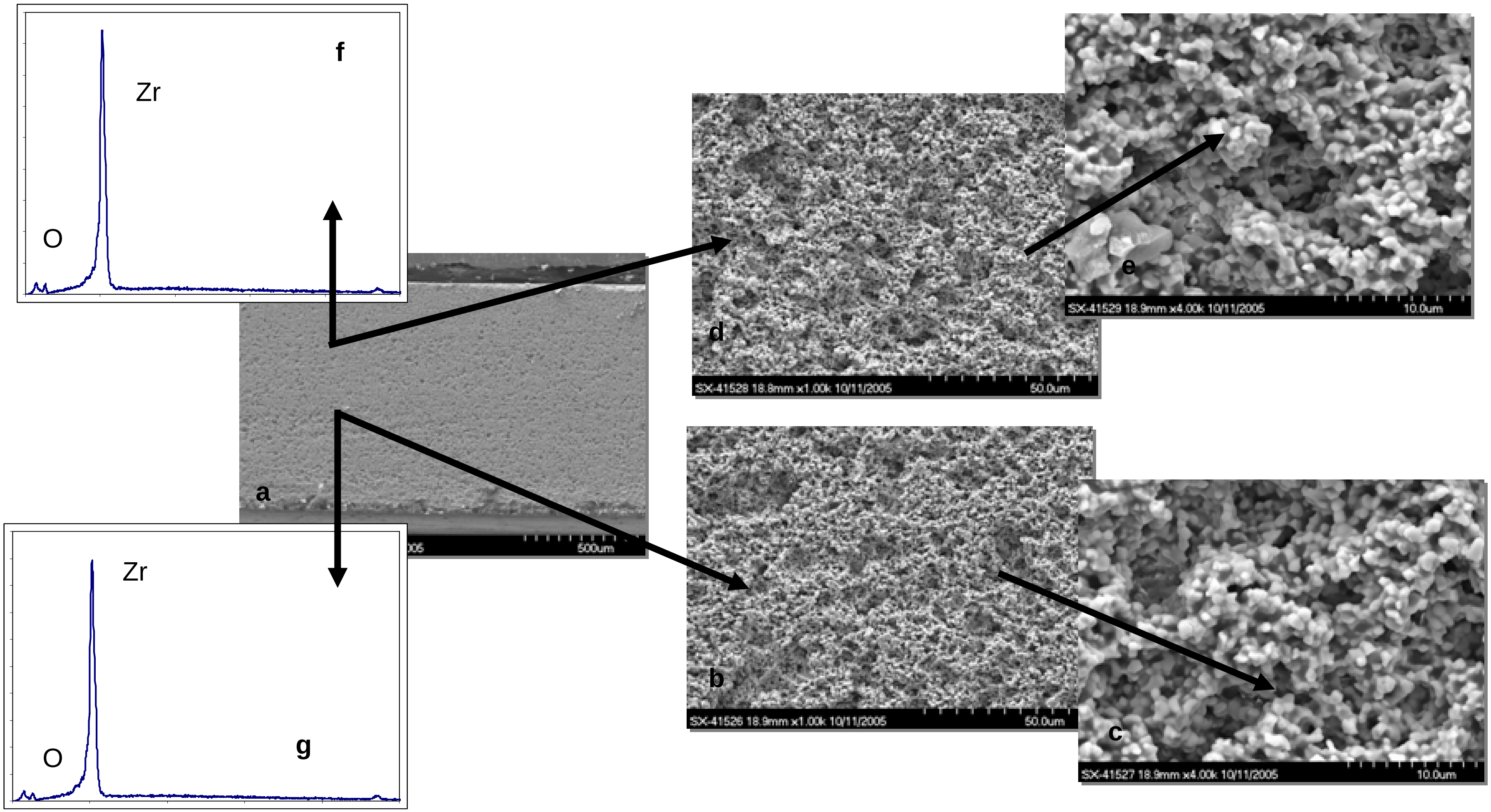
34/62% porosity



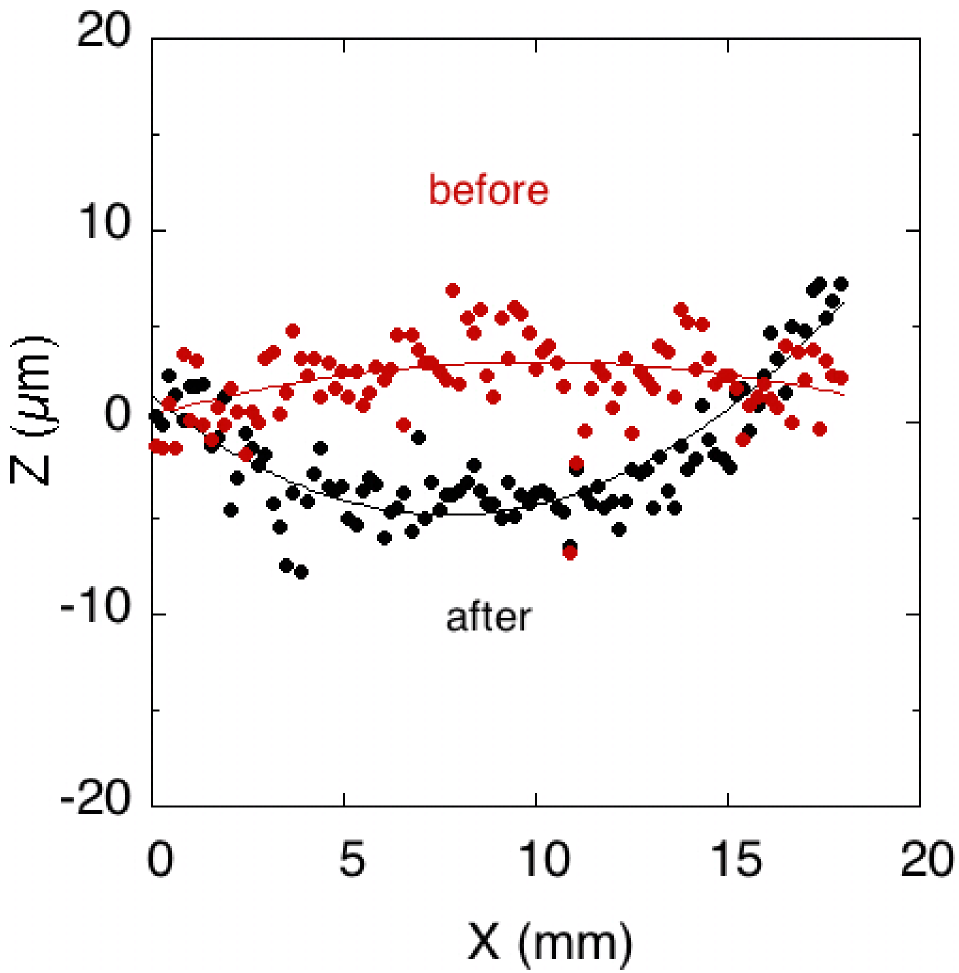
40/66% porosity



Nickel dissolution



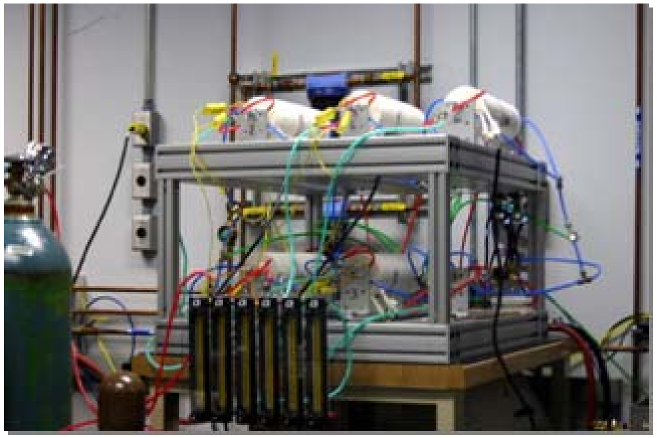
Creep Deformation

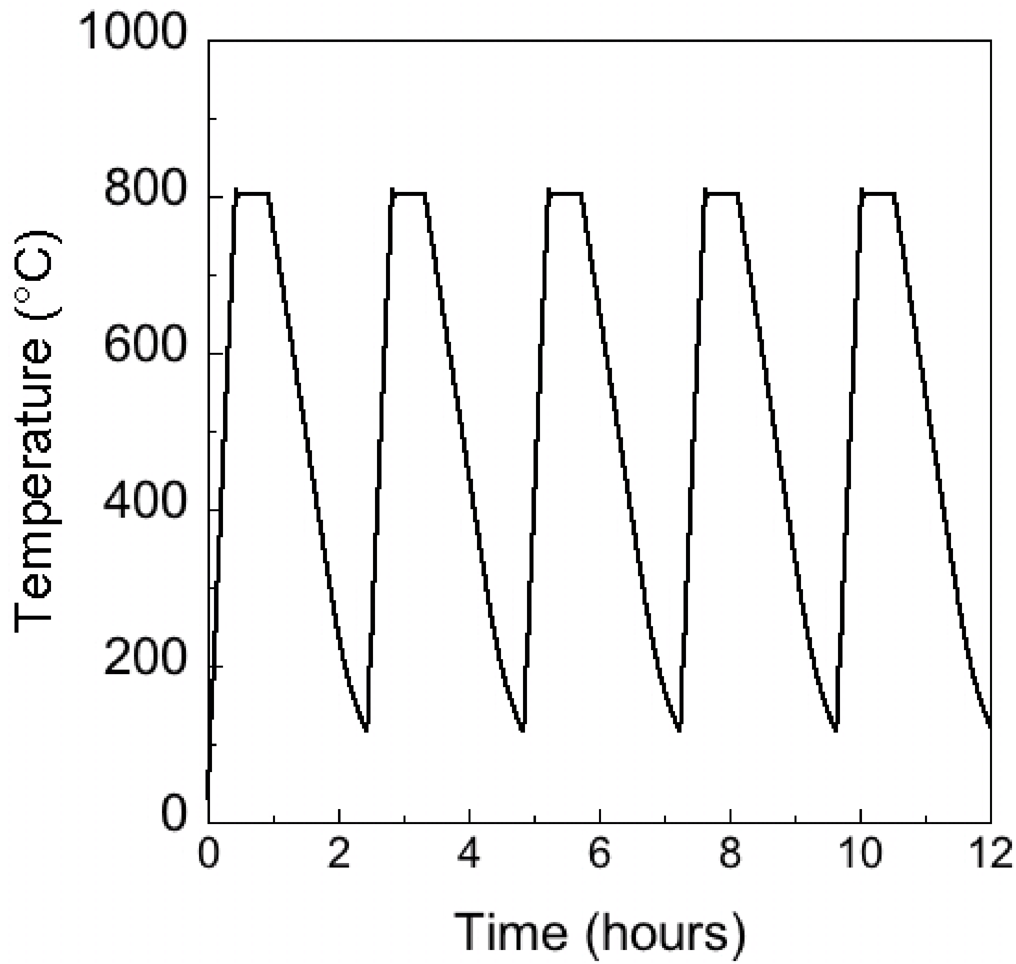


- Stress-relaxation tests of porous YSZ scaffold
- 50-hr stress relaxation test at 800°C in H_2 (4%)-Ar (96%)
- Material experiences minimal stress relaxation
- Nickel is mostly responsible for creep deformation experienced by Ni-YSZ at 800°C.

