# Monolithic and Surface Modified Ceramics

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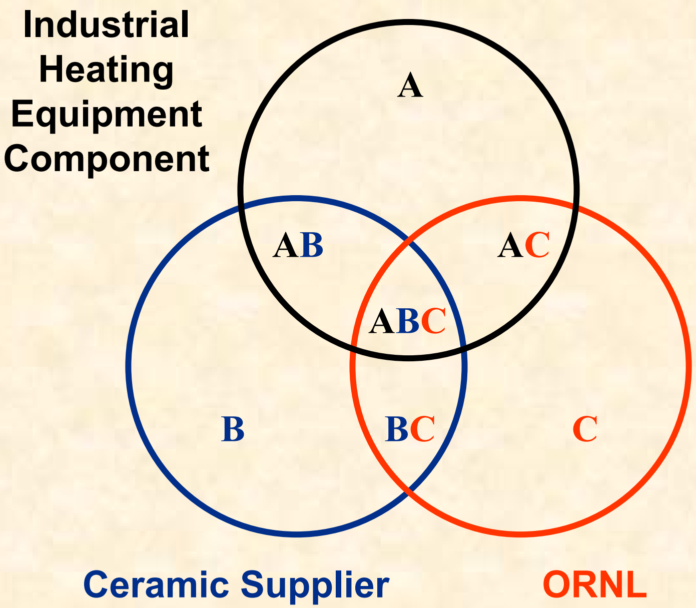
# The Proposed Research Has Two Tasks

- **Monolithic ceramic enabling for industrial heating equipment**
  - Systematic thermomechanical characterization
  - Probabilistic design and life prediction
  - Remaining life assessment
  - Proof testing
- **Develop ceramic coatings with improved thermal and environmental resistance**
  - High temperature
  - Oxidation
  - Corrosion
  - Erosion

# Longer Lasting Ceramic Components for Industrial Heating Equipment are Enabled when End Users, Ceramic Suppliers, and ORNL Work Together



