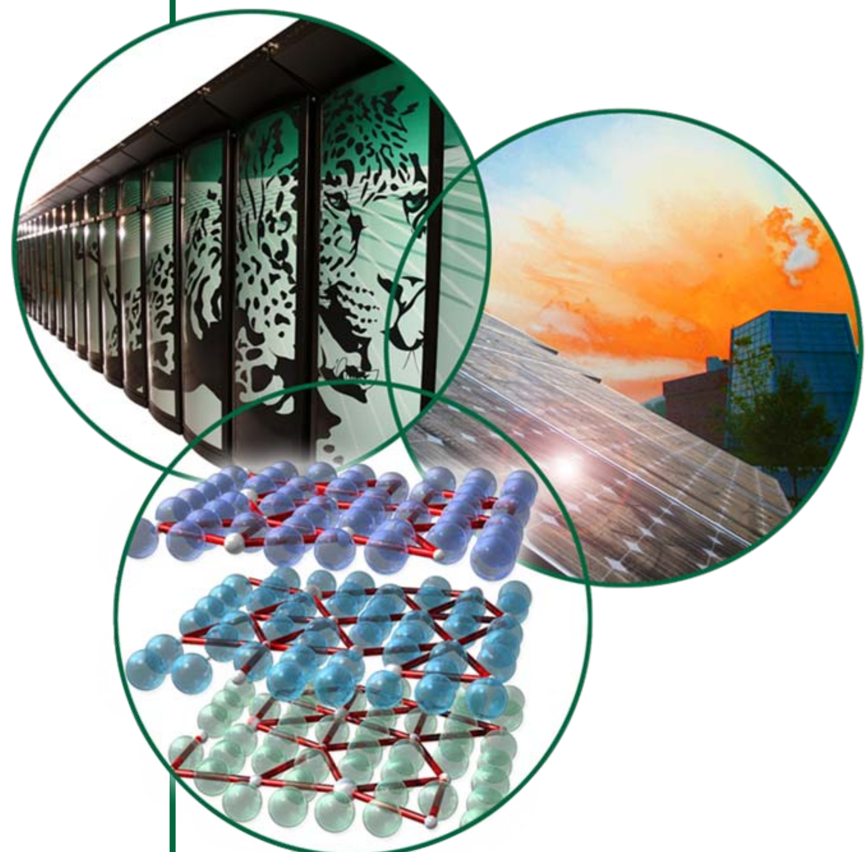
Project ID: pm_09_watkins

Durability of Diesel Engine Particulate Filters



DOE 2009 Vehicle Technologies Annual Merit Review and Peer Evaluation Meeting

May 21, 2009

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Sponsored by
U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Vehicle Technologies Program

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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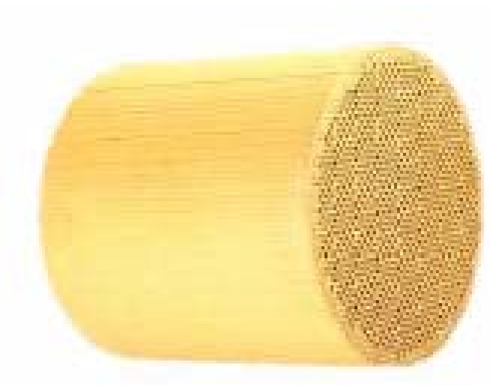
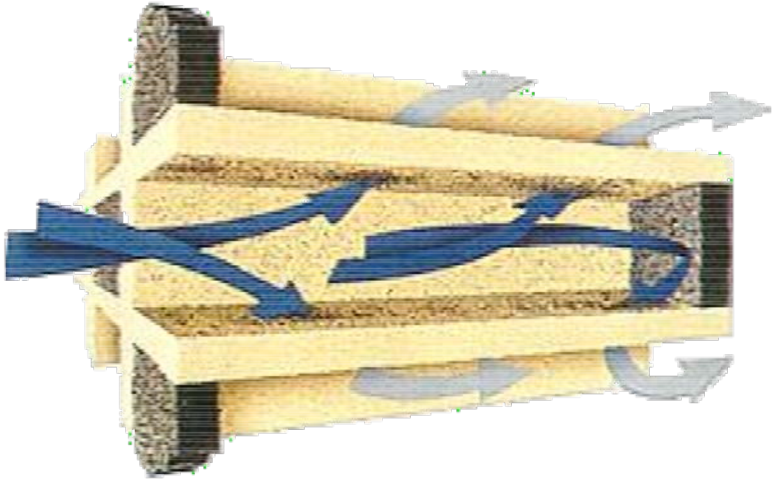
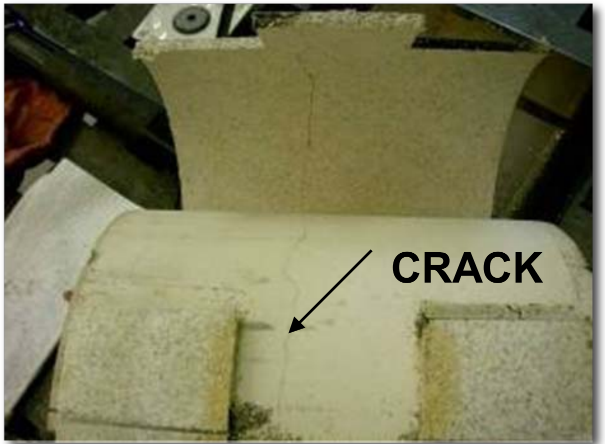
Background





- Diesel Particulate Filters (DPFs) *already* play a key role in meeting stringent 2007 regulations and will continue to be key technology to meet the more stringent 2010 regulations.
- Reliable operation for 500,000 miles required. Reliability could be reduced due to thermal stresses induced in ceramic DPF during regeneration.
- Need for improved materials and designs along with life prediction models to optimize reliability and durability.