Thermal cycling and thermal aging

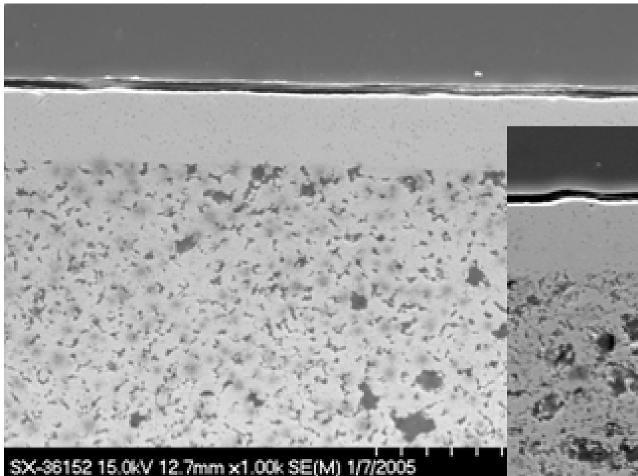
Thermal cycling and thermal aging



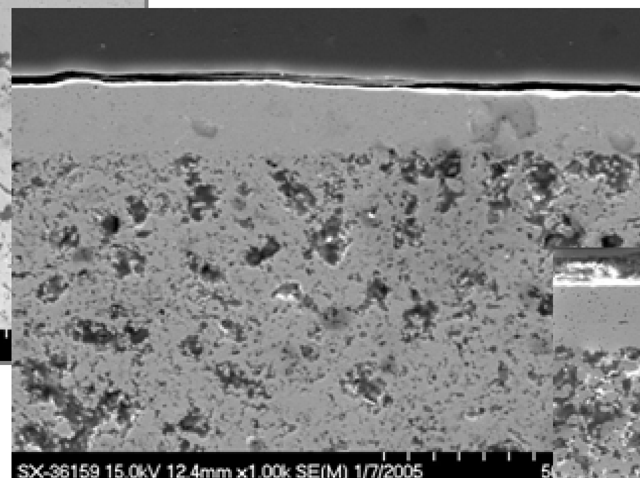


- H_2 (4%)-Ar (96%)
- tubular furnaces

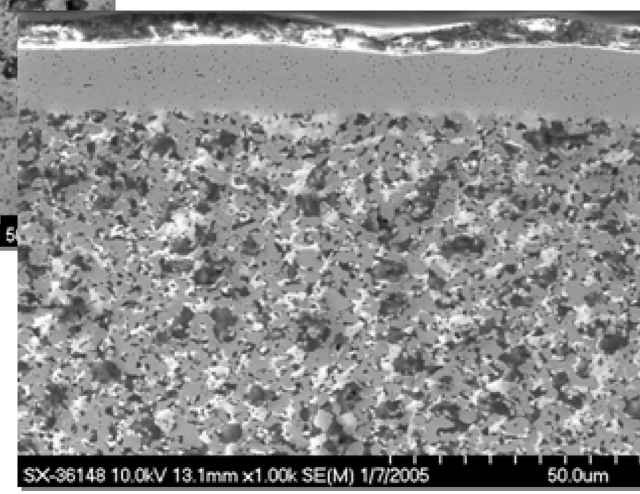
Thermal cycling and thermal aging



27-bilayer



34-bilayer

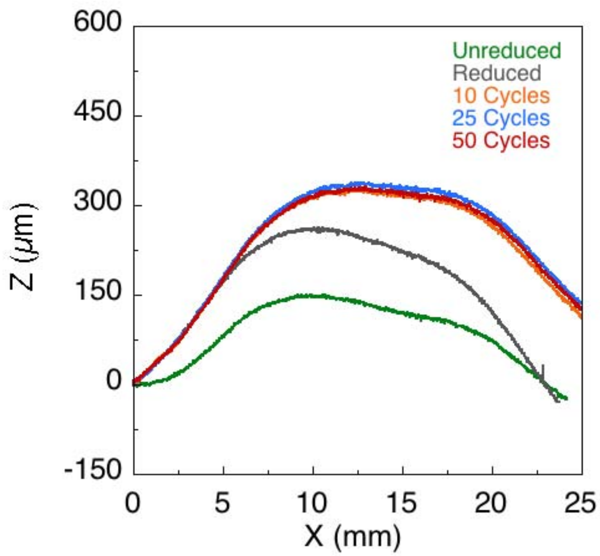


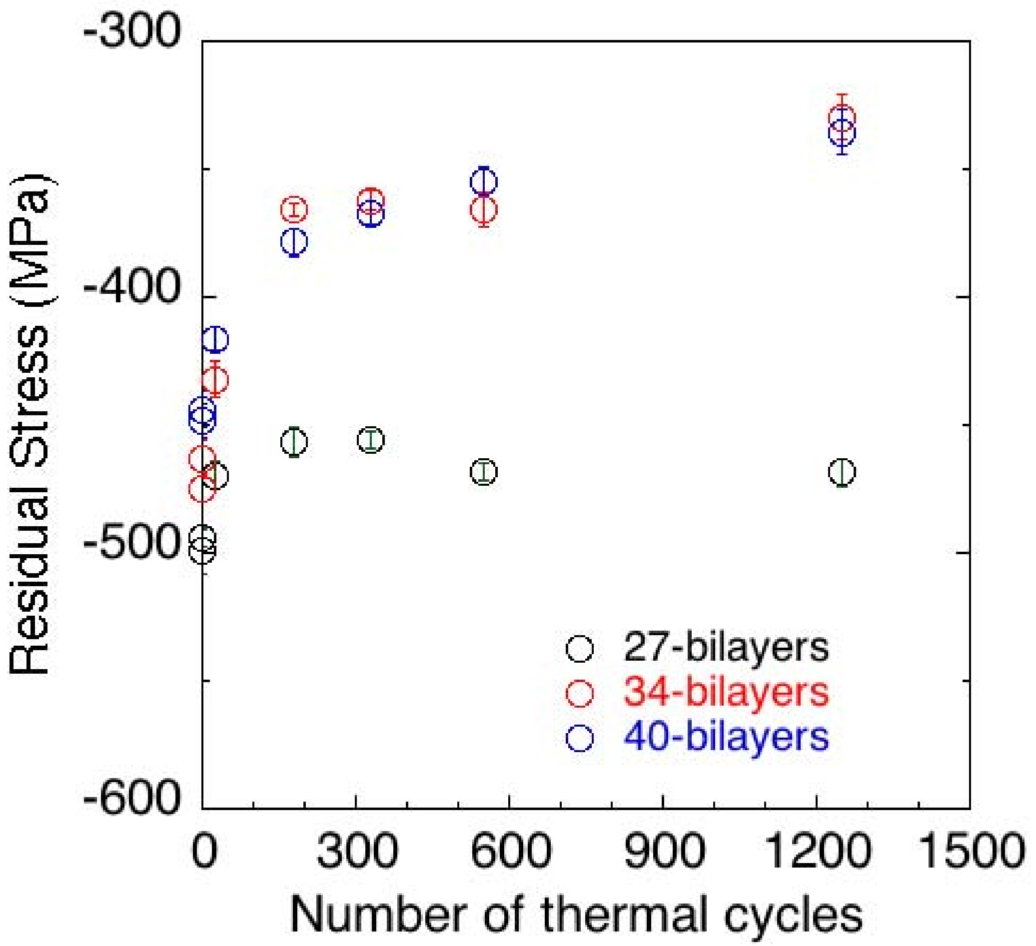
40-bilayer