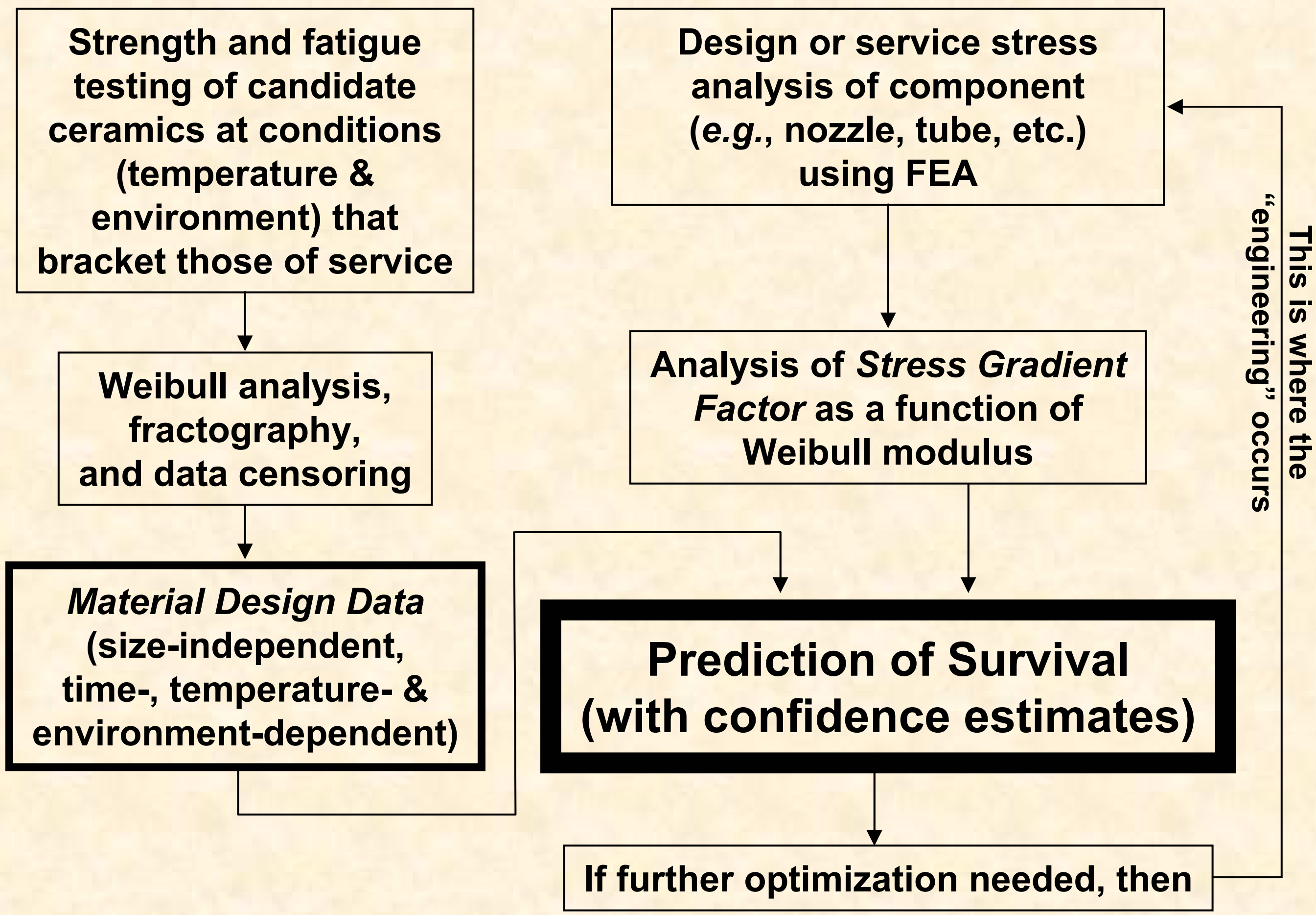

*ABC: Identification of optimum system*

- A: Component(s) identified
- B: Candidate ceramic(s) identified
- C: Design, life prediction, & coatings
- AB: Manufacturability assessed
- AC: Service conditions and effects on materials assessed. EB and TB coatings applied if necessary.
- BC: Matl and manuf optimization

# Task 1:

# Monolithic Ceramic Enabling for Industrial Heating Equipment

# Probabilistic Life Design Combines Weibull Data, FEA, and a Multiaxial Fracture Criterion



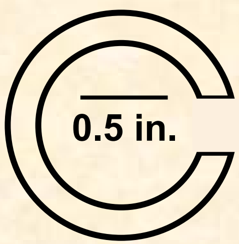
# Modes of Failure Initiation are Used in Component Strength-Size-Scaling Predictions

| | Censored Weibull statistics are analyzed - concurrent flaw distributions are considered | Strengths are then scaled between components sizes according to (concurrent) flaw type |
|---|---|---|
| **Edge flaws (1-D)** | $P_f = 1 - \exp\left[ -k_l L \left( \frac{\sigma}{\sigma_{o_l}} \right)^{m_l} \right]$ | $S_1 = \left[ \frac{k_{l1} L_1}{k_{l2} L_2} \right]^{1/m_l} S_2$ |
| **Surface flaws (2-D)** | $P_f = 1 - \exp\left[ -k_a A \left( \frac{\sigma}{\sigma_{o_a}} \right)^{m_a} \right]$ | $S_1 = \left[ \frac{k_{a1} A_1}{k_{a2} A_2} \right]^{1/m_a} S_2$ |
| **Volume flaws (3-D)** | $P_f = 1 - \exp\left[ -k_v V \left( \frac{\sigma}{\sigma_{o_v}} \right)^{m_v} \right]$ | $S_1 = \left[ \frac{k_{v1} V_1}{k_{v2} V_2} \right]^{1/m_v} S_2$ |

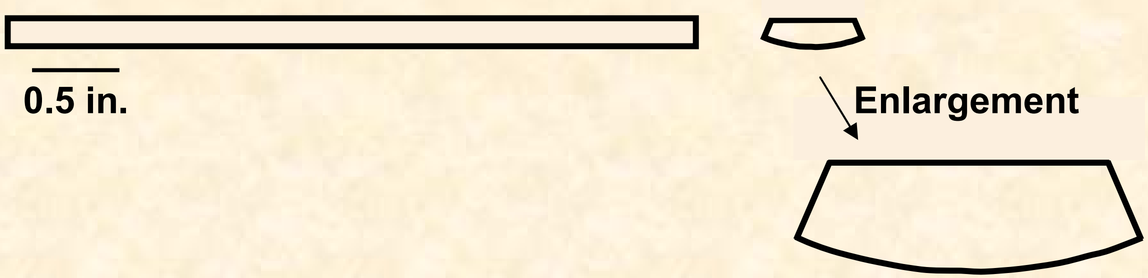
# Mechanical Test Coupons Are Specifically Used to Exploit Strength-Limiting Flaws Whose Activity is Expected During Component Service

