Durability of Particulate Filters

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PM-10461

Durability of Particulate Filters

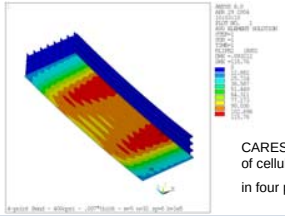
21CTP Technical Goal: **Develop and demonstrate an emissions compliant engine system for Class 7-8 highway trucks that improves the engine system efficiency from ~42% today to 50% by 2010.**

Project Objectives
Minimize fuel consumption required for regeneration of particulate filters by determining the effect of regeneration imposed thermal stresses on ceramic filter life.

FY 2005 Focus
Understand the critical material properties for life prediction and determining the stresses induced in porous cellular ceramics during operation.

Planned Duration
October 2002 to September 2006

DOE Funding/Industry Cost Share
FY04: $300K/$300K; FY05: $300K/$300K



CARES Model of cellular ceramic in four point flexure

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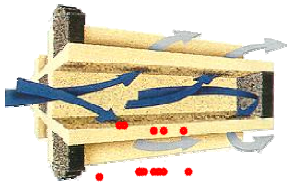
Accomplishments
- NASA CARES Life Model implemented at Cummins.
- Cordierite material properties determined independent of cellular structure.
- Impact of environment on material strength and crack growth rates was established.

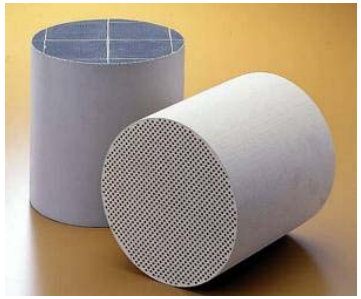
Significant Future Milestones
- Collect filter thermal fatigue data to validate thermal and structural life models. (9-06)
- Refine Life Prediction methodology for porous cellular ceramics. (9-06)

Project ID/Agreement ID	Program Structure	Sub-Program Element	R&D Phase	Date
PM_10461	Materials Technology	HV Propulsion Materials	Applied Technology	8-11-05

Particulate Filter

- Ceramic wall flow substrate





Project Objectives

- Minimize the fuel consumption required for the regeneration of particulate filters.
- Understand the material properties required for Life Prediction.
- Validate the Life Prediction Methodology.

Approach

- Determine the properties of ceramic substrates as a function of temperature.
  - As-received
  - Accelerated Aging
- Model the distribution of stresses and strains by finite-element stress analysis.
  - Flexure sample
  - Filter
- Determine the resistance of ceramic substrates to slow-crack growth and thermal fatigue.
- Validate life prediction models using burner rig and engine tests.
- Identify nondestructive test techniques for ceramic filters.

Project is Necessary to Avoid Filter Damage

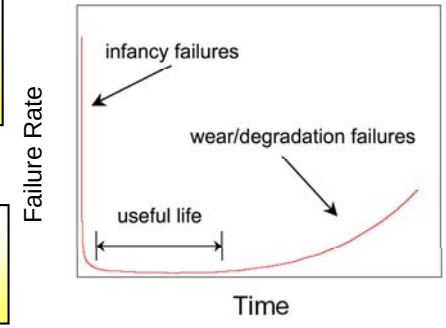
Relevance to 21 CT Goals

- Particulate filters are essential to meet the 0.01g/bhp-hr particulate limits.
- Filter regeneration and control strategy influences the tank mileage for future diesel engines.

Reliability and Durability of Ceramic Filters

The bathtub curve describes the failure rate of many materials and components, including DPFs

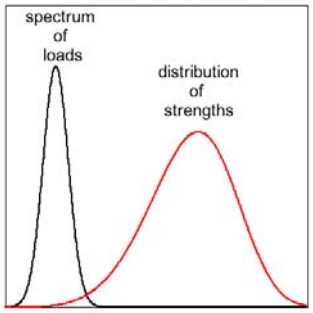
If properly designed, the failure rate of DPFs during the "useful life" stage should be equal to zero.



Slow-crack growth and fatigue are two of the most likely degradation mechanisms

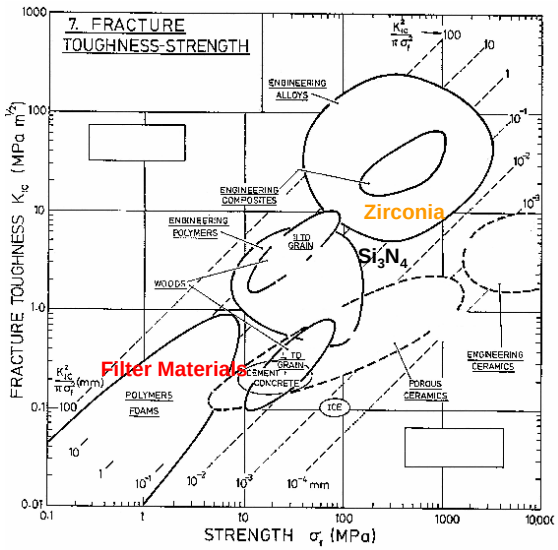
Reliability and Durability of Ceramic Filters

- Failure is defined by the intersection of the spectrum of loads and the distribution of strengths.
- The spectrum of loads includes thermally-induced stresses and stresses induced by vibration and shock.
- The strength of ceramic filters is stochastic and can be described by a statistical distribution (e.g.- Weibull distribution).