Overview

Timeline

- Start: June 2004
- End: Sept. 2010
- 76% complete

Budget

- Total Project funding
  - DOE-$1.55M
  - Contractor-$1.7M
- Funding received:
  - FY08 $300k
  - FY09 $149k

Barriers*

- Design data & modeling tools
  - New test methods needed: porosity
  - Lifetime = f(properties) for models
- Performance
  - Increased thermal stresses due to active filter regeneration forced by lower NO_x standard

Targets

- HD diesel engines compliant with 2010 EPA regulations

Partners

- Cummins Inc.
- Corning Inc.

* FreedomCar and Vehicle Technologies Program, Multi-Year Program Plan 2006-2011, Sept 2006, pp. 3.4-9, 10, 21.

Objective

- **Implement test techniques to characterize the physical and mechanical properties of ceramic diesel particulate filters (DPFs) and develop analysis and inspection tools for assessing their reliability and durability.**

Milestones

- **Milestone08: Determine the elastic moduli of *coated* DPFs as a function of time at temperature.**

- **Milestone09: Determine the change in thermal shock resistance of field tested DPFs and the thermal shock resistance of one alternate substrate DPF material.**

Approach

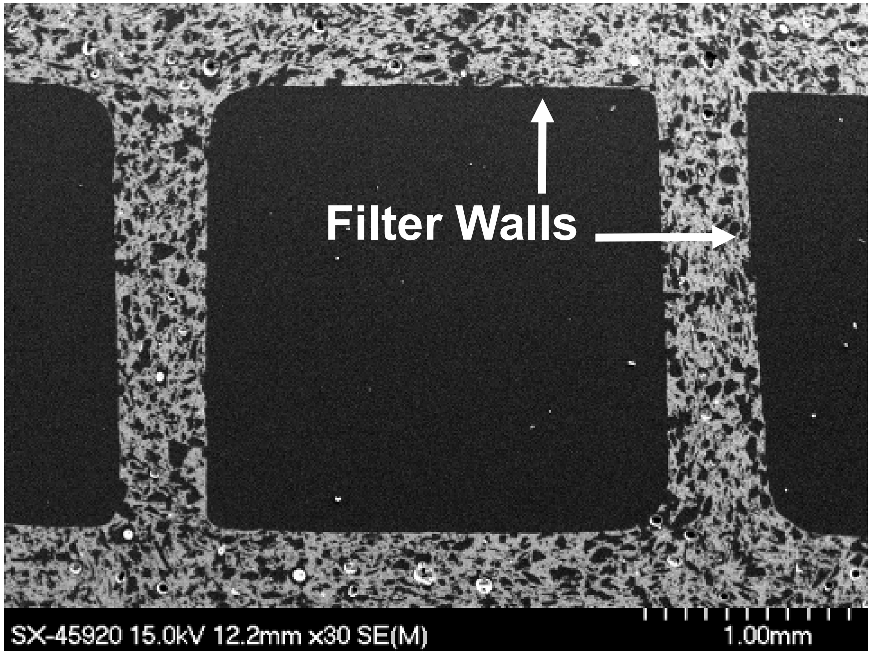
- Rank the thermal shock resistance of candidate DPF substrates.
- Application of probabilistic design tools and non-destructive evaluation (NDE) techniques to DPF ceramic substrates.
- Refinement of DPF service lifetime prediction models based on characterization of field returned filters.

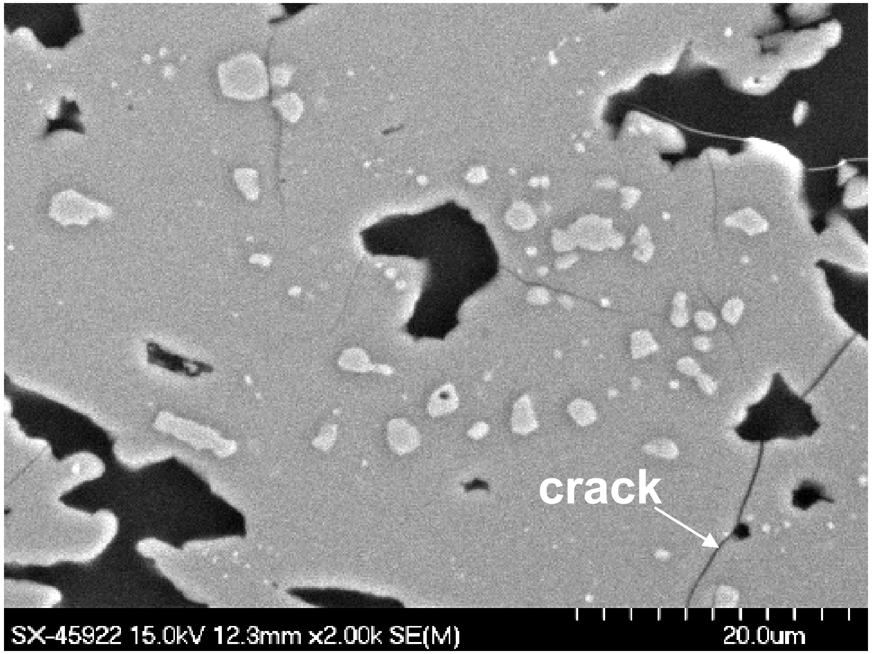
DPFs must withstand large temperature gradients associated w/ regeneration

- **Simple thermal shock parameter used for comparison**
- **Usual: $R_s = \sigma/\alpha E$, (σ = strength)**
- **Here: $R_K = K_{IC}/\alpha E$**
  - **Easier to perform fracture toughness tests than strength (less material and fewer samples)**