**Buttonhead Tensile Specimen - ASTM C1273**


**C-Ring Specimen (Comp:OD, Tens:ID) - ASTM C1323**



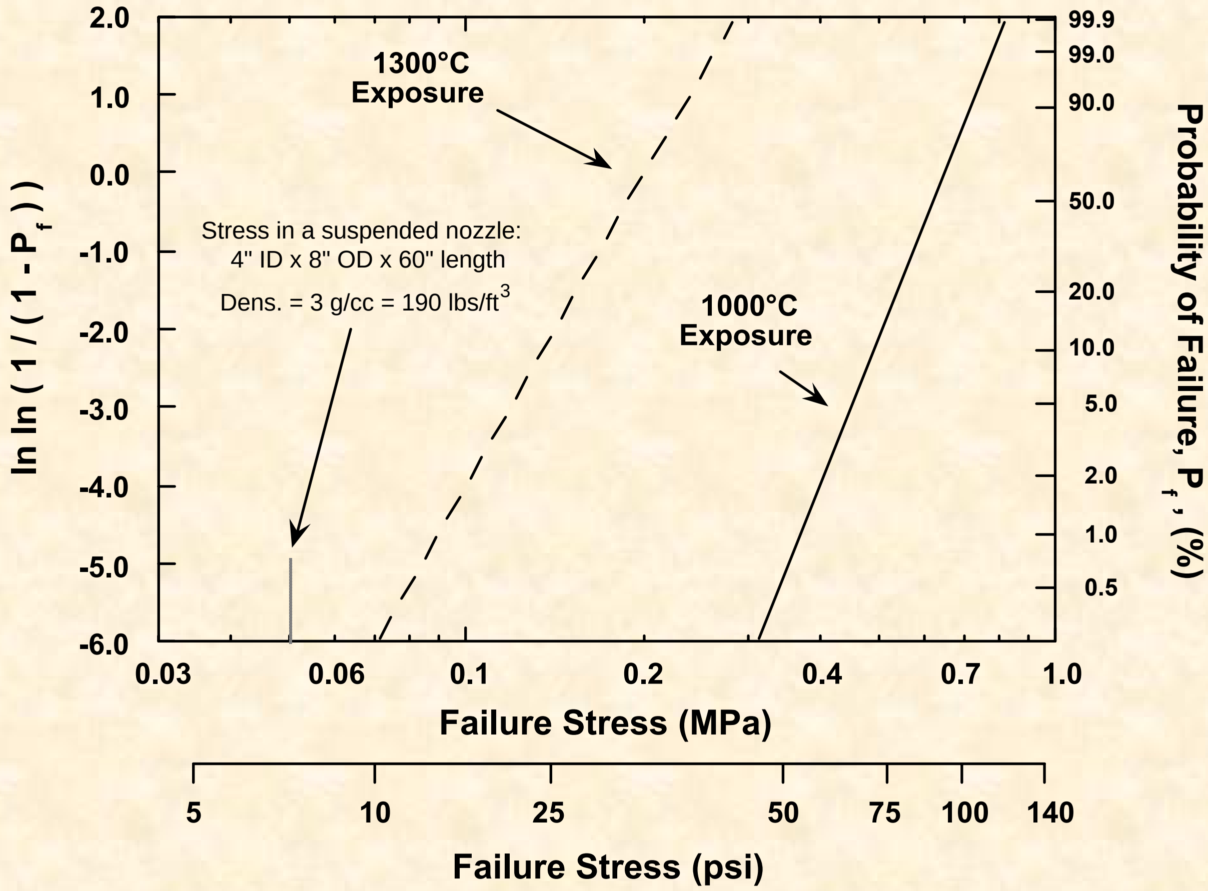

**Sectored Tube Flexure Specimen (4-pt-bending)**