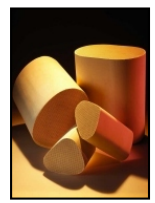


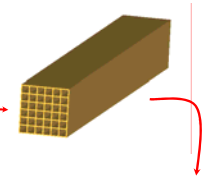
CARES Life Prediction Software

- Life prediction program developed for monolithic ceramics by NASA
  - CARES predicts the probability of failure of monolithic ceramics as a function of time. It assesses the risk-of-failure that the component will fracture prematurely as a result of subcritical crack growth.
- Key Question
  - Does this approach work for high porosity, cellular structure ceramics?



Reliability and Durability of Ceramic Filters - Structure





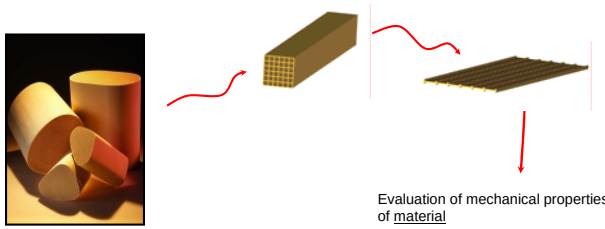
Mechanical evaluation of test specimens obtained from filter

CARES

- Elastic Properties
- Transport Properties
- Strength
- Crack Growth

Considerable confusion in the literature regarding structure properties versus material properties for modeling.

Reliability and Durability of Ceramic Filters - Material



Evaluation of mechanical properties of material

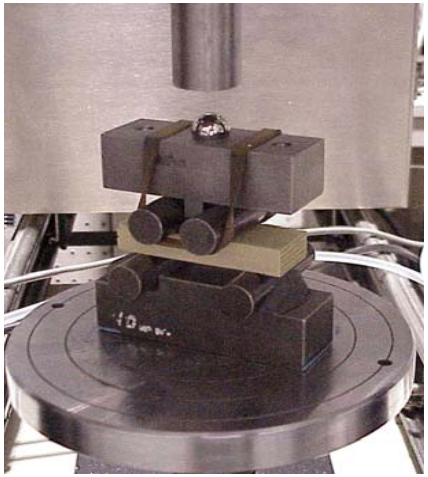
CARES

- Elastic Properties
- Transport Properties
- Strength
- Crack Growth

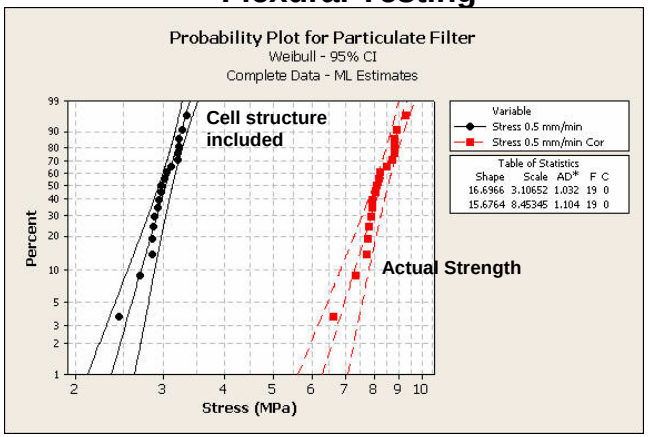
Limited material property information available for life prediction