- **Properties measured**
- **K_{IC}, Fracture Toughness (at room temperature) – Double Torsion**
- **α, Coefficient of Thermal Expansion up to 1000^{o}C – TMA**
  - **CTE analyzed parallel and perpendicular to extrusion**
- **E, Elastic Modulus (up to 1000^{o}C) – RUS**

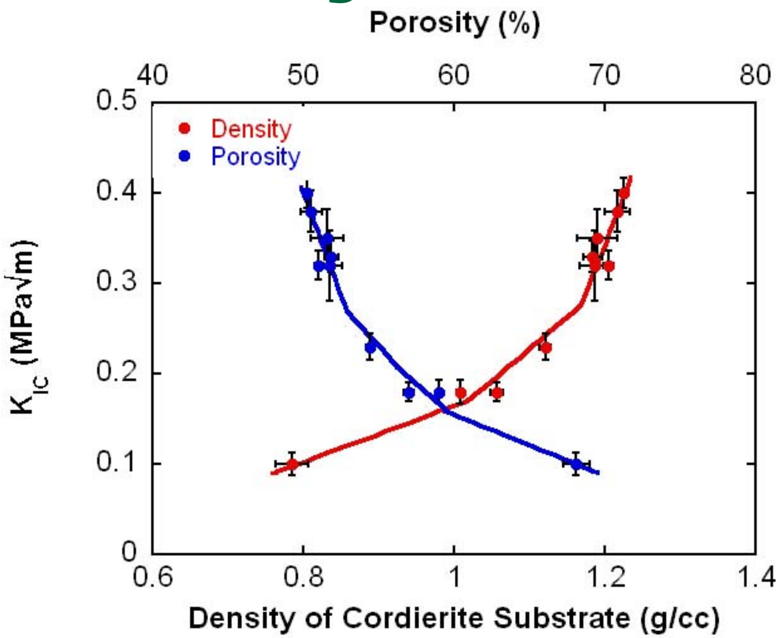
Microstructure: >50% porosity and microcracks

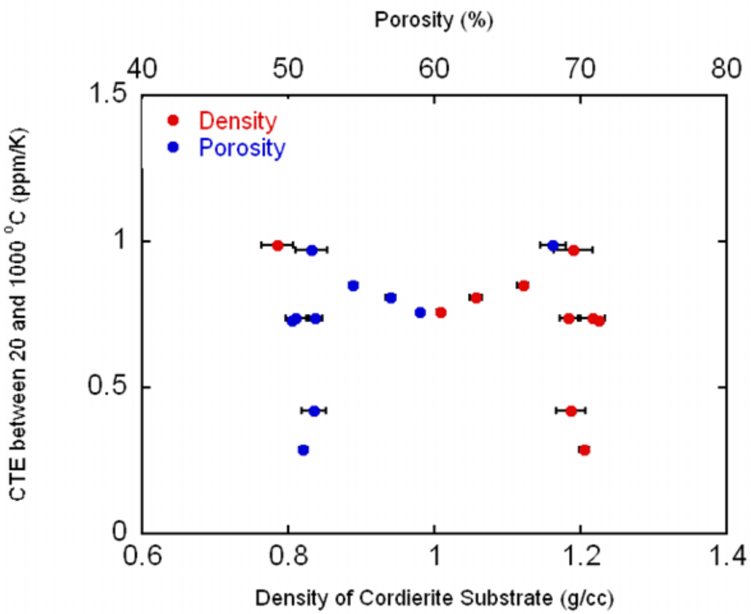




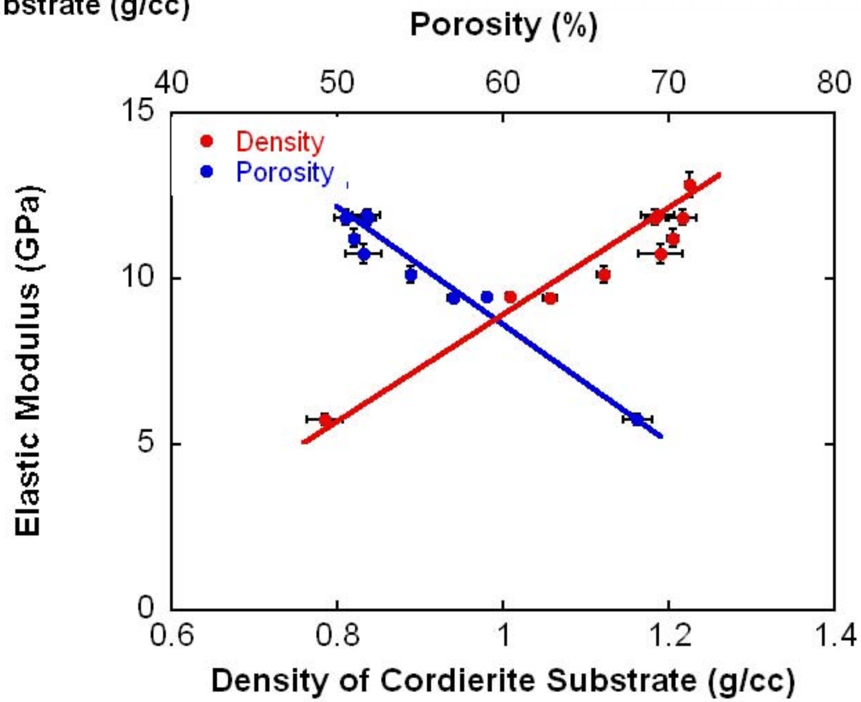
- **Cordierite: $2MgO•2Al_2O_3•5SiO_2$**
- **Anisotropic parallel and perpendicular to extrusion direction**

Porosity dominates properties





- Strong correlations with K_{IC} and E
- Porosity dominates all other conditions: bare, coated, field-tested, etc.