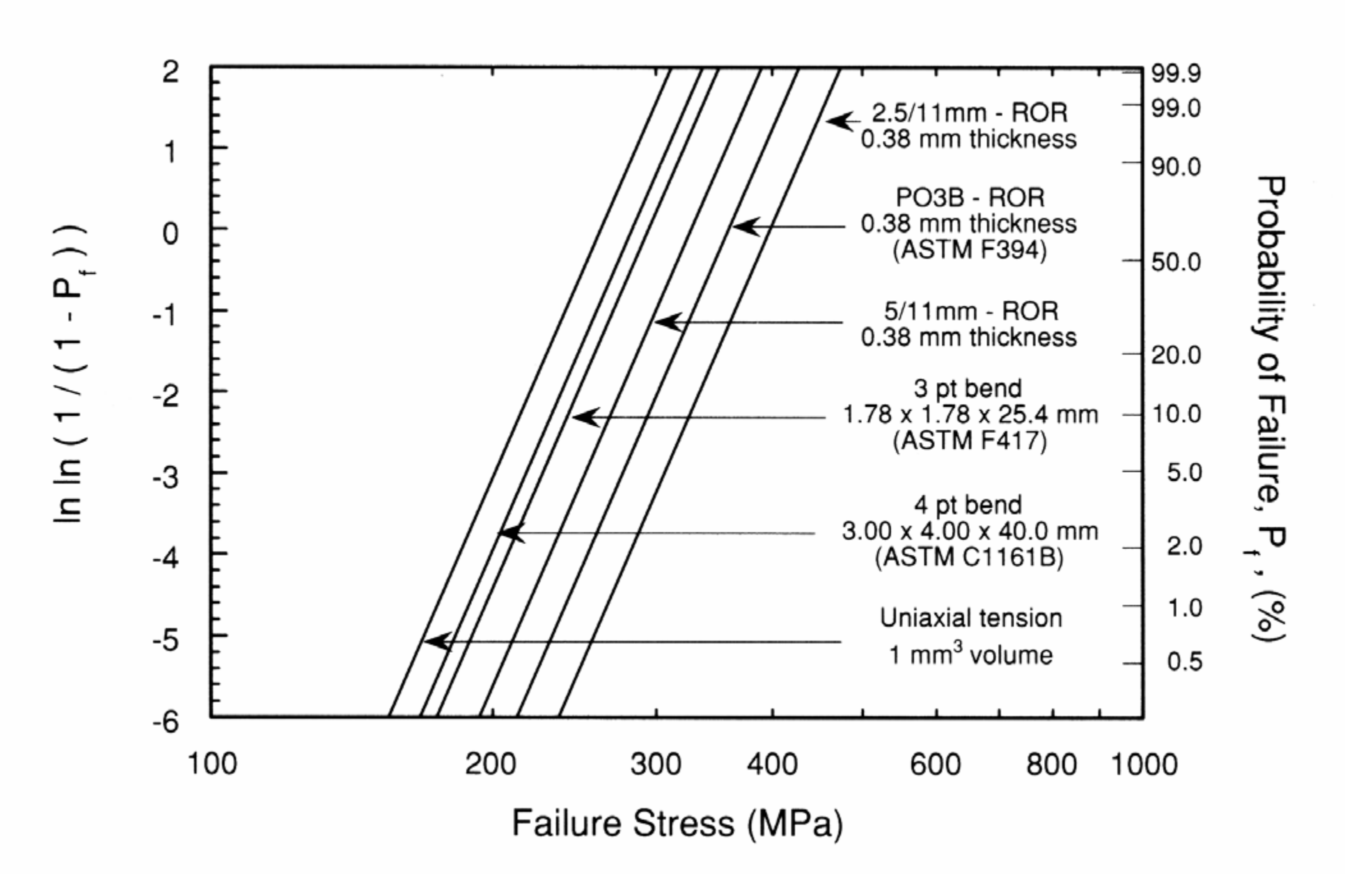

**Strength-Limiters:**

- Volume Flaws (Buttonhead Tensile Specimen)
- Surface Flaws (Hoop) (C-Ring Specimen)
- Surface Flaws (Axial) (Sectored Tube Flexure Specimen)