Material Strength Tests

Flexural Test Set-Up

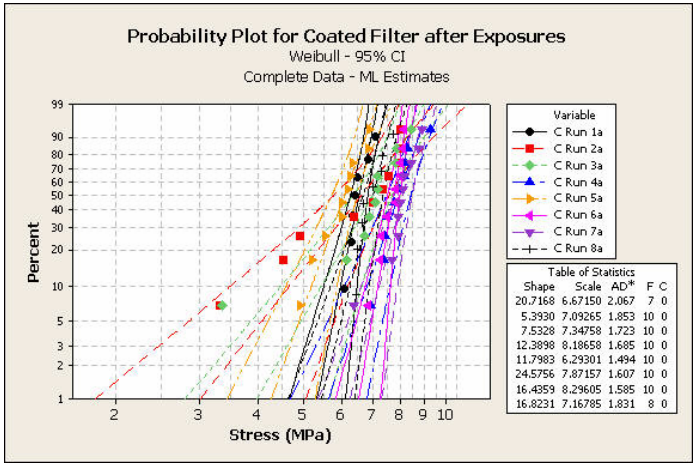


Flexural Testing

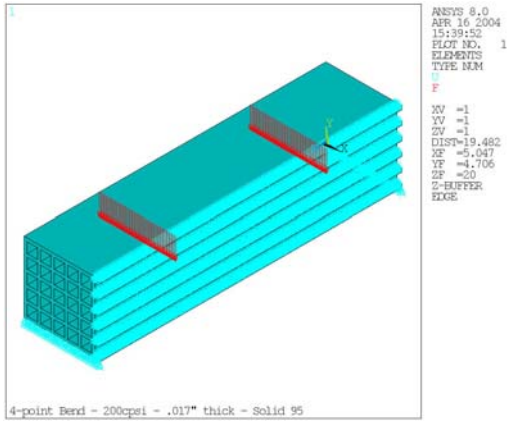


Literature strength values may include geometry.

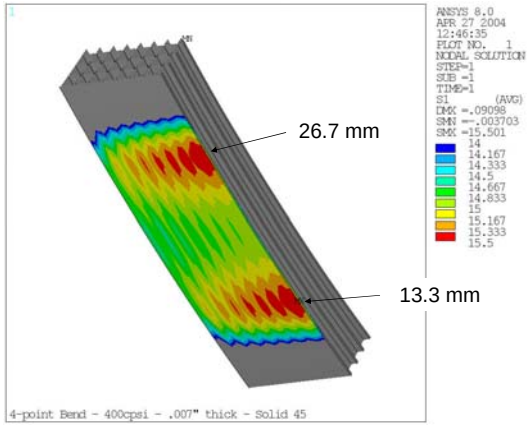
Example of Environmental Exposure Tests



FE Model of Flexure Sample

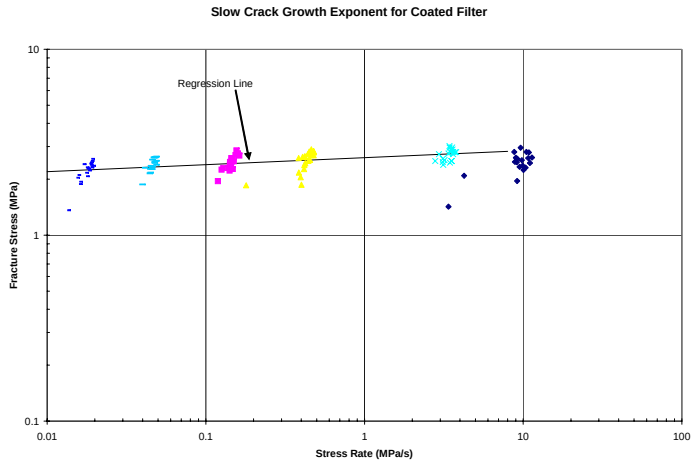


First Principal Stress – Lower half of sample



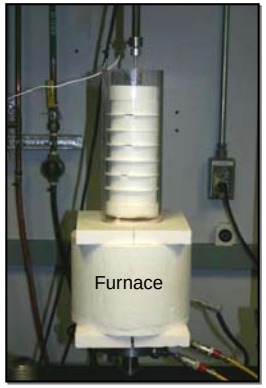
FEA Results matched MOI calculated for cellular structure by Tom Watkins, ORNL

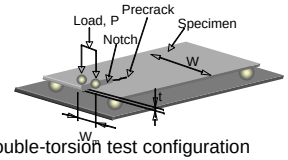
Dynamic Strain Rate Used to Calculate Fatigue Exponent