- CTE a function of crystal chemistry

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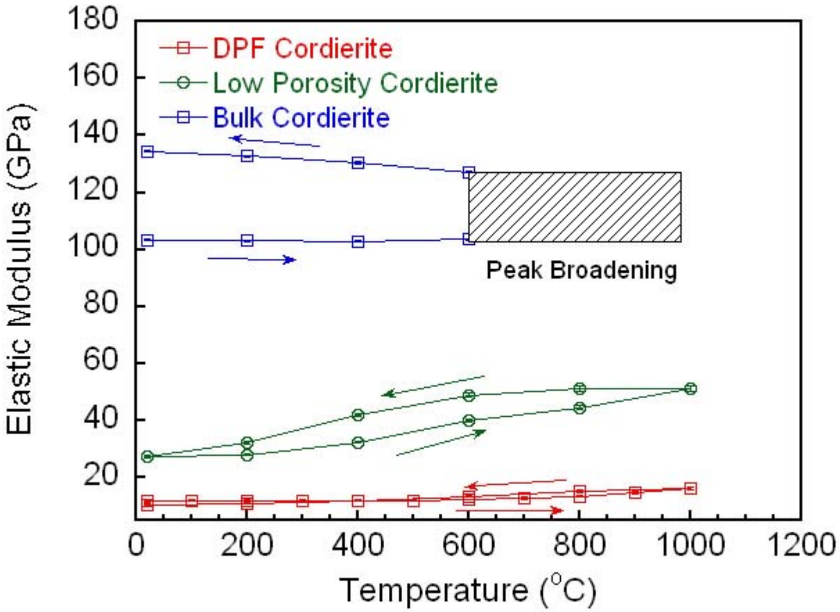
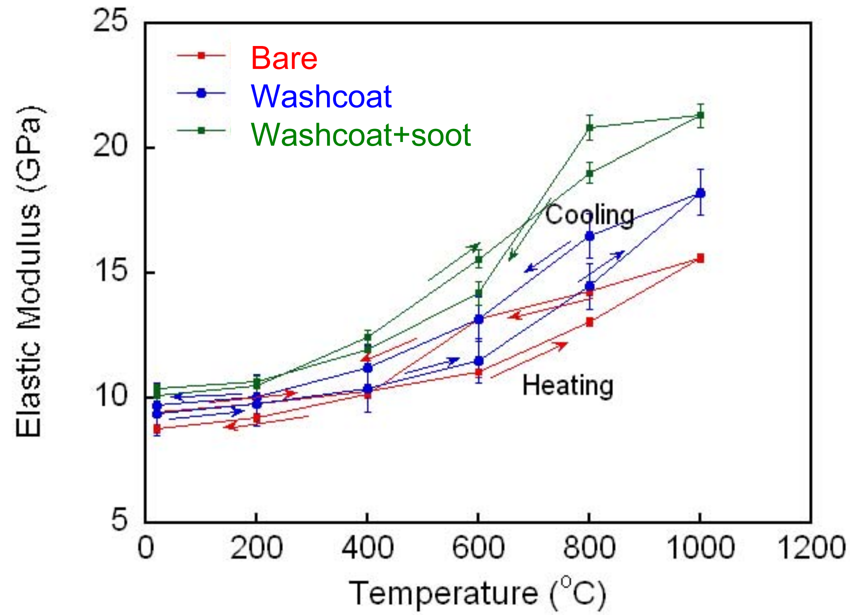
Elastic moduli: hysteresis observed on heating & cooling





- **Elastic moduli low relative to dense cordierite due to porosity**
  - **Measured using resonant ultrasound spectroscopy**
- **Hysteresis attributed to microcrack healing and re-cracking**
- **Washcoat and soot increase elastic moduli**

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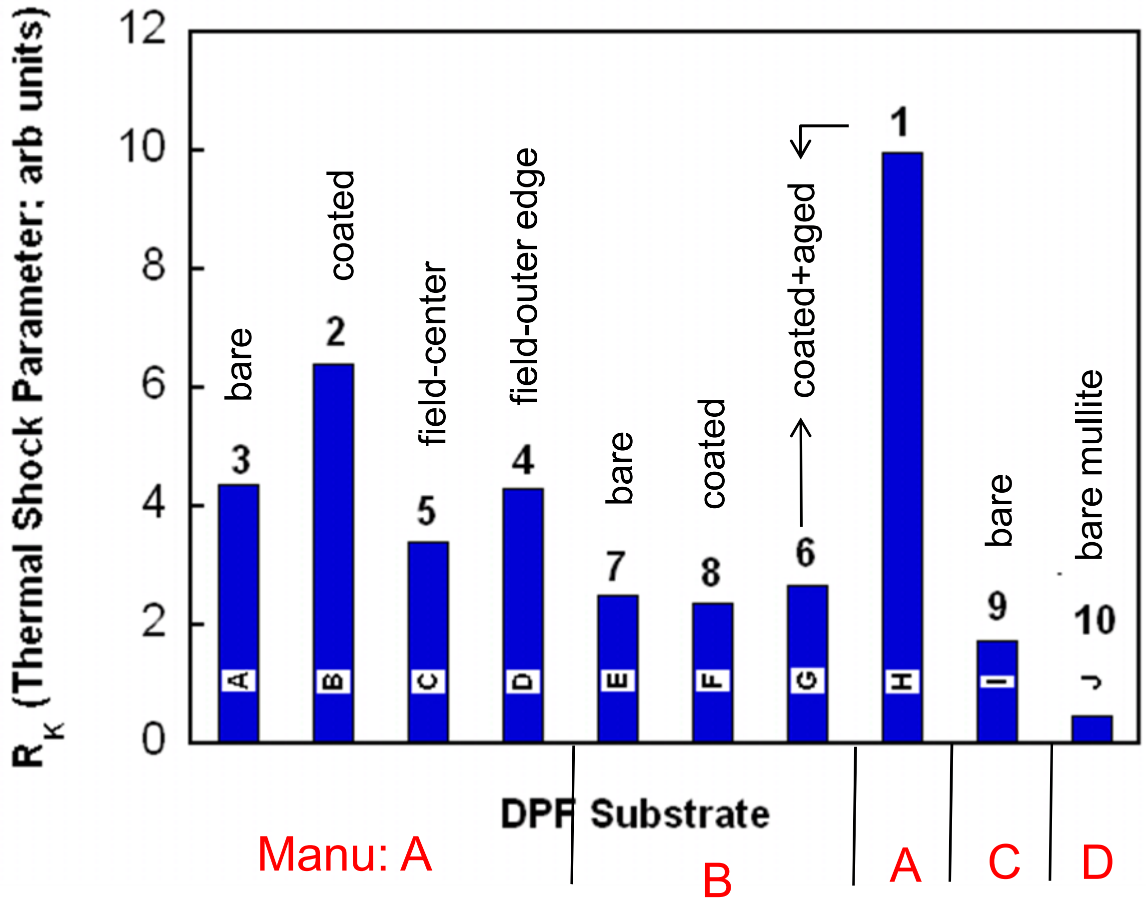
Thermal shock ranking methodology developed