- Ni-YSZ substrate
- 10-µm thick YSZ layer

Thermal cycling and thermal aging

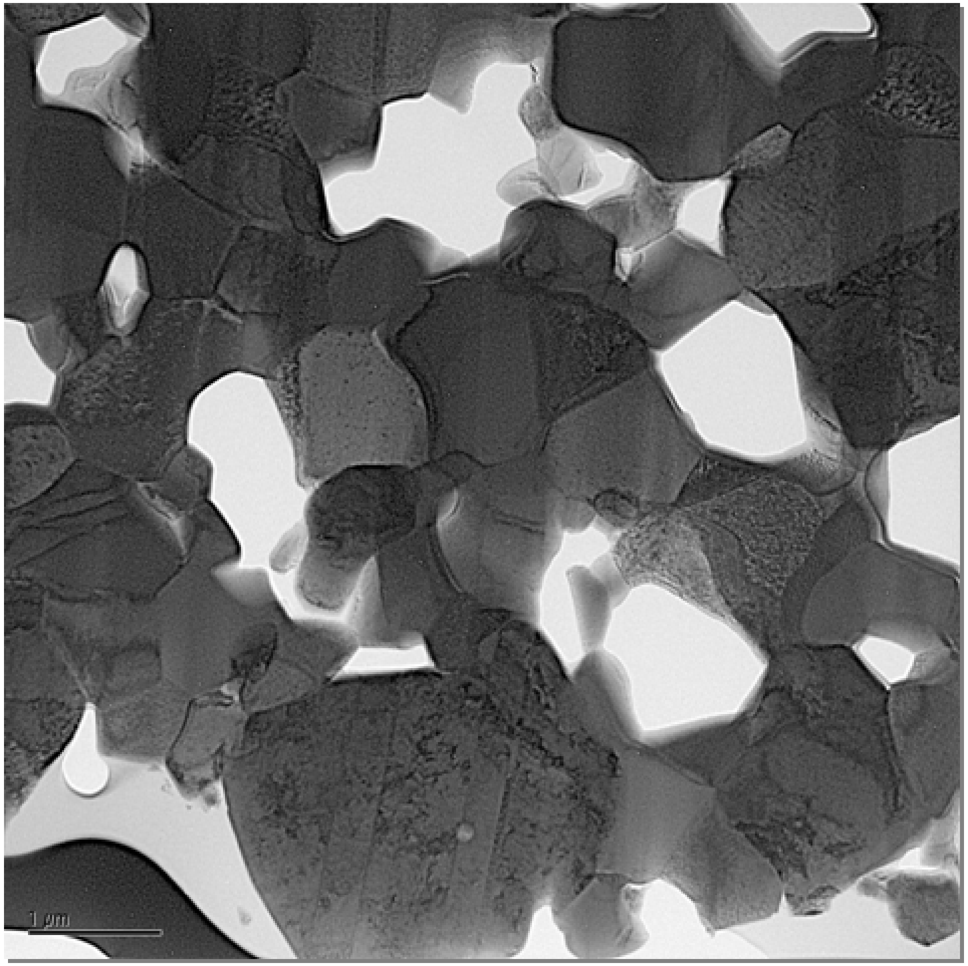
- residual stresses determined in YSZ layer by X-ray diffraction
- Curvature measurements by laser profilometry





Thermal cycling and thermal aging

- Microstructural and physical characterization in progress
- Aging tests in progress to distinguish between thermal and cycling effects