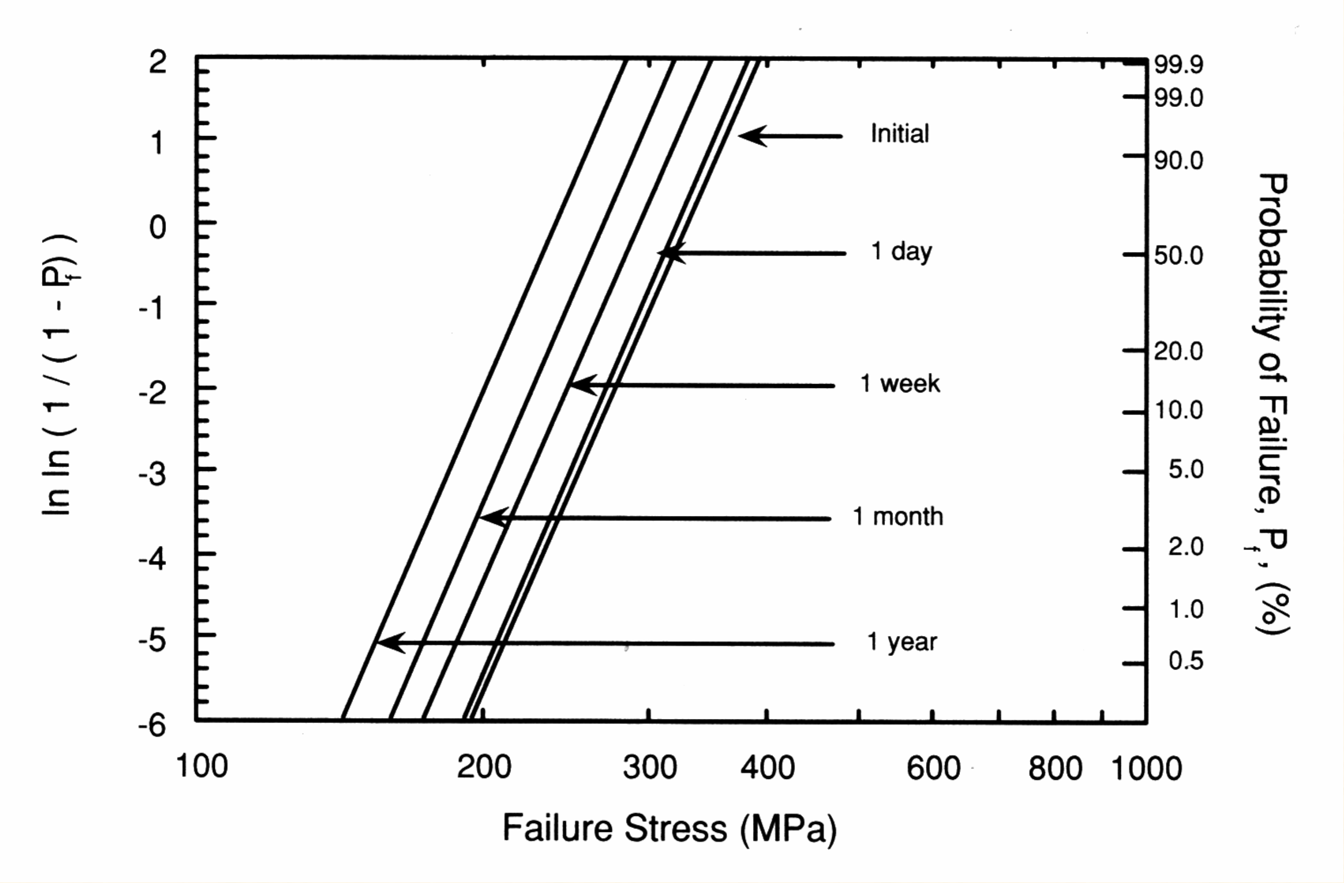
# Example of a Failure Probability Prediction of Mg-Carbon Ladle Used in Steel Production