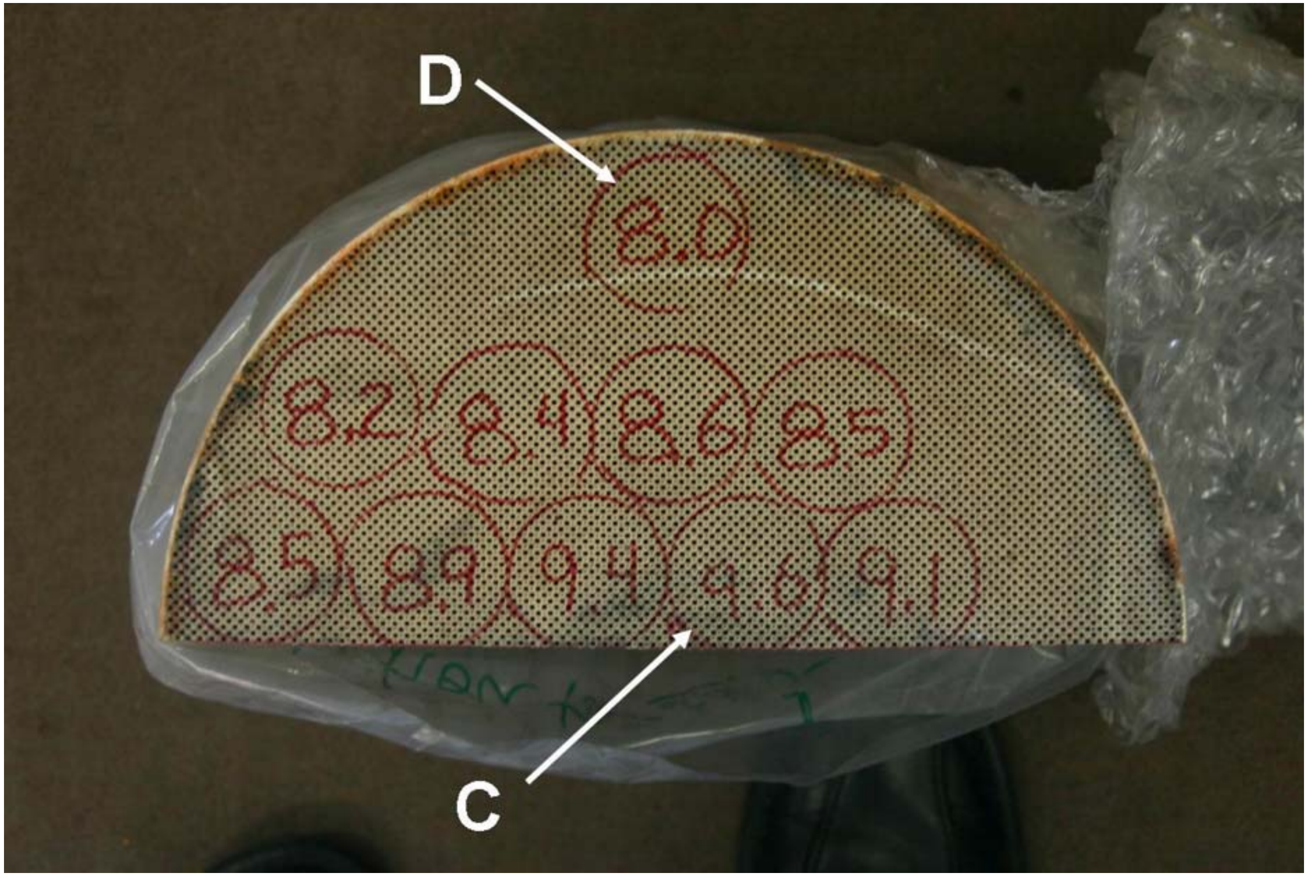


$R_K = K_{IC}/\alpha E$

- Note that the above analysis is highly simplified; assumes:
  - Homogeneity
  - Isotropy