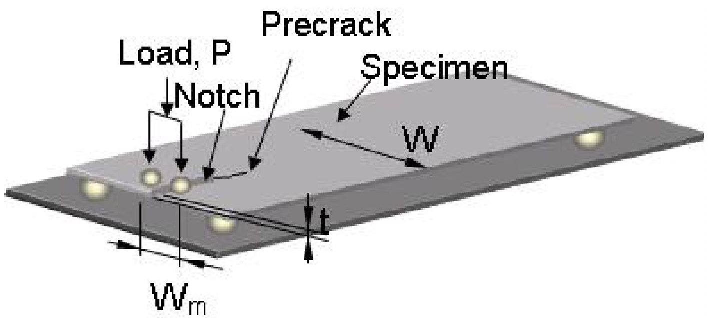
Slow crack growth

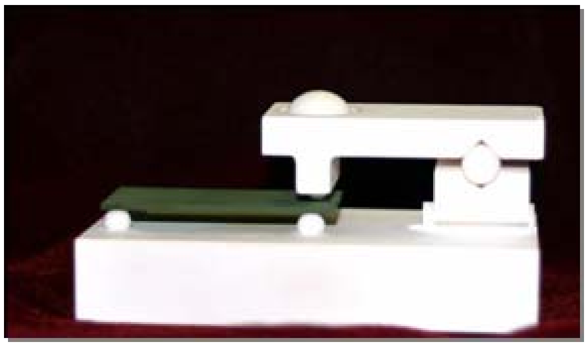
Slow-crack growth

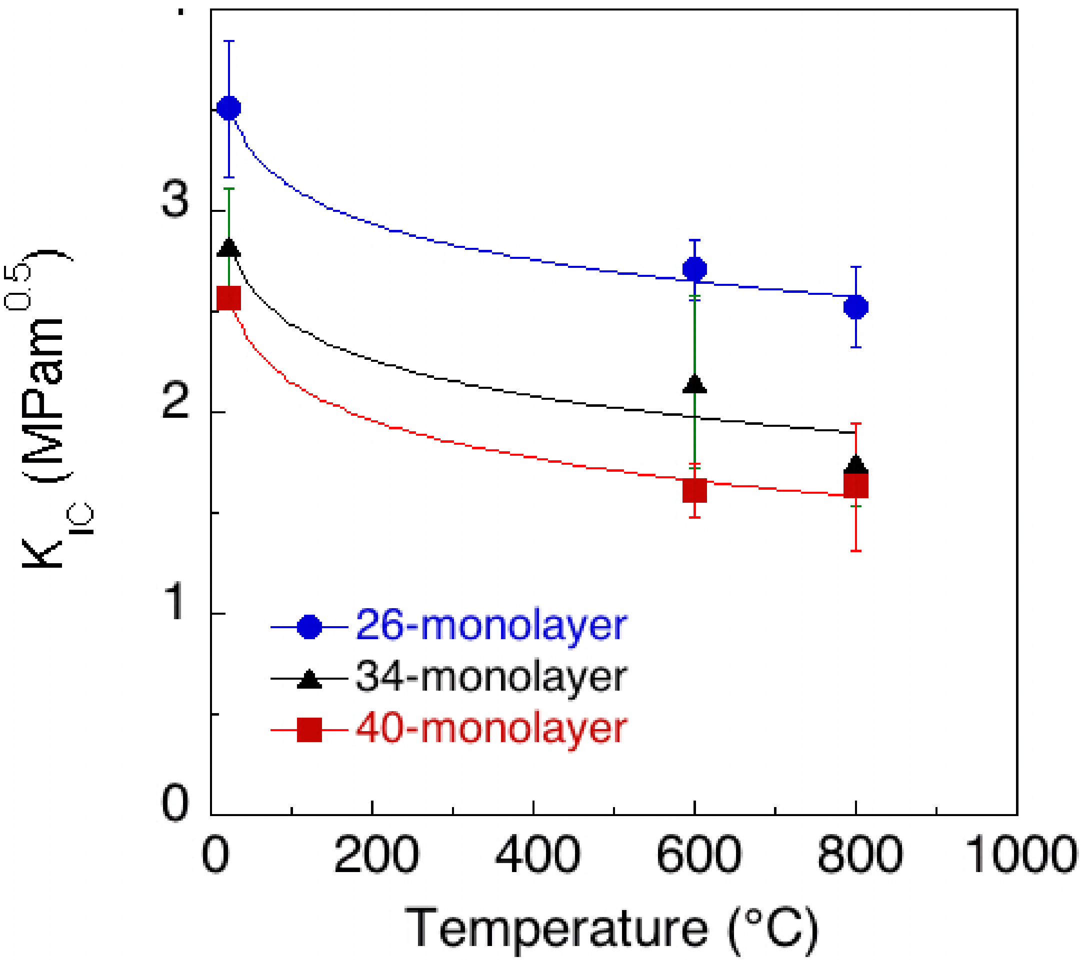
- Slow-crack growth of preexisting flaws is recognized as a primary source of static fatigue failure of ceramics.
- Knowledge of crack velocities can be used to predict the service life of ceramic components.