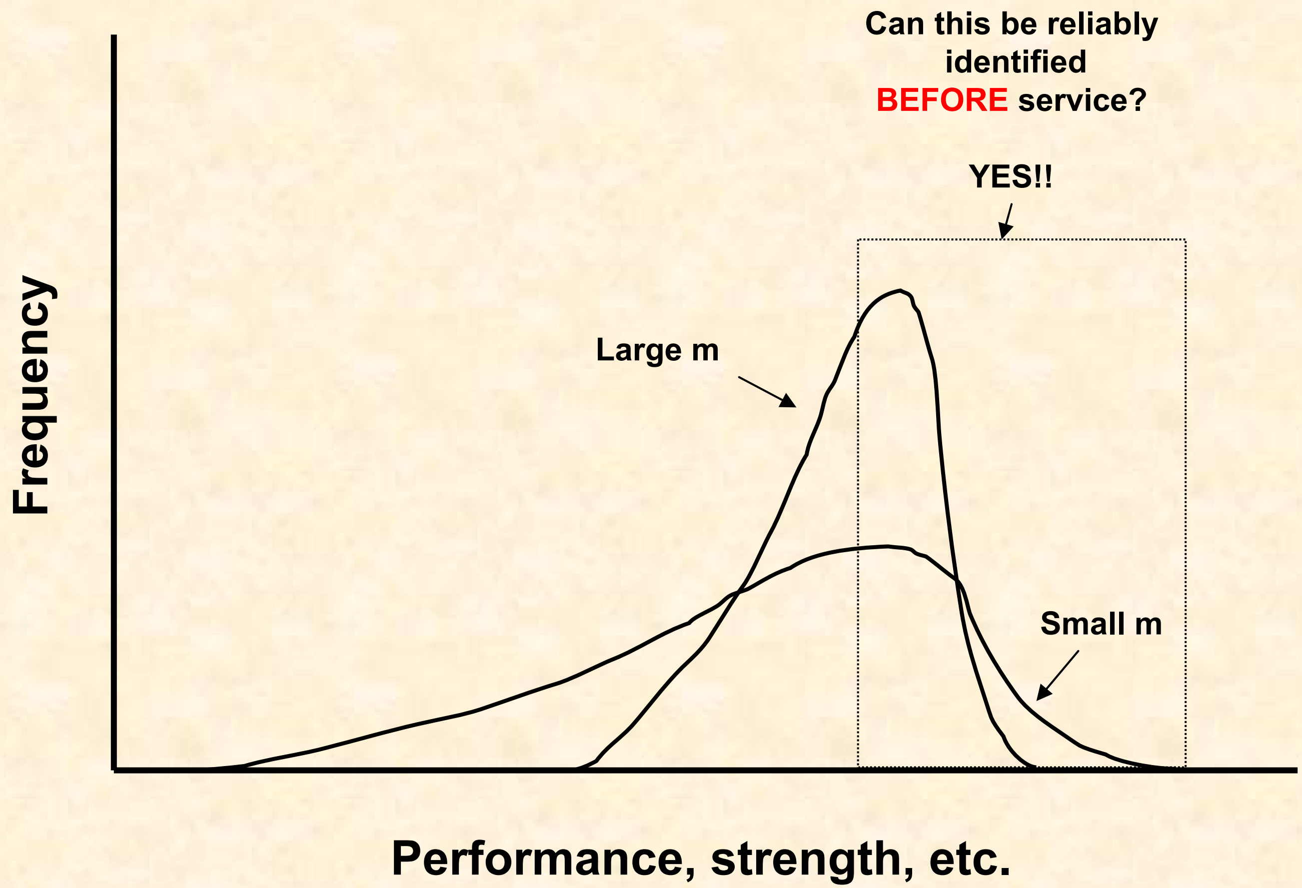
# Example of How Different Size Test Coupons Exhibit Strength-Size-Scaling in an Alumina



# Example of How Strength Can Be Compromised With Time in an Alumina



# Proof-Testing, and the Probabilistics and Confidence Bounds Associated With it, can Eliminate Potential Poor Performing Components From the Population



# Task 2:

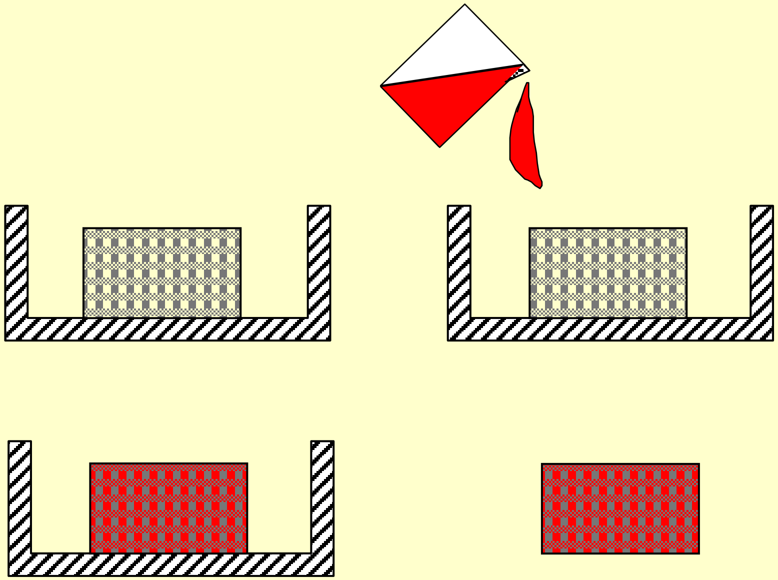
# Develop Ceramic Coatings with Improved Thermal and Environmental Resistance