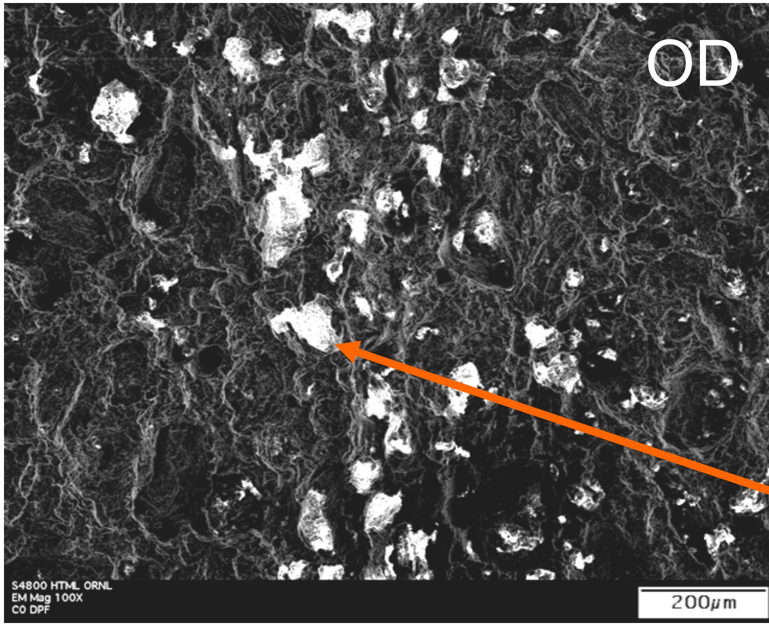
Cummins NDE: Pulse echo for variations from core to outside diameter; borescope for cracks

$$velocity^2 \propto \frac{E}{\rho}$$



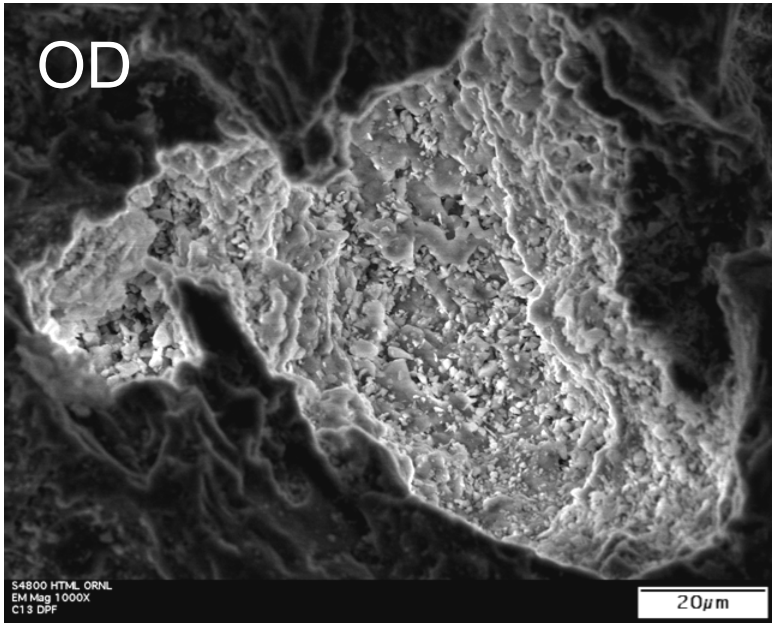
- Measured time ↓, velocity ↑, apparent length ↓
- E/ρ ↑ from core to OD