$$v = A[K_I / K_{IC}]^n$$

Fracture toughness



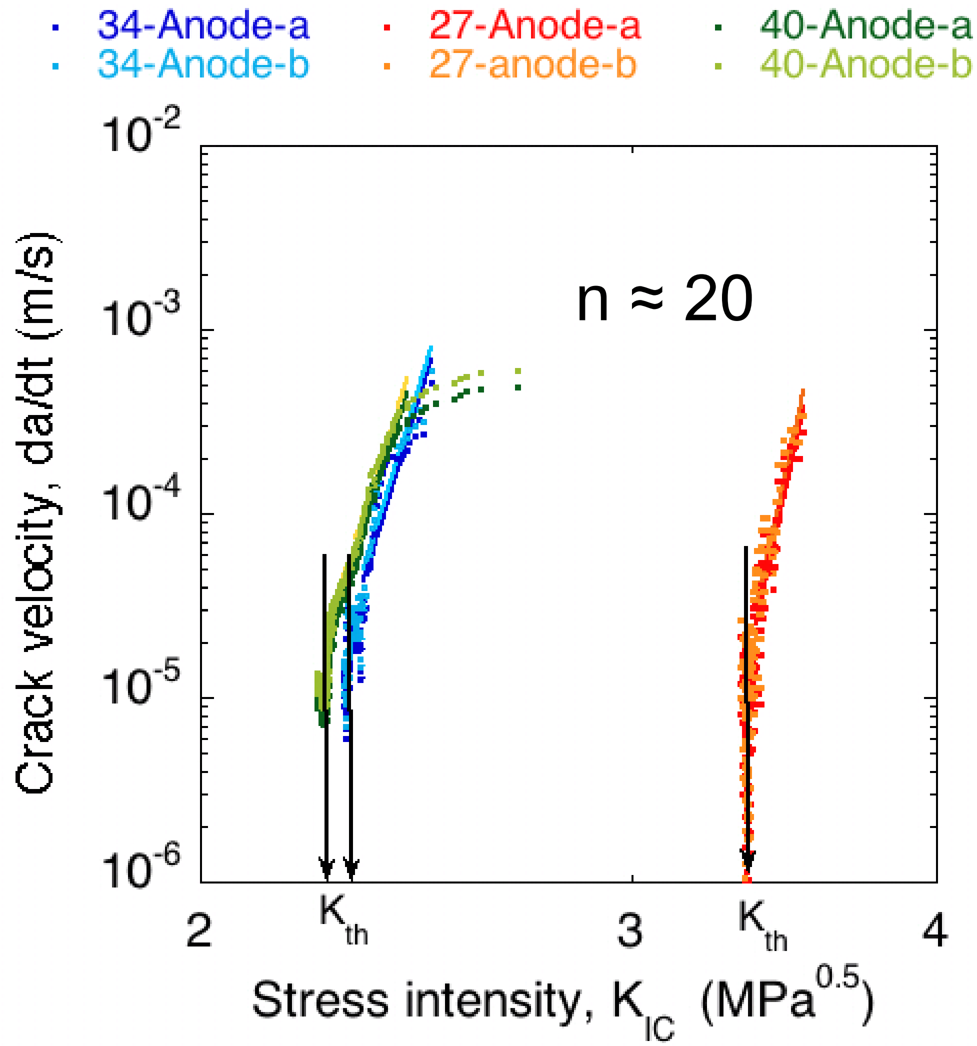




- fracture toughness and slow-crack growth determined by double-torsion testing

Slow-crack growth

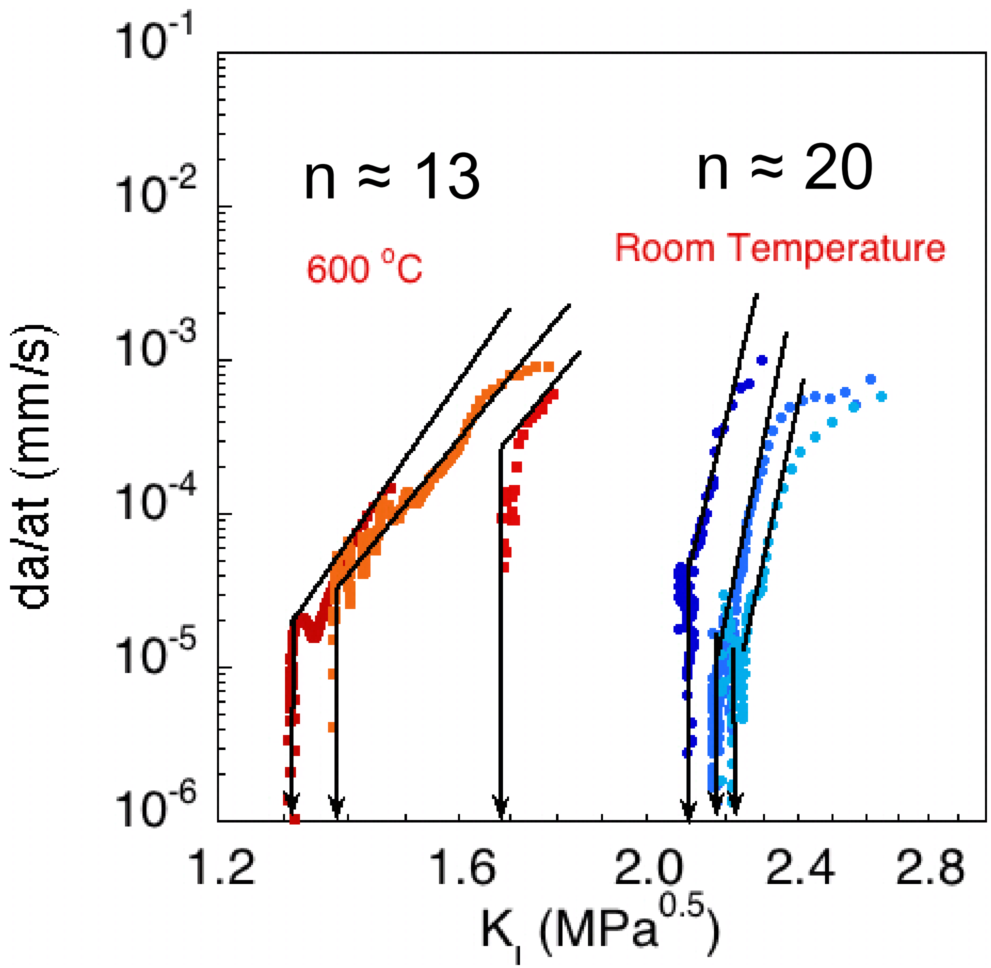
Double-torsion test method



- Ni-YSZ
- 20°C

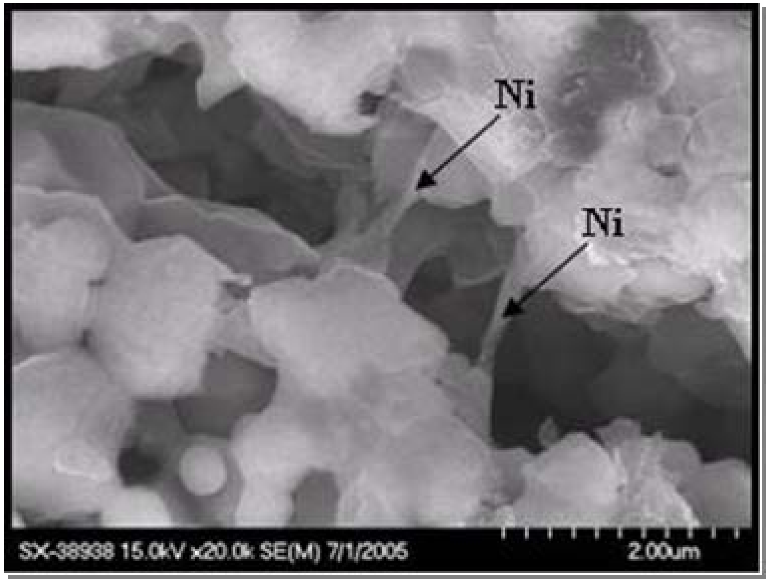