# Slurry Infiltration and Dip Coating are Efficient Methods to Apply Thermal and Environmental Barriers on the Surfaces of Metal and Ceramic Components

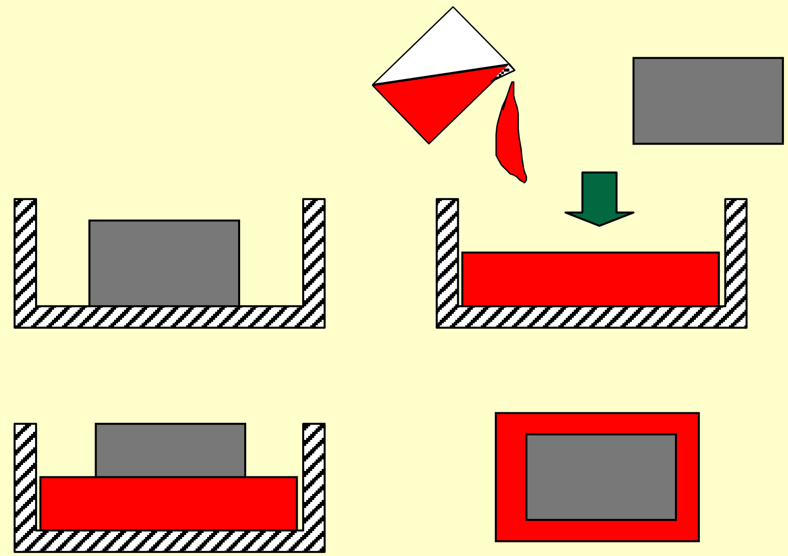
- Utilizes a slurry (powdered material suspended in an aqueous or organic solvent ) and a porous support structure (*i.e.*, component)
- Slurry is poured or pulled into the structure under vacuum
- Densification can be traditional via sintering furnace or utilizing the HDI
- Complex shapes are feasible
- Process is recyclable
- Process is diverse (material chemistry and materials solids loadings)