Used to Calculate Time to Failure

Determination of slow-crack growth parameters



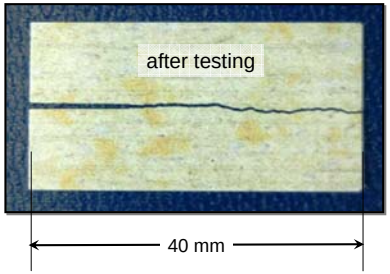


double-torsion test configuration

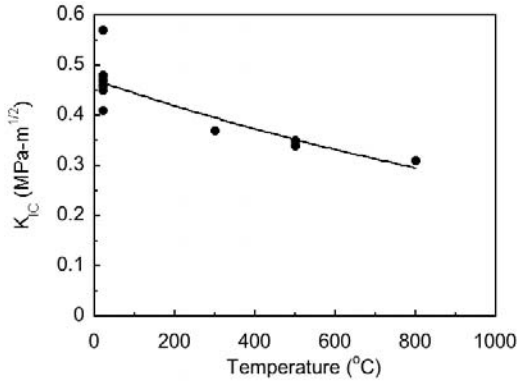
Alumina double-torsion test fixture

Fracture Toughness and SCG Testing at 500°C

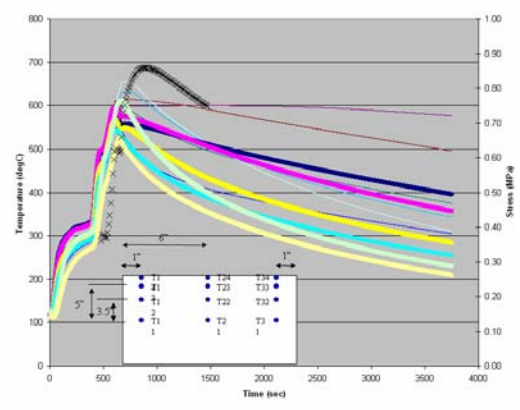
porous cordierite
double-torsion
test specimen



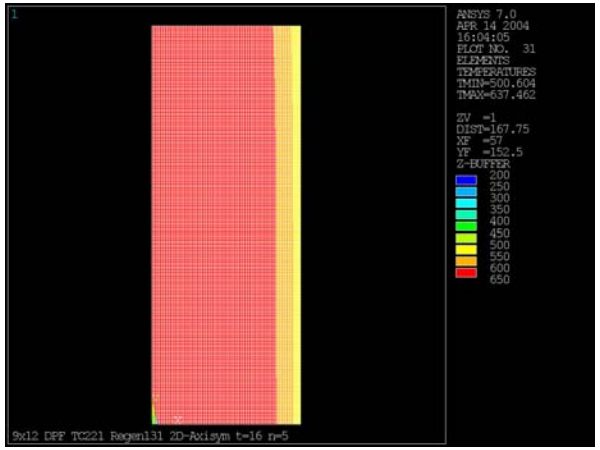
K_{IC} of porous cordierite as a function of temperature



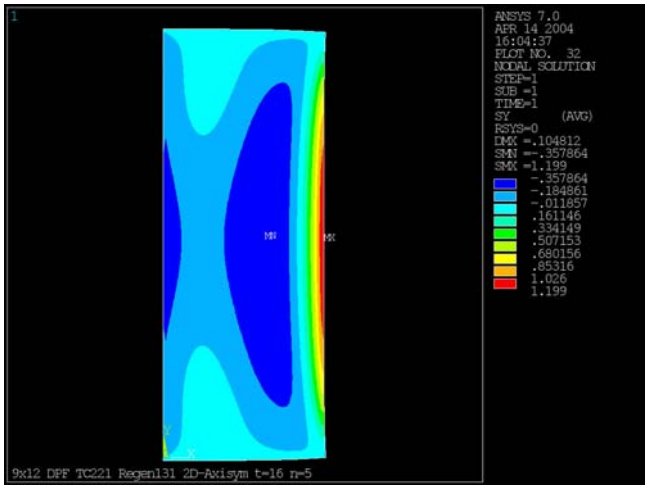
Sample Thermocouple Data Used to Calculate Stresses



Temperature Data Input into FE Model



Sample Stress Plot



Summary

- A methodology has been established to predict the reliability and durability of ceramic Diesel particulate filters.
- The computer program CARES was selected to perform reliability calculations. An interface between CARES and ANSYS, which is used to perform a thermomechanical stress analysis of the filter, was developed.
- The isothermal strength distributions of porous cordierite filters have been determined and used in reliability calculations
- Slow-crack growth has been identified as the most likely mechanism responsible for the degradation of strength of porous cordierite filters.

Summary (cont.)

- The slow-crack growth behavior of porous cordierite filters is being investigated through dynamic fatigue testing and double-torsion testing.
- The results from these tests will be incorporated in CARES to predict the reliability of porous ceramic filters as a function of service history and time.

Technology Transfer

- Cummins has engaged the suppliers in this CRADA.
  - Filter Material Suppliers
  - Catalytic Coaters
  - Mat Material Suppliers
  - Canners

Future Work

- Validate life prediction models using burner rig tests. Now to Sept 2006.
- Correlate static fatigue and KV curves. Now to Sept. 2006.
- NDE Techniques for porous cellular ceramics. On-going.

(See Notes page for further information)

Acknowledgements

- Cummins
  - Randy Stafford, Matthew Henrichsen, Brian Bridges, Tao You, Richard Varo, Russell Chiang, Evangelos Siannis, Jeff Cooper, Raj Rajiyah
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