Slow-crack growth

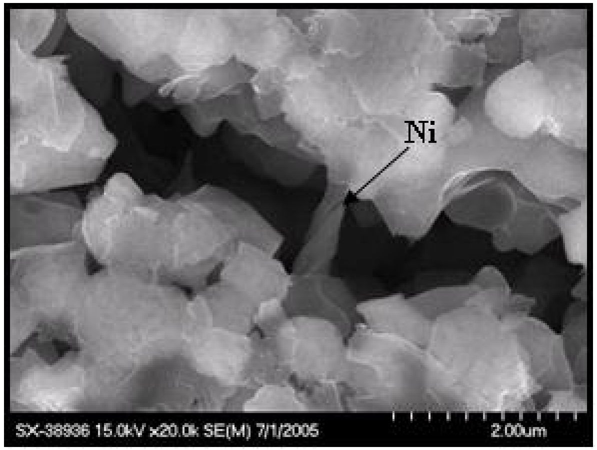
Double-torsion test method

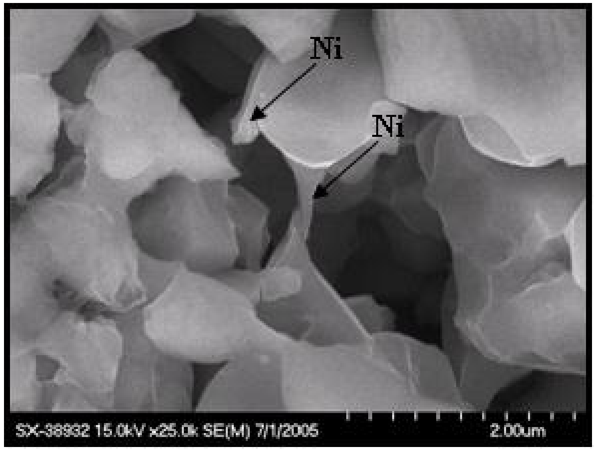


- Ni-YSZ
- H_2(4%)-Ar(96%)

Slow-crack growth





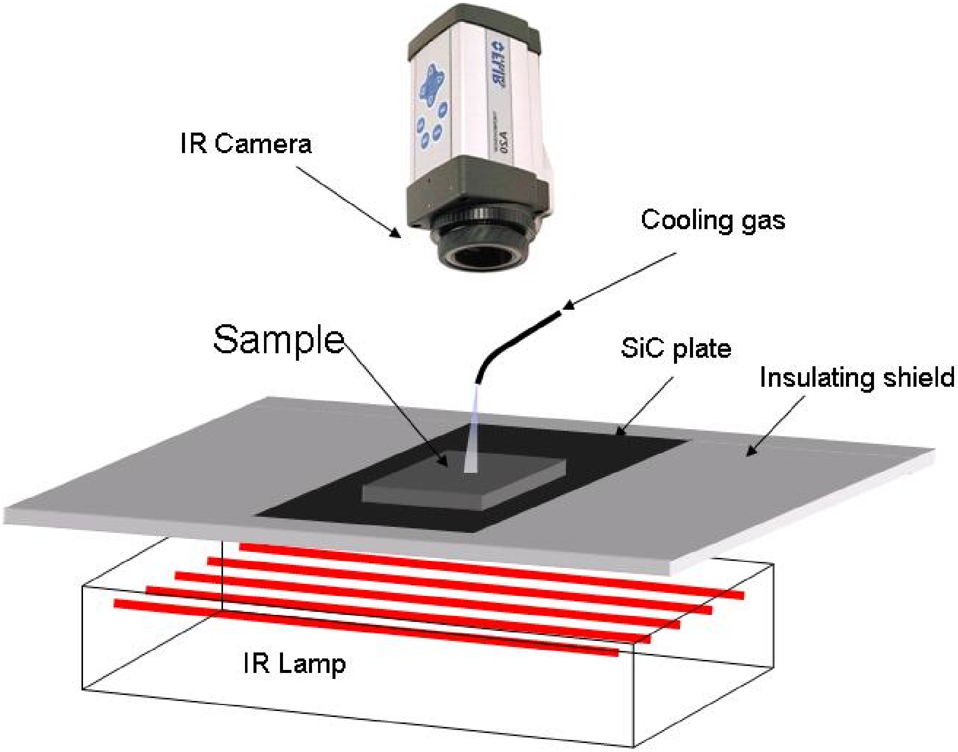


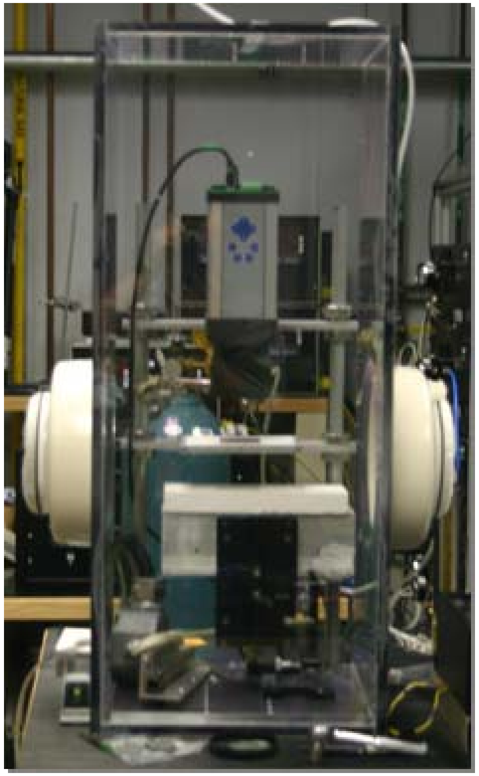
Role of microstructure on crack growth in Ni-YSZ at 600°C