# Slurry Infiltration and Dip Coating Processes

**Slurry Infiltration**



**Dip coating**



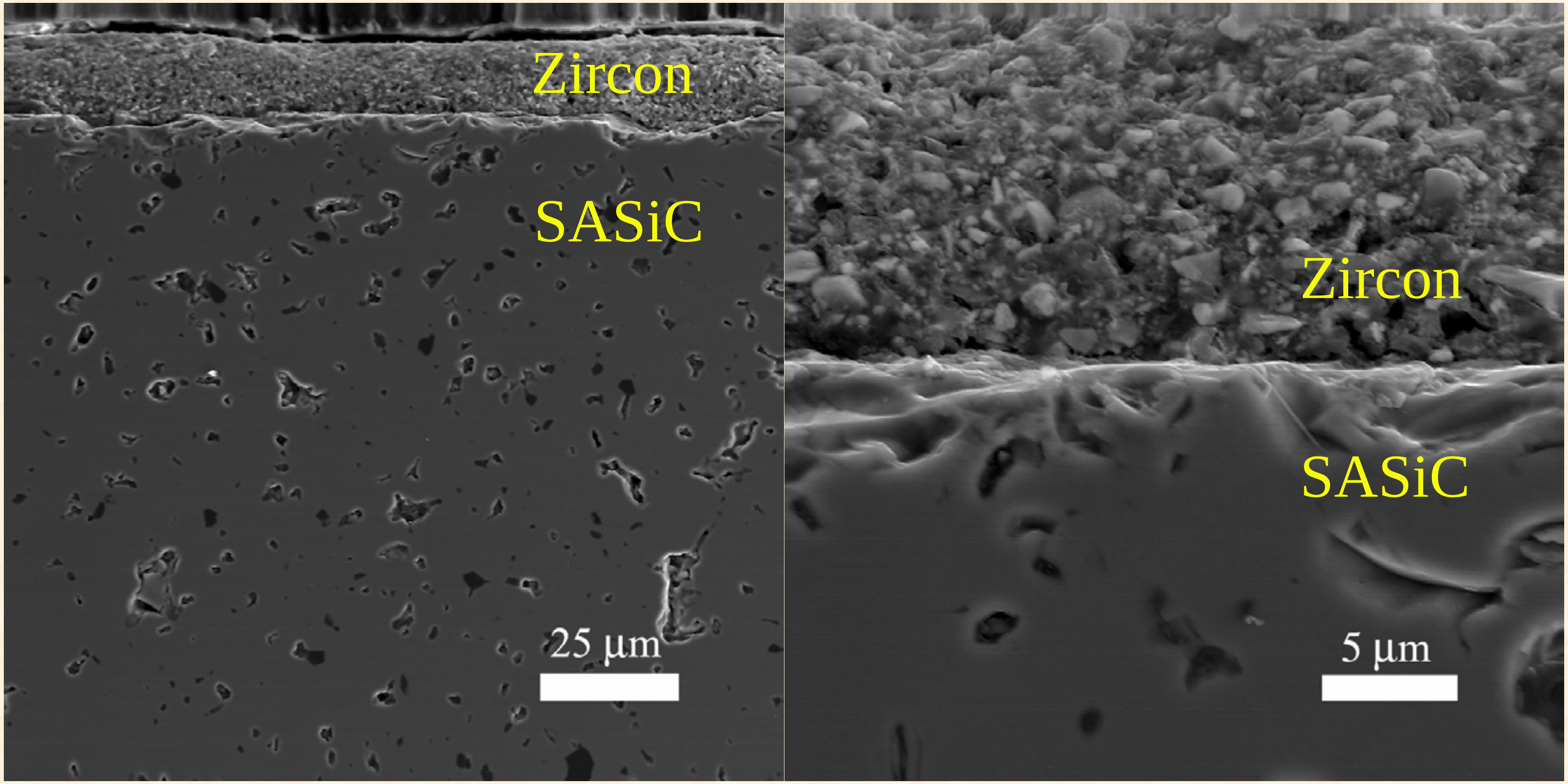
# Slurry-Based Coating Processes

| Techniques | Advantages | Issues |
|---|---|---|
| Vacuum Infiltration | Can coat internal or weave type structures | Viscosity of slurry/depth of slurry penetration |
| Spin Coating | Thin coating | Difficult to coat 3D structures |
| Screen Printing | Controlled coating thicknesses and densities. Scaleable | Difficult to coat 3D structures |
| Pad Rolling | Controlled coating thicknesses and densities. Scaleable | Difficult to coat 3D structures |
| Spray Coating | Inexpensive. Conducive to 3D structures | Thickness/flatness variation. Line of sight. |
| Dip Coating (glazing) | Inexpensive. Conducive to 3D structures | Thickness variation as a function of dip direction |
| Dip Coating (solgel/polymerization) | Conducive to 3D structures | Thickness of coating with one coat. May require multiple passes. Shrinkage may be high. |
| Dip Coating (precursor/ conversion) | Conducive to 3D structures | Shrinkage may be high. May require multiple passes |

# Existing Coatings Research at ORNL

| Material | Proposed Environment |
| --- | --- |
| Mullite | High Temperature, Fossil, Microturbine |
| Doped alumino-silicates, e.g., barium strontium doped alumino-silicate (BSAS) | Microturbine |
| Rare earth disilicates ($RE_2Si_2O_7$), e.g., yttrium disilicate | High Temperature, Fossil, Microturbine |
| Zircon | High Temperature, Fossil |
| Calcium Aluminate | High Temperature, Fossil |

# Polished Cross Sections of SA-SiC Substrates Coated with Zircon by Screen-Printing and Densified Using the High Density Infrared Process (HDI)



# Summary

- The use of probabilistic life design methods can enable the use of ceramic components in industrial heating equipment
  - Strength-size-scaling issues are manageable
  - Time-dependent loss in strength (fatigue) is manageable
- Slurry infiltration and dip coating processes can be used to apply thermal and environmental barrier coatings to metals and ceramics and also can be an enabler

- *Longer lasting ceramic components for industrial heating equipment can be enabled when end users, ceramic suppliers, and ORNL work together*