Modeling: Service changes apparent properties

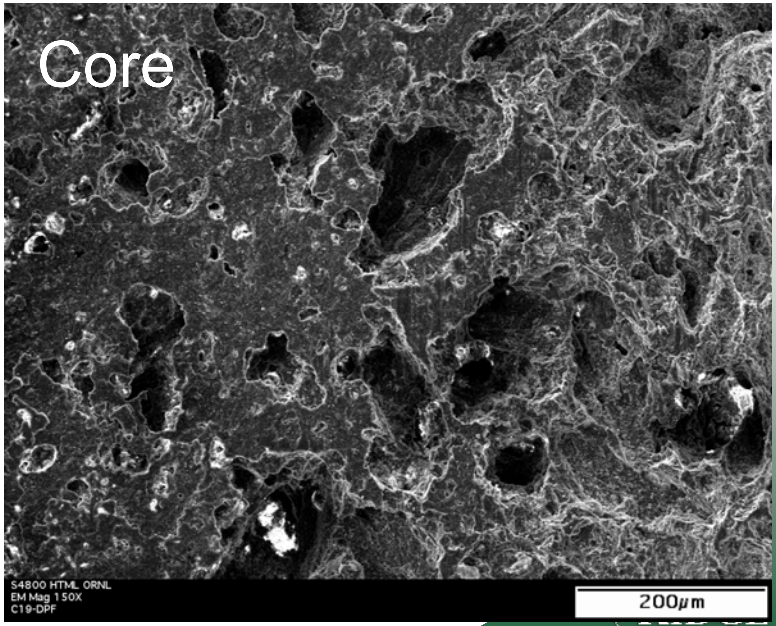


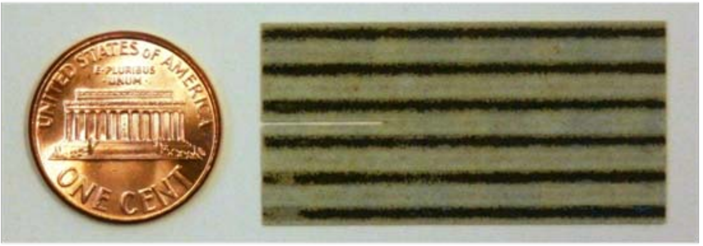
Extrusion direction

Soot particles



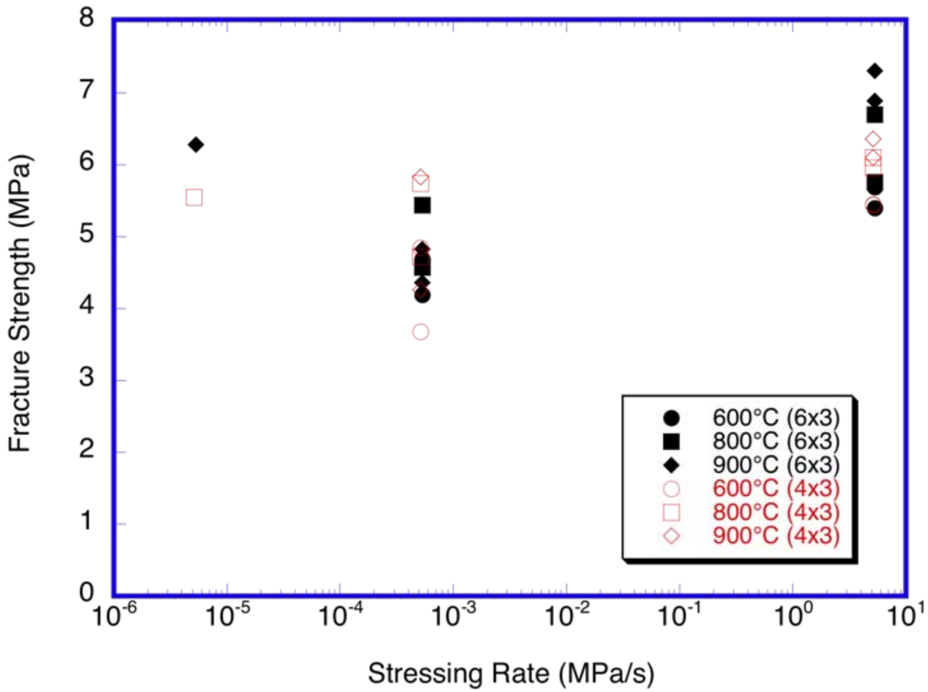
Material	Average CTE (ppm/K)	Elastic Modulus (GPa)	K_{IC} ($MPa\sqrt{m}$)	Density (g/cc)
Virgin (not coated)	0.42	11.91±0.15	0.32±0.04	1.19±0.02
C coated	0.97	10.74±0.29	0.35±0.03	1.19±0.03
D coated	0.73	12.84±0.37	0.40±0.02	1.23±0.02



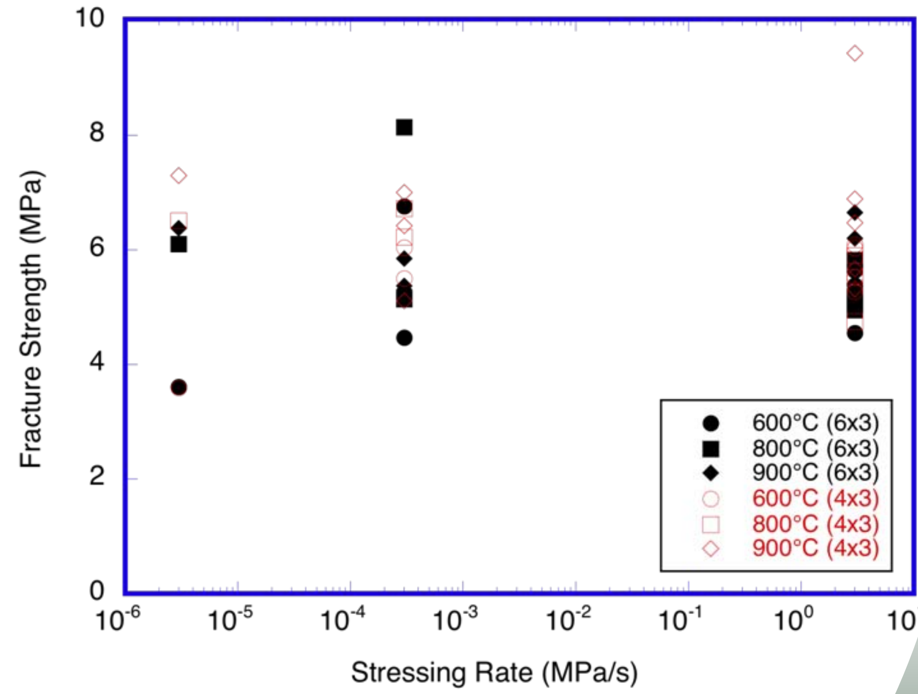


Probabilistic design: Dynamic Fatigue Response is not Influenced by the Applied Catalytic Coating