Future Work

Future Work

Probabilistic analysis to predict durability and reliability





Verification of reliability predictions for bi- and tri-layers subjected to arbitrary temperature distributions

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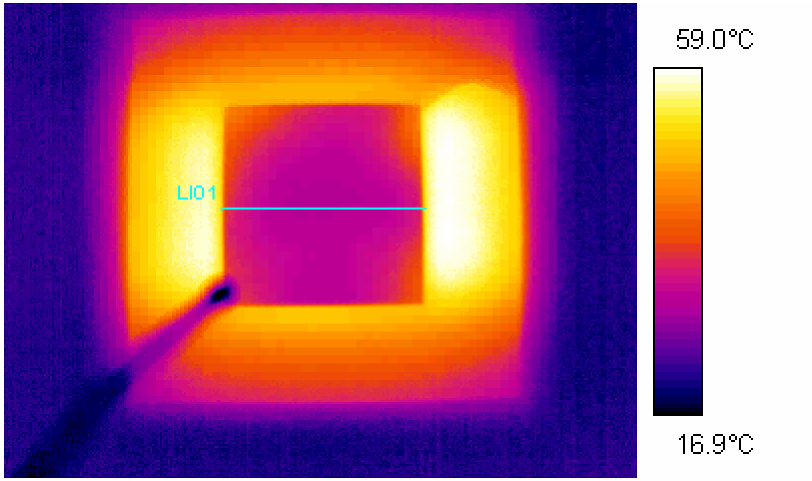

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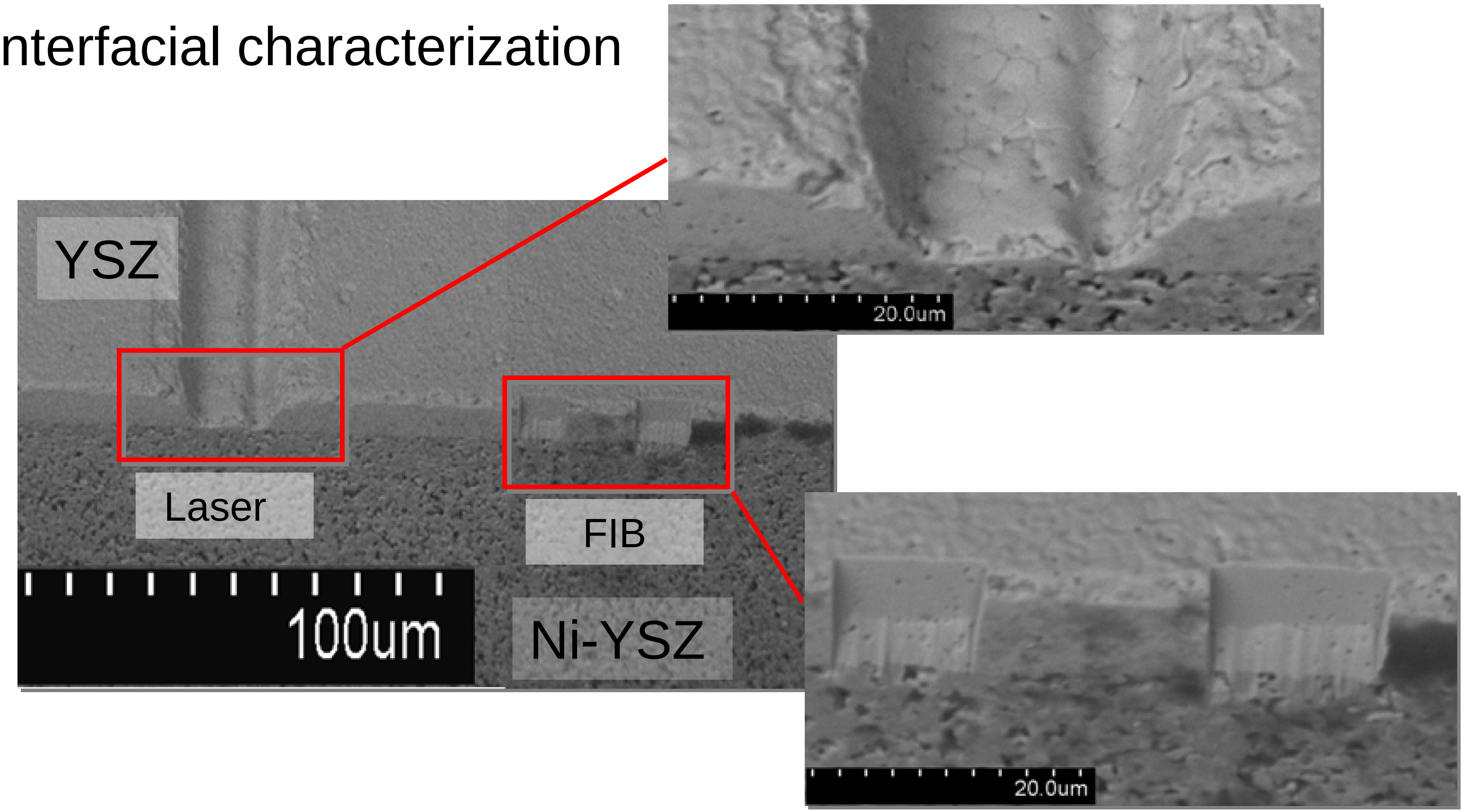
Future Work

Interfacial characterization



Summary

- Nickel is responsible for the creep deformation of Ni-YSZ at 800°C
- Residual stresses in Ni-YSZ decrease in magnitude with number of thermal cycles.
- The fracture toughness of Ni-YSZ decreases with both porosity and temperature
- Ni-YSZ exhibits slow-crack growth both at ambient and elevated temperatures. The microstructure does play a role on crack propagation
- Thermal and physical properties of materials have been determined