Bare Cordierite DPF

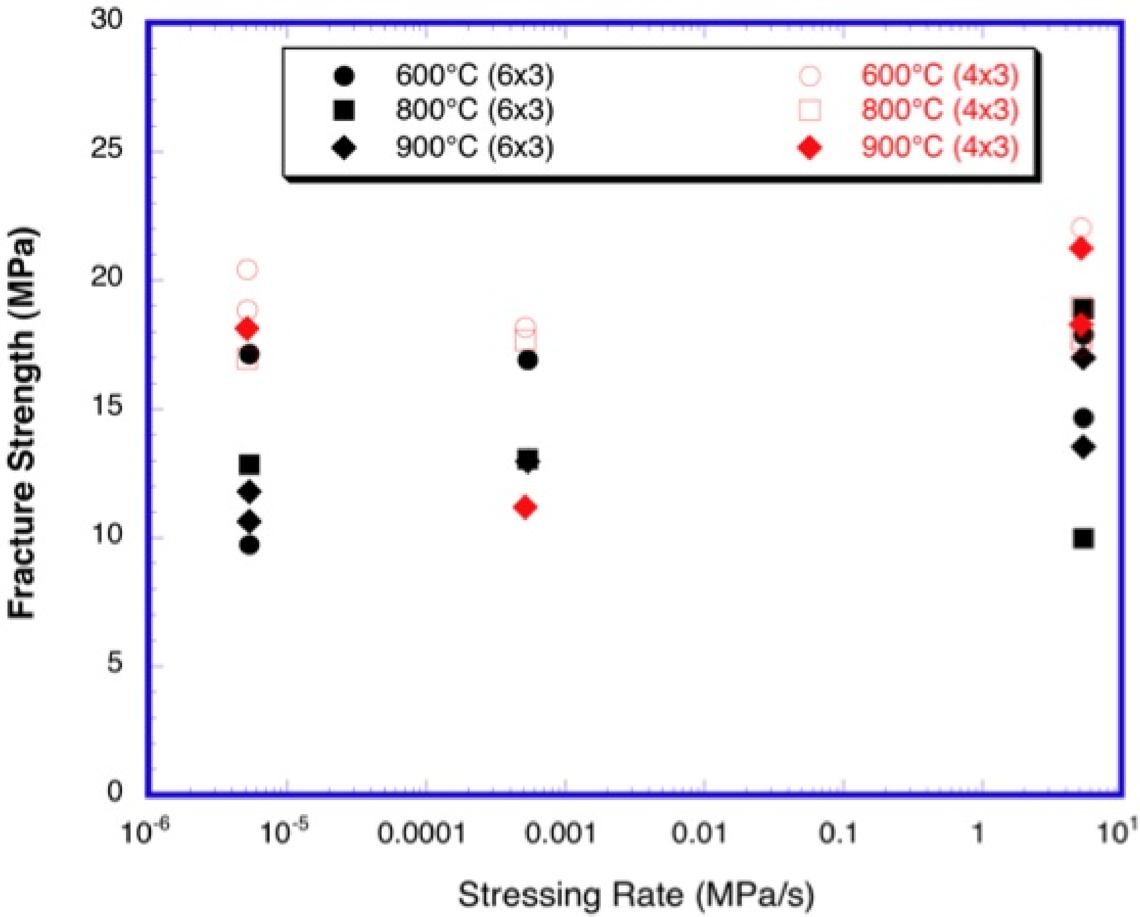


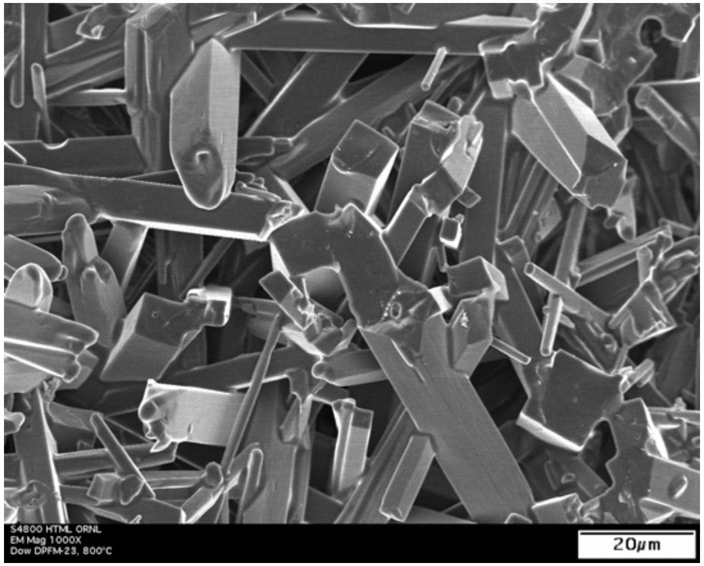
Coated Cordierite DPF

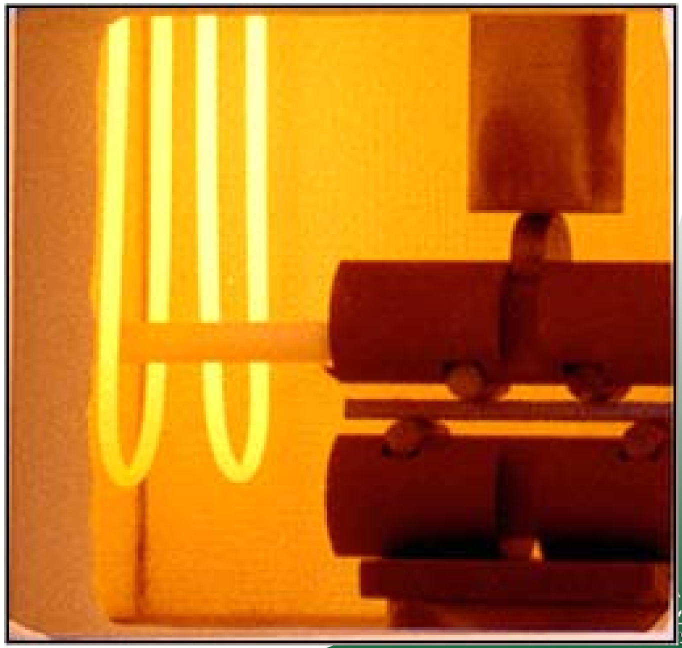


- Dynamic fatigue: 3 x 10^{-5} – 3 MPa/s, 600, 800 and 900°C, in air

Probabilistic design: Little Stress Rate Effect Observed in the Mullite DPF







However, there is a minor effect on the specimen size on the fracture strength due to the difference in flaw population

Future Work

- Continue interaction of washcoat, soot and substrate on properties
- Continue determining properties as a function of location in DPF (core vs. outer)
- Collaborate with Dr. Sampath at SUNY-Stony Brook on further development of NDE technique
- Characterize the dynamic and static fatigue response Aluminum-titanate and SiC DPFs

Summary

- Carried out physical and mechanical property measurements on several coated and uncoated substrates and ranked their relative thermal shock resistance (continued from FY2007).
- Identified the relationship between porosity and the elastic-fracture properties for diesel particulate filter substrates.
- Characterized field returned diesel particulate filters and compared their properties to virgin filters. This information would be utilized to refine the DPF service lifetime prediction models.